Spatial analysis of diarrhoea and environmental risk factors in an urban context in Senegal, West Africa

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auf Antrag von

Prof. Dr. Jürg Utzinger,

Prof. Dr. Guéladio Cissé

Prof. Dr. Anna-Sofie Stensgaard

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Prof. Dr. Martin Spiess

Dekan der

Philosophisch-Naturwissenschaftlichen Fakultät

Dedicated to my beloved parents:

You are and will stay always in our hearts,

I get to this PhD level because of all the efforts you have made in our studies

From primary school to the University,

You always wanted us to succeed,

This work is for you!

Peace to your souls!

Faculty representative

Prof. Dr. Jürg Utzinger, PhD

Swiss Tropical and Public Health Institute

Basel, Switzerland

Supervisor

Prof. Dr. Guéladio Cissé

Swiss Tropical and Public Health Institute

Basel, Switzerland

Chair

Prof. Dr. Kaspar Wyss

Swiss Tropical and Public Health Institute

Basel, Switzerland

Co-supervisor

Dr. Aminata Niang-Diène

Université Cheikh Anta Diop de Dakar

Dakar, Senegal

Co-referee

PD, Dr Christian Schindler

Swiss Tropical and Public Health Institute

Basel, Switzerland

External expert

Prof. Dr. Anna-Sofie Stensgaard

University of Copenhagen

Copenhagen, Danemark

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Table of content

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Summary

Background: Diarrhoeal diseases continue to be a major public health concern globally, associated with high childhood mortality and morbidity, particularly in low- and middle-income countries (LMICs). Although the number of deaths due to diarrhoea decreased considerably over the past 25 years, morbidity has declined only moderately. In 2015, diarrhoea was responsible for nearly half a million deaths (9%) among children under the age of 5 years. Most of the diarrhoea-related deaths were attributable to unsafe water, inadequate sanitation and lack of hygiene. In 2015, an estimated, 844 million and 2.3 billion people around the world still lack access to basic drinking water service and sanitation facilities, respectively, mainly in LMICs, and particularly in sub-Saharan Africa.

In Senegal, diarrhoea is the leading cause of childhood deaths and about 14% of the burdens, as expressed by of disability-adjusted life years (DALYs), were due to diarrhoeal diseases in children below the age of 5 years.

While diarrhoea is among the leading infectious diseases, most studies were conducted in capital cities or rural areas, while little information is available for “secondary cities” so-called “medium-sized cities”. Secondary cities in many African countries, including Senegal, are faced with a lack of epidemiological data at small scale (e.g. neighbourhood level): prevalence and incidence, aetiologies and exposure factors. Data at small scale, as well as spatially and explicit assessment of disease risk like diarrhoea are lacking in secondary cities for effective guidance and planning of interventions. Against this background, data at small scale are needed in such urban settings to establish the local epidemiology and implement appropriate preventive measures. To address this research gap, the work undertaken in the current PhD thesis was conducted in a context of secondary cities, characterized by rapid urbanization, where control of infectious diseases, including diarrhoea, is a challenge.

Goal and objectives: The overarching goal of this PhD thesis was to provide disaggregated evidence on diarrhoeal diseases prevalence and incidence among children under the age of 5 years, including risk factors, in order to improve the control of the disease through the implementation of targeted preventive measures in the secondary city of Mbour, located in the south-western part of Senegal. To achieve this goal, the PhD thesis pursued the following five specific objectives: (i) to provide an overview of the urbanization trends of the secondary city of Mbour and its effects on water supply, sanitation, wastewater and solid waste management systems; (ii) to determine the prevalence of diarrhoea among children under the age of 5 and associated risk factors in four different zones of the city;

(iii) to investigate the association between childhood diarrhoeal incidence and climatic factors, such as temperature and rainfall; (iv) to describe the spatial pattern of diarrhoeal disease risk and to estimate the spatially varying association between diarrhoea risk and potential risk factors or covariates; and (v) to assess the knowledge and management practice of diarrhoea among mothers and caregivers of enrolled children.

Methods: The methodology developed in this thesis combines several types of data collection, and analytical approaches. We collected data from readily available secondary sources from local services (e.g. routine health facility data on diarrhoeal incidence, demographics and mapping data), available remote sensing sources for the climatic data (e.g. temperature and rainfall), and obtained primary data from combined field surveys conducted in Mbour: cross-sectional epidemiological household surveys, drinking water sampling and analysis, mapping of environmental risk factors at city and household level and direct observations.

Two cross-sectional household surveys were conducted in Mbour. The first survey was carried out in the dry season, between February and March 2014 among 600 children under the age of 5 years in eight randomly selected neighbourhoods located in four urban zones in Mbour namely: (i) Urban Central Area (UCA); (ii) Peri-Central Area (PCA); (iii) North Peripheral Area (NPA); and (iv) South Peripheral Area (SPA). The second survey was conducted in the rainy season between September and October 2016 among 800 children and covered all 25 neighbourhoods of the city, including the eight neighbourhoods sampled in the first survey. In both surveys, households were randomly selected using a spatial multi-stage cluster sampling approach, adopted within each zone and neighbourhood. The presence of a mother with at least one child under the age of 5 years was the primary household inclusion criterion. Questionnaires were administered to children's parents/ caregivers to assess basic household socioeconomic and demographic characteristics and water, sanitation and hygiene (WASH) conditions, and to determine their knowledge, attitudes and management practices of diarrhoea (KAP).

Water samples from children's households and community sources (public taps and wells) were analysed for contamination with faecal coliform bacteria and *Escherichia coli* by using membrane filtration technique.

A hand-held global positioning system (GPS) device was used in the field to locate the interviewed households and the major environmental risk factors for diarrhoea (solid waste dumping, stagnant wastewater points, flood-prone areas and stagnant rainwater points in the city).

Results: The findings of this study showed that childhood diarrhoea had a varying spatial pattern across the city. The findings from the cross-sectional household surveys showed that 26% and 34% of the children surveyed in 2014 and in 2016 respectively were suffering from diarrhoea during the two weeks preceding the survey. The prevalence was higher among children living in the UCA in 2014 and in 2016 (36.3% and 38.3%) and in the PCA in 2014 and in 2016 (44.8% and 34.8%). In UCA, the highest prevalence was observed in the neighbourhood near coastal area, namely Tefess (57.1%), Zone Résidentielle (54.3%) and Golf (31.4%). In PCA, the highest prevalence was observed in the neighbourhood Baye Deuk (57.1%). Diarrhoeal prevalence were significantly associated with household sociodemographic characteristics, such as unemployment of mothers, use of open bags for storing household waste, evacuation of household waste in public streets, and use of shared toilets. Untreated stored drinking water and stored water contaminated with *E. coli* were associated with diarrhoea infections in children, while drinking water source did not appear as a significant risk factor for diarrhoea.

Results from the time-series analysis showed a seasonal pattern of diarrhoeal cases in Mbour with two annual peaks: one peak in the cold dry season (December-March) and one peak in the rainy season (July-October). The study revealed that diarrhoeal cases were more clustered around urban settings compared to rural settings; and temperature and rainfall were associated with diarrhoeal incidence in Mbour.

Conclusion: Diarrhoeal diseases constitute an important public health problem among children under the age of 5 years in the secondary city of Mbour, Senegal. Our findings call for specific public health measures to tackle diarrhoea at the more affected areas, through the implementation of WASH intervention programmes, including promotion of solid waste and wastewater management, health education programmes for mothers of young children and family members about water treatment and storage, handwashing, the use of oral rehydration salt (ORS) and zinc supplementation and its preparation at household level, for a successful diarrhoea management.

Résumé

Contexte : Les maladies diarrhéiques continuent d'être un problème major de santé publique dans le monde, et associées à une mortalité et une morbidité élevée chez les enfants de moins de cinq ans, particulièrement dans les pays en développement. En 2015, la diarrhée était responsable de près d'un demi-million de décès (9%) chez les enfants de moins de cinq ans, malgré les progrès accomplis en matière de prévention et de traitement. Bien que le nombre de décès dus à la diarrhée ait diminué au cours de ces dernières 25 années, la morbidité due à la diarrhée n'a diminué que modérément. La plupart de ces décès étaient imputables à une eau insalubre, à un assainissement inadéquat et à une hygiène insuffisante. Malheureusement, 844 millions et 2.3 milliards de personnes dans le monde n'ont toujours pas accès à un service d'eau potable et à des installations sanitaires de base appropriées, principalement en Afrique sub-Saharienne. Au Sénégal, la diarrhée est la première cause de décès chez les enfants de moins de cinq ans; les fardeaux les plus élevés en termes d'années de vie ajustées sur l'incapacité (DALYs) chez les enfants étaient et sont encore causés par les maladies diarrhéiques qui représentent 14% des DALYs dans ce groupe d'âge en 2015.

Alors que la diarrhée est l'une des maladies infectieuses les plus importantes chez les enfants, les études antérieures investiguant les interactions entre l'urbanisation, l'environnement et la santé ont été menées dans les grandes villes plutôt que dans les petites et moyennes villes appelées aussi villes secondaires en Afrique. Les villes secondaires sont confrontées à un manque crucial de données. Dans ces villes, des données épidémiologiques sur l'état de santé de la population (prévalence et incidence d'une maladie) ainsi que sur l'étiologie et sur les facteurs de risques à petites échelles sont souvent mal documentées ou indisponibles. Dans ce contexte, des données à petites échelles (c'est-à-dire à l'échelle du quartier) sont nécessaires dans ces villes secondaires pour établir l'épidémiologie locale et mettre en œuvre des mesures préventives et de contrôle appropriées, car la plupart des données existantes sont à l'échelle nationale ou d'une ville entière. Pour combler les lacunes de recherche et le déficit d'information dans ces villes, ce travail de thèse a été mené dans un contexte d'une ville secondaire caractérisée par une urbanisation rapide, où le contrôle des maladies infectieuses telle que la diarrhée, est encore problématique.

Objectifs : L'objectif général de cette thèse était de générer des données désagrégées à petite échelle sur la prévalence et l'incidence des maladies diarrhéiques chez les enfants de moins de cinq ans ainsi que sur les facteurs de risque environnementaux associés à la diarrhée afin d'améliorer le contrôle de la maladie grâce à la mise en œuvre de mesures de prévention ciblées dans la ville secondaire de Mbour au Sénégal. De manière spécifique, il s'agissait de:

(i) donner un aperçu des tendances de l'urbanisation de la ville de Mbour et de ses effets sur les facteurs de risque de la diarrhée; (ii) déterminer la prévalence de la diarrhée chez les enfants de moins de cinq ans et les facteurs de risque associés; (iii) étudier l'association entre l'incidence de la diarrhée infantile et les facteurs climatiques, telles que la température et les précipitations; iv) cartographier la distribution spatiale de la diarrhée et estimer l'effet des facteurs sociodémographiques et climatiques sur la morbidité diarrhéique à l'aide d'un modèle CAR bayésien; et (v) évaluer les connaissances et pratiques de prise en charge de la diarrhée infantile chez les mères/soignants des enfants.

Méthode : La méthodologie utilisée est basée sur une approche multidisciplinaire comprenant des enquêtes épidémiologiques transversales auprès des ménages, un échantillonnage et une analyse de la qualité de l'eau et une enquête géographique. Deux enquêtes transversales auprès des ménages ont été menées à Mbour. La première enquête a été réalisée pendant la saison sèche froide, entre Février et Mars 2014, auprès de 600 ménages choisis au hasard dans huit quartiers situés dans quatre différentes zones urbaines à Mbour, à savoir: (i)-zone centrale urbaine (UCA); (ii)-zone péricentrale (PCA); (iii)-zone périphérique nord (NPA); et (iv)-zone périphérique sud (SPA). La deuxième enquête a été menée pendant la saison des pluies entre Septembre et Octobre 2016, auprès de 800 enfants et a couvert les vingt-cinq quartiers de la ville, y compris les huit quartiers échantillonnés lors de la première enquête. Dans les deux enquêtes, les ménages ont été sélectionnés au hasard en utilisant une approche d'échantillonnage spatial à plusieurs degrés dans chaque zone et quartier. La présence d'une mère avec au moins un enfant de moins de cinq ans était le critère d'inclusion du ménage. Des questionnaires ont été administrés aux parents/tuteurs des enfants afin d'évaluer les caractéristiques socioéconomiques et démographiques des ménages, et de déterminer leurs connaissances, attitudes et pratiques de gestion (KAP) de la diarrhée. Des échantillons d'eau ont été prélevés dans les eaux de boisson stockées au niveau des ménages et au niveau des sources d'eau communautaires (robinet public et puits). Ces eaux ont été analysées pour détecter la contamination par des bactéries notamment coliformes fécales et *Escherichia coli* en utilisant une technique de filtration sur membrane. Une enquête géographique facilitée par l'utilisation d'un GPS a été également conduite pour localiser les ménages interrogés et les principaux facteurs de risque environnementaux de la diarrhée (déversement de déchets solides, points d'eaux usées stagnantes, zones inondables et points d'eau de pluie stagnants dans la ville).

Résultats: Les résultats des enquêtes épidémiologiques ont montré que 26.0% et 33.9% des enfants enquêtés, respectivement en 2014 et 2016, ont souffert de la diarrhée durant les deux semaines précédant l'enquête. Cependant, la prévalence est inégalement répartie dans la ville. Elle est plus élevée chez les enfants vivant à UCA (36.3%) en 2014 et (38.3) en 2016 ; et à PCA (44.8%) en 2014 et (34.8%) en 2016. Dans UCA, la prévalence était plus élevée dans les quartiers côtiers, à savoir, Tefess (57.1%), Zone Résidentielle (54.3%) et Golf (31.4%). Dans PCA, la prévalence était élevée à Baye Deuk (57.1%). L'analyse stratifiée par groupe d'âge a montré que la prévalence de la diarrhée était plus élevée chez les enfants âgés de plus de 2 ans (24-59 mois) durant les deux enquêtes. En outre, la prévalence de la diarrhée était significativement associée aux caractéristiques sociodémographiques des ménages enquêtés, tels que le chômage des mères, l'utilisation de sacs ouverts pour stocker les déchets ménagers, l'évacuation des ordures ménagères dans les rues publiques et l'utilisation de toilettes communes. L'eau potable stockée non traitée et l'eau stockée contaminée par *Escherichia coli* étaient associées à des infections diarrhéiques chez les enfants, alors que la source d'eau potable ne semblait pas être un facteur de risque significatif de la diarrhée. Les résultats de l'analyse des séries chronologiques ont montré un profil saisonnier des cas de diarrhée à Mbour avec deux pics annuels: un durant la saison sèche froide (Décembre à Mars) et un autre durant la saison des pluies (Juillet-Octobre). L'étude a aussi révélé que l'incidence de la diarrhée observée entre 2011 et 2014 était associée à la température et les précipitations à Mbour.

Conclusion : En conclusion, l'approche développée a permis d'identifier les populations et les espaces à risque pour la diarrhée dans la ville de Mbour. Nos résultats appellent à des mesures de santé publique adaptées à la diarrhée infantile à travers la mise en œuvre de programmes d'intervention portant sur l'accès à l'eau, l'assainissement et à une hygiène de base, y compris la promotion de la gestion des déchets solides et des eaux usées, un programme d'éducation sanitaire pour les mères d'enfants de moins de cinq ans, notamment sur les avantages et l'utilisation du traitement SRO/Zinc et de sa préparation au niveau des ménages dans le sens d'une bonne gestion de la diarrhée.

List of acronyms and abbreviations

ANSD	National Agency of Statistics and Demography
aOR	Adjusted odd ratio
ARI	Acute respiratory infections
CAR	Conditional autoregressive spatial model
CDC	Centers for Disease Control and Prevention
CHW	Community health worker
CI	Confidence interval
DALYs	Disability-adjusted life years
DHIS2	District health information system
DHS	Demographic health survey
ENSAN	National survey on food security and nutrition
ESKAS	Swiss Government Excellence Scholarship
GBD	Global Burden of Disease
GIS	Geographical information systems
GPS	Global positioning system
GS	Geographical survey
IAGU	African Institute for Urban Management
IHME	Institute of Health Metrics and Evaluation
IRR	Incidence rate ratio
JMP	Joint Monitoring Programme
KAP	Knowledge, attitudes and practices
LMICs	Low- and middle-income country
LRTs	Likelihood ratio test
LST	Land surface temperature
MCA	Multiple correspondence analysis
MGDs	Millennium Development Goal
Mi	Micronutrient initiative
MODIS	Moderate Resolution Imaging Spectroradiometer
MoH	Ministry of Health
MSAS	Ministère de la Santé et de l'Action Sociale
NPA	North Peripheral Area
ONAS	National Office for Sanitation of Senegal
OR	Odds ratio

ORS	Oral rehydration salt
PATH	Program for Appropriate Technology in Health
PCA	Principal component analysis
PEPAM	Projet Eau potable Assainissement du Millénaire
PEV	Programme Elargi de Vaccination
RGPH	Recensement Général de la Population et de l'Habitat
RS	Remote sensing
SD	Standard deviation
SDE	Société Sénégalaise des Eaux
SDGs	Sustainable development goals
SES	Socioeconomic status
SPA	South Peripheral Area
Swiss TPH	Swiss Tropical and Public Health Institute
UCA	Urban Central Area
UN	United Nations
UNICEF	United Nations Children's Fund
UTM	Universal Transverse Mercator
USAID	United States Agency for International Development
WASH	Water, sanitation and hygiene
WGO	World Gastroenterology Organisation
WHO	World Health Organization

List of Tables

List of figures

1 Thesis outline

This PhD thesis aims to provide further disaggregated evidence on diarrhoeal diseases prevalence and incidence among children under the age of 5 years, and determine risk factors, in order to improve the control of diarrhoeal disease through the implementation of targeted preventive measures in the secondary city of Mbour, in the south-western part of Senegal. These well-tailored interventions will more appropriately contribute to reducing the burden of the disease in the city.

The thesis is presented in a journal-article format, comprising four peer-reviewed publications and one preparing for publication. It is structured as follows: After the current outline (chapter 1), the thesis presents an introduction, including a literature review (chapter 2), in which I describe the urbanization trends and the issues around access to drinking water and sanitation, which are among the main risk factors for diarrhoeal diseases in African cities. Thereafter, an overview of the health risks related to water, sanitation and hygiene (WASH) with a focus on diarrhoeal diseases is given. Chapter 3 starts with a summary of water and sanitation issues in the Senegalese context, in particular, and gives background for the thesis. This is followed by a short chapter (chapter 4) on the background and objectives of the PhD study. Chapter 5 outlines the methodology used in the current thesis, including the conceptual framework, the description of the study area and the different methods and approaches used.

Chapters 6 through 10 offer five articles describing the main results from the case studies carried out in the rapidly growing secondary city of Mbour. In chapter 6, this PhD thesis provides a general overview of the study area through a visualization of the urbanization trends of Mbour, highlighting both the demographic growth and spatial expansion of the city boundaries over the past 60 years, and the urban infrastructures related to drinking water and sanitation coverage, wastewater and solid waste management in a readily accessible and innovative video. This article has been published in *Geospatial Health* (November 2017). In chapter 7, I present the findings from the first cross-sectional survey conducted during the cold dry season in 2014 assessing diarrhoeal prevalence and its associated risk factors among children under the age of 5 years. This chapter has been published in *Infectious Diseases of Poverty* (July, 2017). In chapter 8, I present findings from routine health surveillance and climatic data assessing the relationship between diarrhoeal incidence and climatic factors such as temperature and rainfall. This article has been published in the *International Journal for Environmental Research and Public Health* (September, 2017).

Chapters 9 and 10 present findings from the second cross-sectional survey conducted in the rainy season in 2016. One article pertaining to spatial patterns of diarrhoea and is being prepared for submission; one article pertaining to knowledge and practices of mothers and caregivers on diarrhoeal management among under 5-year-old children in a medium-size town of Senegal has been published in the *Journal Acta Tropica* (March 2019).

Chapter 11 discusses the main findings beginning with a summary of the key results of the case studies (chapters 6 to 10) in reference to the aforementioned PhD study objectives and lessons learned. In the first two sections, the key findings from the case studies are discussed, in the broader context of diarrhoea epidemiology, WASH and climatic factors in Mbour. The third section discusses the contribution of the spatial sampling and analysis methods applied in the current PhD thesis from a broader public health perspective. The fourth section explains how the results are consistent with the research mission of the Swiss Tropical and Public Health Institute (Swiss TPH) through innovation, validation and application. The fifth section considers the limitations of the study and future research needs.

Finally, the last chapter provides some general conclusions and recommendations, including policy implications for public health in the context of global environmental change, sustainable development goals and cities in terms of prevention, treatment and focused interventions for improving children's health in the secondary city of Mbour and in other similar cities in West Africa.

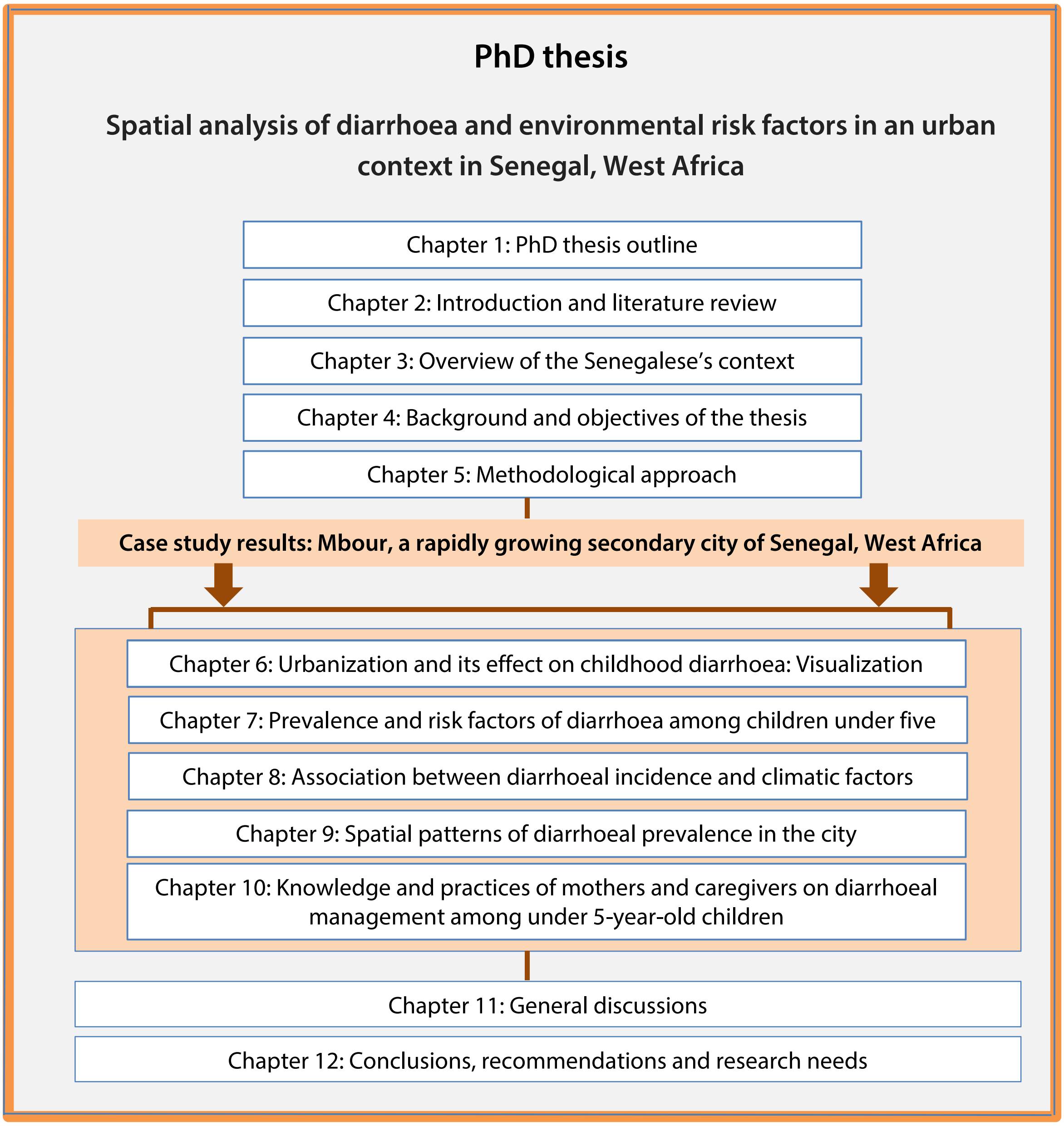


Figure 1.1: Schematic PhD thesis structure

2 Introduction

This PhD thesis aims to provide local data on diarrhoeal prevalence and incidence in Mbour Senegal, and to determine associated risk factors. This introductory chapter describes urbanization trends and its effect on access to safe drinking water, sanitation and hygiene, which are the main risk factors for diarrhoeal diseases. The following sections provide a succinct overview of the literature with regard to urbanization trends in Africa, the challenge of access to safe drinking water and sanitation in African cities and to discuss implications for public health, placing emphasis on urban health hazards and health risks.

2.1 Urbanization in Africa

African cities are rapidly growing, but infrastructure improvements, especially for water and sanitation systems often do not keep pace with the growth.

Urbanization, which is mostly the result of migration from rural to urban areas in addition to natural urban demographic growth, is one of the key 21st century challenges to improving global urban conditions (Sclar et al., 2005). Urbanization is a planetary-scale change process. Since the early 1800s, movements of people, especially from the rural areas to urban areas, have been recorded (Muggah, 2012). Accordingly, in the past 100 years, the proportion of the world's population living in urban areas has increased from 13% in 1900 to 32% in 1955, and from 38% in 1975 to 45% in 1995 and 49% in 2005 (WHO, 1998; O'Neill et al., 2012). This represents a move from 220 million people in 1900 to 3.2 billion people in 2005 living in cities, mainly to take advantage of job and educational opportunities, among others issues (Opoko and Oluwatayo, 2014).

The year 2007 marked a definitive shift, for the first time in human history, more people were lived in urban as opposed to rural areas (Harpham, 2009; Butala et al., 2010). In 2009, Africa exceeded one billion inhabitants; 395 million (nearly 40% of the population) were living in urban areas (UN-HABITAT, 2010). According to the latest United Nations (UN) projection, in mid-2017, 17% of the world's population lives in Africa (1.3 billion), and more than half (1.3 billion people) of the expected population growth (2.2 billion people) between 2017 and 2050 is expected to occur in Africa (Figure 2.1) (UN, 2017). Africa's population might rise to 2.4 billion by 2050, with 56% of the population expected to be urban dwellers by then.

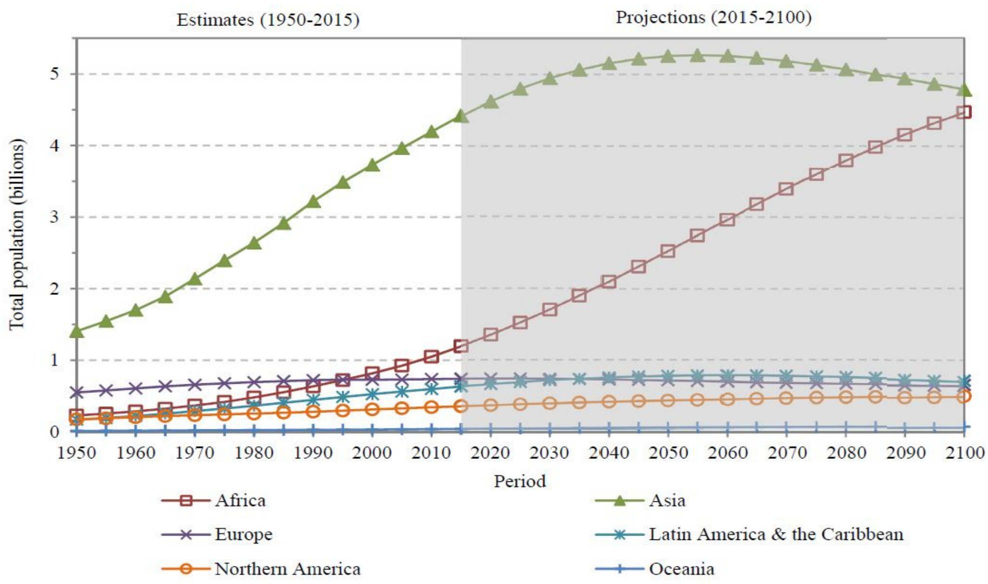


Figure 2.1: Population by region: estimates, 1950-2015, and medium-variant projection, 2015-2100 (from United Nations, World Population Prospects: The 2017 Revision)

The strong dynamic of urbanization not only occurs in the capitals of African cities but also in small and "secondary cities", also known as "medium-sized cities" (Cissé et al., 2011). Indeed, more than half of the increase of urban population in the coming years are expected to occur in big cities and in small and secondary cities with less than half a million inhabitants (mostly between 100,000 and 500,000 inhabitants) (Potts, 2009; WHO, 2009; UN-HABITAT, 2014; Satterthwaite, 2016b).

2.2 Urbanization-related infrastructure challenges in African cities

While cities are often rightly portrayed as drivers of economic growth and opportunity for many low-and middle-income countries (LMICs), essential service provision and infrastructure improvements have not kept pace with the urban population growth (Lucci and Lynch, 2016). This means that access to basic services and livelihoods in the city remain precarious for many people. The uneven condition of infrastructure and services in urban Africa date back to the colonial period (Dodman et al., 2017). Although many post-colonial governments promised universal access to public water supplies and sanitation systems, this promise has remained largely unfulfilled, with significant implications for the risks faced by urban dwellers (Batley, 2006). Despite initiatives such as the International Drinking Water Decade (1990-1999) and the Millennium Development Goals (MDGs) (2001-2015), governments have proven unable or unwilling to meet the demand of the growing urban population (Dodman et al., 2017).

Access to basic services, such as education, health care, safe drinking water and adequate sanitation is vital to securing and sustaining human development, and to reducing poverty (UN, 2013). The health, wellbeing and economic status of a community depend on its sustainable water supply, its ability to acquire sanitation infrastructure, to get knowledge on hygiene practices and to implement these practices. WASH produces evident effects on the health of a population (Esrey and Habicht, 1986; Esrey et al., 1991; Fewtrell et al., 2005; Cairncross et al., 2010b).

However, despite the importance of WASH in people's lives and in economic development, and notwithstanding the substantial progress made towards the UN Millennium MDG n°. 7),which were to ensure environmental sustainability, including a target to have, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation, universal access to safe drinking water and sanitation remains a huge challenge in sub-Saharan Africa, where many people are not properly provided for by these basic services.

At the end of 2015, the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation estimated that 844 million people and 2.3 billion people in the world were still without access to basic drinking water services and sanitation facilities, respectively (WHO/UNICEF, 2017). Most of them were concentrated in sub-Saharan Africa. The indicators for access to drinking water and sanitation suggest that the number of people accessing improved water sources has increased from 76% in 1990 to 91% (6.6 billion people) coverage in 2015, and that the number of people using basic sanitation rose from 54% to 68% (5.0 billion people). Even so, the progress towards achieving the MDG targets related to water and sanitation is misleading (WHO/UNICEF, 2015). Indeed, sub-Saharan Africa failed to meet the target in 2015. The WHO/UNICEF/JMP for Water Supply and Sanitation estimated that 32% (about 319 million people) of the sub-Saharan population still used unimproved drinking water sources, including unprotected wells, springs and surface water, while 70% (about 695 million Africans) lacked access to improved sanitation facilities in 2015 (WHO/UNICEF, 2015). In sub-Saharan Africa, less attention has been paid to the provision of water and sanitation in the allocation of aid by governments and by bilateral and multilateral donors, compared to education and health care (Ndikumana and Pickbourn, 2017). This can be seen in the uneven progress made towards achieving the different MDGs. The region appears to have made progress in improving health and education outcomes, while provision of safe drinking water and basic sanitation remain major challenges.

The challenges of water and sanitation service delivery in sub-Saharan Africa are exacerbated by the fact that many poor urban residents live in unplanned and underserved informal settlements, also known as slums or peri-urban areas (Lüthi et al., 2010). Urban authorities do not have the capacity and often do not plan for service provision in these areas. Therefore, efforts are still needed in the water and sanitation sector in sub-Saharan Africa. With the adoption of the Sustainable Development Goals (SDGs) in 2015, it remains to be seen whether sub-Saharan Africa will be able to achieve the SDG n°.6 targets, which are to ensure universal and equitable access to safe water and basic sanitation for everyone by 2030.

2.2.1 Water issues in African cities

Water is the most essential need in people's lives. According to Henry Picheral (2001) "water is recognized as an essential variable in the aetiology and epidemiology of diseases. It is a pathway of pathogens in the case of waterborne diseases (infectious or parasitic), which it disseminates. Water quality is a major public health problem both in LMICs with high biological risks and in developed countries, where water quality is threatened by other forms of pollution" (Picheral, 2001).

In Africa, access to safe drinking water remains a major concern for governments and populations due to rapid rates of urbanization. Urban growth is expected to add 1.3 billion people to African cities by 2050, making the difficult task of urban water provision even more challenging (McDonald et al., 2011; UN, 2017). As the population continues to grow, drinking water supply needs to increase even more rapidly; and overcoming the challenges of providing fresh, safe drinking water to urban dwellers becomes a global urgency. The challenge is enormous. Most freshwater systems are already stressed and urban growth is just one of the several major challenges facing humans' use of freshwater (Vorosmarty et al., 2010). Provision of fresh, clean water to urban dwellers requires tackling three main issues, and cities can be placed along the three corresponding axes: water availability, water delivery and water quality (McDonald et al., 2011). African cities face especially huge challenges to addressing these three main water management issues.

The capacity to access water in urban and peri-urban areas in Africa depends on technical, economic, social and political parameters. In addition to peri-urban household poverty, the regulation of housing status plays a decisive role in whether or not people can access essential services, including water. In many African cities, the situation around access to drinking water is critical, especially in peri-urban areas where city authorities (whether local or central government) do not provided adequate water services for irregular housing or informal settlements. Peri-urban households are often excluded from piped services.

Unsustainable use of water resulting from government subsidies often exceeds the regenerative capacity of water resources, creating water shortages in cities, despite the great hydraulic potential that the country has (Boadi et al., 2005). Dos Santos, in her study in Ouagadougou, indicated that, having access to water at home does not give sustainable access, because water cuts, a real strategy used to regulate the water shortage, may force households to turn to an “unimproved” water source, despite being equipped with a tap at home (Dos Santos and LeGrand, 2007). This situation is prevalent in African cities, where water services for low-income urban and peri-urban dwellers remain unfordable and variable in terms of quality and quantity. This, coupled with high water prices, force peri-urban residents to use alternative sources of water that are relatively more exposed to disease-causing contamination (Fewtrell et al., 2005). Previous studies have shown that creation of urban slums due to rapid population growth depend on inadequate safe drinking water supply, which increases the risk of infectious diseases like diarrhoeal diseases, a major water-related disease, in urban areas (Butala et al., 2010; Dos Santos, 2012; Patel et al., 2013; Sambe-Ba et al., 2013).

2.2.2 Sanitation issues in African cities

Although progress has been made globally to improve sanitation for the world’s poorest, only 28% of the population in sub-Saharan Africa had access to improved sanitation in 2015; varying from 41% in urban to 20% in rural areas (WHO/UNICEF, 2017). In urban environments, the progress made has been outpaced by population growth. A major challenge in urban areas is for city planners to extend drinking water and sanitation services to reach the cities’ poorest, who are often located in informal settlements, characterized by poor conditions, low incomes, high population density, lack of legal land tenure, lack of planning, poor infrastructure, poor access to formal water, sanitation and waste management services (Lüthi et al., 2010; Scott et al., 2013). Due to the lack of sanitation service provision in such environments, households are commonly responsible for building and managing their own sanitation needs, which often results in the use of low-quality non-standardized facilities (Scott et al., 2013).

In Africa, sewage systems are rare and most of the urban population use on-site technologies (Strauss et al., 2000). Sanitation is predominantly on-site and typically takes the form of traditional pit latrines or septic tanks. Most of the population uses traditional pit latrines, the most common sanitation option in Africa. The health benefits they provide depend on how they are constructed and used. In urban sub-Saharan Africa, only 41% of the population have at least basic sanitation facilities, such as improved latrines or septic tanks, and overall, 8% still practice open defecation (WHO/UNICEF, 2017). Sanitation facilities are typically shared among multiple families in urban areas.

The low overall rate of access to improved sanitation is partly due to negligible service coverage in areas, where most people still reside. Due to weak institutional policies and lack of both human and capital resources, sanitation and waste management in many African cities are in deplorable condition. In African cities, faecal sludge is often poorly managed and inadequate infrastructure means that solid waste is regularly disposed of by dumping in open spaces, water bodies, and surface drains, which poses environmental and public health risks especially in settlements that are unplanned and informal in nature (Kennedy-Walker et al., 2014). It is important to analyse the links between water, sanitation and health in different complex contexts, in order to better understand the specific health risks in urban areas.

2.2.3 Hygiene issues in African cities

Hygiene includes all the activities aimed that people can increase their health status through the improving hygiene practices in their daily life. According to WHO, hygiene consists of the conditions and practices that help maintain health and prevent the spread of diseases, for example, frequent hand washing and face bathing with soap and water. Keeping hands clean is one of the most important ways to prevent the spread of infection and illness. However, in many settings of the world, especially in sub-Saharan Africa, practicing personal hygiene is difficult due to lack of resources, such as clean water and soap (WHO/UNICEF, 2015; CDC, 2016). Many diseases (including diarrhoeal diseases) can be spread when hands are not washed frequently or properly.

Moreover, hand washing with soap after defecation as well as before eating and cooking is crucial to interrupt the faecal-oral transmission of pathogens. Many WASH-related diseases are transmitted by pathways other than the faecal-oral route, such as person-to-person contact, food intake, etc. There are three other domains in which hygiene is essential for health, namely (i) food hygiene; (ii) water and personal hygiene; and (iii) domestic and environmental hygiene (Boot and Cairncross, 1993). Water hygiene includes behaviours ensuring safe water consumption (safe water collection, transportation, storage, and handling), personal hygiene consists of all practices resulting in cleaner individuals, such as hand washing and bathing, Food hygiene aims to limit disease transmission through food intake, whereas domestic and environmental hygiene ensures cleanliness of living environments. Food hygiene suffers when contaminated water is used to wash serving utensils and hands are not washed prior to cooking. Previous studies have shown that handwashing before food preparation, before feeding children, after coming in contact with excreta or after using the toilet has positive health effects (Pengpid and Peltzer, 2012; Oloruntoba et al., 2014). Despite the fact that hygiene has long-established links with public health, it was not included in any MDG targets or indicators. In 2015, the coverage of basic handwashing facilities with soap and water was only 15% in sub-Saharan Africa (WHO/UNICEF, 2017).

2.3 Resulting health risk in African cities

Urbanization is one of the leading global trends of the 21st century that has a significant impact on health (Hotez, 2017). Although cities bring about opportunities, such as jobs and services, they also entail challenges to achieving better health and can concentre health risks and introduce new hazards (WHO, 2010). The majority of urban Africans live in small and medium-sized cities and towns of fewer than 500,000 inhabitants, many of which are rapidly growing (Satterthwaite, 2016a). Residents of these cities have high levels of exposure to environmental risks such as water pollution and rising sea levels, which are more likely to be exacerbated by climate change and other pressing global challenges, like inadequate provision of basic services and threats of new and emerging diseases (Dodman, 2017; Seto et al., 2011). The health issues in these cities are becoming increasingly acute in urban areas, especially for residents of low-income neighbourhoods and informal settlements with high risks of infection, mostly among children (WHO, 2009; UN-HABITAT, 2010).

The capacity to plan urban growth, manage risk, and adapt to emerging hazards is lacking in many small and medium-sized cities (Wisner et al., 2015). This leads to processes of risk accumulation that pose threats to poverty reduction and sustainable development (Adelekan et al., 2015). As urban populations grow, the quality of local ecosystems and the urban environment will play an increasingly important role in determining public health status, with issues ranging from solid waste disposal, provision of safe water and sanitation, and injury prevention, to the interface between urban poverty, environment and health. As most urban slum dwellers live in tropical countries, their health is also threatened by a variety of tropical diseases influenced by social and environmental factors (Utzinger and Keiser, 2006).

Indeed, African urban dwellers are affected by poverty and are exposed to a double burden of disease, i.e. communicable diseases (e.g. diarrhoeal diseases, tuberculosis and HIV/AIDS,) and non-communicable diseases (e.g. diabetes and high blood pressure) (Salem and Fournet, 2003; WHO/ONU-HABITAT, 2010). Infectious diseases, including diarrhoeal diseases, worm infections and other infectious diseases, which are associated with inadequate water and sanitation provision (Strunz et al., 2014), are among the major health problems for urban dwellers, particularly among people living in slums and informal settlements. Risks to human health are accentuated in urban environments, where populations are dense and the likelihood of exposure to disease is especially high due to deficient facilities for drinking water supply and basic sanitation (Sy et al., 2010; Sy et al., 2011a; Satterthwaite and Bartlett, 2017). Lack of these services leads to health inequalities and greater health risks for vulnerable groups (e.g. young children and women of reproductive age) and poses major challenges for controlling infectious diseases, like diarrhoea. Poor water quality, poor environmental sanitation (excreta management, drainage of wastewater and rainwater) and poor hygiene affect directly or indirectly the health and wellbeing of people, mostly children.

Inadequate access to safe drinking water and improved sanitation produces everyday hazards for the under-served or unserved populations, with the highest risks borne by people accessing water from unsafe and untreated sources, such as shallow wells (Dodman et al., 2017). Unimproved water and sanitation is generally linked to several health outcomes. For example, the risk for gastrointestinal pathogens is strongly associated with a lack of direct water source in the home, which itself limits hand washing, and proper cleaning of food and utensils (Ferreira Carneiro et al., 2002). The influence of onsite sanitation systems are rich in total faecal coliforms, helminths, viruses, intestinal protozoa and various chemical and physical pollutants (EPA, 1994). The intrusion of these polluted effluents in the water distribution system can generate various diarrhoeal diseases in the human population (Mara and Feachem, 1999; Carr and Strauss, 2001).

Several studies have shown that inadequate water and sanitation are associated with diarrhoeal morbidity and mortality in children (Esrey and Habicht, 1986; Esrey et al., 1991; Clasen et al., 2006; Cairncross et al., 2010b; Dos Santos, 2012; Dos Santos et al., 2015). There is also evidence that diarrhoeal diseases could be prevented by ensuring access to safe, improved water and sanitation (Prüss-Üstun et al., 2014; Wolf et al., 2014; Prüss-Üstün et al., 2016). Public health actors would benefit from knowing the characteristics of urbanization in African cities and about new hazards that threaten the health of populations in these cities, especially in terms of infectious diseases like diarrhoea in the context of climate change.

2.4 Focus on diarrhoeal diseases

2.4.1 Definition of diarrhoea

Diarrhoea is a major waterborne disease that creates high disease burdens in populations worldwide, mostly in children under the age of five years. It is an ancient disease that has been described as far back as the Greek civilizations, dating back to the time of Hippocrates (460-370 B.C). In his writings, Hippocrates described the diseases as "abundant liquid stool at short intervals" (Cocheton et al., 1987). Diarrhoea is defined by the World Health Organisation (WHO) and the United Nations Children's Fund (UNICEF), "as the passage of three or more loose or liquid stools per day, or more frequent passage than is normal for the individual"(WHO, 2017a). In the case of breastfeeding infants, diarrhoea is defined by the presence of stools more liquid and more frequent than usual.

Based on its symptoms and duration, diarrhoea is classified into one of three types by the WHO: (i) acute watery diarrhoea, (ii) acute bloody diarrhoea (so called dysentery), and (iii) persistent diarrhoea (WHO, 2017a). Diarrhoea is acute when it lasts for several hours or days (less than 14 days). It is persistent when it lasts 14 days or more. Epidemiological evidence shows that diarrhoea can cause several adverse health conditions in children, such as dehydration, malnutrition, serious non-intestinal infections, underweight, and stunting (Black et al., 2003). In addition to this, there are four levels of severity namely, mild diarrhoea, medium, severe and lethal. In the most severe cases, diarrhoea can cause death by depleting body fluids, resulting in profound dehydration.

2.4.2 Diarrhoeal diseases burden in children under 5 years of age

Diarrhoeal diseases have long been recognized as a leading cause of mortality and morbidity, especially in LMICs. The global burden of diarrhoea among children under the age of five years was first estimated by Snyder & Merson in a meta-analysis published in 1982 (Snyder and Merson, 1982). Using data from 24 published studies on acute diarrhoeal diseases in developing countries, the authors estimated the median incidence of diarrhoea as 2.2-3.0 episodes per child per year. Based on 1980 population estimates, the estimated total yearly morbidity and mortality was 744-1,000 million diarrhoea episodes and 4.6 million diarrhoea-related mortality cases among children under 5 years of age, globally (Snyder and Merson, 1982). In 1992, Bern et al. updated the analysis of Snyder & Merson through a meta-analysis of studies published from 1980 to 1990. The authors found no change in diarrhoea incidence (2.6 episodes per child per year) but a decrease in annual mortality (3.3 million deaths per year) (Bern et al., 1992). A study published in 2003 also indicated no change in median incidence (3.2 episodes per child per year) but revealed again a decline in diarrhoea-related mortality (2.5 million deaths per year) (Kosek et al., 2003). A systematic review conducted by Fischer Walker et al. in 2012 showed that the global incidence remained at the same level, 2.9 episodes per child per year, but that global diarrhoea-related mortality among children under-five had decreased to 711,800 deaths per year in 2010 (Fischer Walker et al., 2012).

In addition to these earlier studies, the Global Burden of Disease (GBD) study, a standardised approach for assessing health worldwide, initiated by the World Health Organization (WHO) and the World Bank, estimated the global burden of diarrhoeal diseases from 1990 to 2015 (Lopez and Murray, 1998). The GBD study indicated that diarrhoea deaths among children under the age of 5 years fell by 28.6% between 2010 and 2015 (Institute for Health Metrics and Evaluation (IHME), 2015). However, despite the substantial decline in diarrhoeal diseases mortality over the past 15 years fell from 1.2 million in 2000 to 500,000 in 2015, mortality and morbidity rate due to diarrhoea remain unacceptably high among children under the age of five years (WHO, 2015b). Nowadays, diarrhoeal diseases and pneumonia are the leading cause of childhood deaths in LMICs. They are responsible for almost one-quarter of all deaths in children under the age of 5 years. Every year, more than 1.4 million children die from diarrhoea and pneumonia, particularly in settings with limited access to health care services, nutritious foods, and basic sanitation and hygiene (Walker et al., 2013).

Diarrhoeal diseases account for 1 in 10 childhood deaths worldwide, making diarrhoea the second leading cause of death among children under the age of 5 years (UNICEF/WHO, 2009; Black et al., 2010; Fischer Walker et al., 2012; Liu et al., 2012; WGO, 2012; WHO, 2014b). Diarrhoea still causes 9% of all deaths in children under the age of 5 years (WHO, 2015b; UNICEF, 2016b). This means that over 1,400 children die each year or about 526,000 children a year, despite the availability of a simple treatment solution. According to Fischer et al (2012) in 2010, each child in LMICs experienced an estimated 2.9 episodes of diarrhoea, resulting in nearly 1.7 billion episodes among children under the age of 5 years; the incidence rate was highest among children aged 6-12 months and lowest among those aged 24 to 59 months, with 5.3 and 2.7 episodes, respectively, per year (Fischer Walker et al., 2012).

2.4.3 Geographic distribution of diarrhoea mortality rate in children under five

The global distribution of diarrhoea-related mortality among children under 5 varies geographically (Figure 2.2). In 2015, the majority of under-five deaths attributable to diarrhoea occurred in sub-Saharan Africa (10%) and South Asia (10%), compared to Europe (4%), East Asia and the Pacific (5%), the Middle East and North Africa (7%).

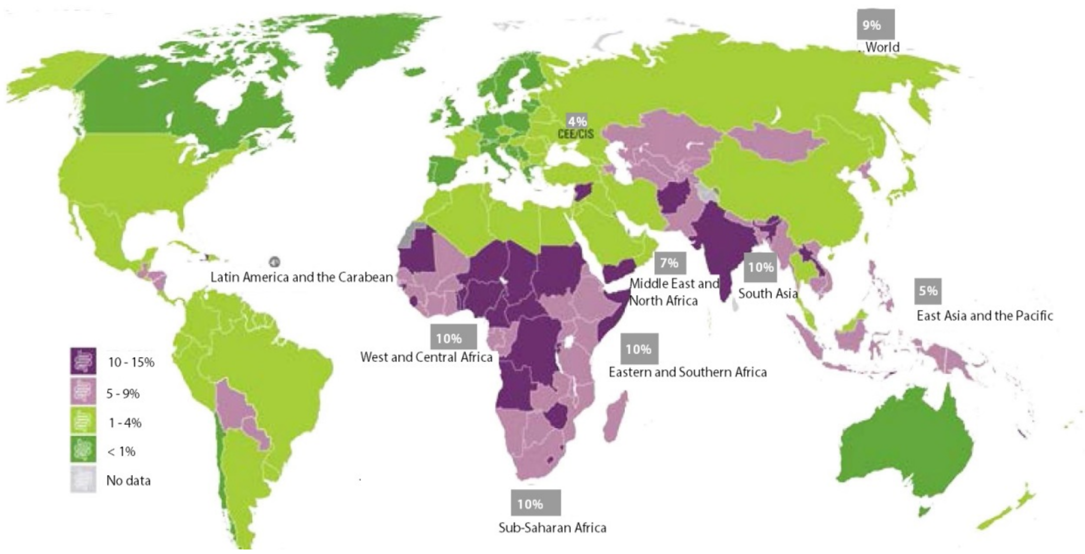


Figure 2.2: global distributions of percent of deaths among children under-five attributable to diarrhoea in 2015 (Adapted from (MCEE) provisional estimates 2015)

2.4.4 Diarrhoeal diseases aetiology

Diarrhoea is a common symptom of several possible gastrointestinal infections in the intestinal track, which can be caused by a variety of infectious pathogens (Kotloff et al., 2013; Lanata et al., 2013; Becker et al., 2013). These include bacteria (e.g. *Campylobacter* spp, *Escherichia coli, Salmonella* spp, and *Shigella* spp.), viruses (e.g. adenovirus, astrovirus and rotavirus), and other parasitic microorganisms (e.g. *Cryptosporidium* spp., *Entamoeba histolytican*, and *Gardia intestinalis*) (Becker et al., 2013; WHO, 2017a). The clinical symptom of diarrhoea is the result of an intricate relationship between the aforementioned infectious agent, the host's immune response, and the management and environmental factors imposed on the host (Nida, 2010). A systematic review on deaths due to diarrhoea conducted by Lanata et al. (2013) highlighted the five most important pathogens causing diarrhoea-related deaths: rotavirus (18% of all deaths), enteropathogenic *Escherichia coli* (14%), enterotoxigenic (ETEC) (7%), norovirus (8%), and *Shigella* (6%) (Lanata et al., 2013).

The findings are in line with the Global Enteric Multicentre (The GEMS) study also published in 2013, which is a large prospective matched case-control study that investigated aetiological causes of moderate-to-severe diarrhoea in children under 5 years in Africa and Asia. The GEMS study estimated the burden of aetiology of diarrhoea and concluded that rotavirus, *Cryptosporidium* spp., ETEC, and *Shigella* spp. were the most common causes (Kotloff et al., 2013). The findings of the GEMS study are consistent with a study conducted by Pires et al., (2015, which found the same pathogens to be among the most important causes of diarrhoea

(Pires et al., 2015). One of the differences between these two studies was related to the relative contribution of norovirus to diarrhoea incidence and mortality. The GEMs study estimated a lower contribution of this pathogen than the 2015 study. These findings suggest that diarrhoea prevention and treatment efforts among children under the age of 5 years should focus on rotavirus, *Cryptosporidium* spp, *Shigella* spp., enterotoxigenic and enteropathogenic *E. coli* and norovirus (Kotloff et al., 2013; Platts-Mills et al., 2015; GBD, 2017).

2.4.5 Diarrhoea transmission

2.4.5.1 WASH factors and diarrhoea transmission

Diarrhoea is a waterborne disease transmitted mainly through the ingestion of faecally contaminated water or food, person-to-person transmission and direct contact with infected faeces (Ashbolt, 2004; Eisenberg et al., 2012). Rotavirus, which is an important pathogen for childhood diarrhoea, is highly contagious and is easily transmitted between children via faecal-oral pathway, often via contact with hands, surface and objects, and waterborne infections (Ansari et al., 1991; Tate et al., 2012; Kotloff et al., 2013). Human beings exposed to the faeces of infected humans or animals are at risk of receiving the pathogens and of contracting diarrhoea (WHO, 2017a). The infection is spread through multiple transmission pathways, such as person-to-person, direct contact with faecal matter, consumption of faecally contaminated water or food, household or community level pathways, environmental to person pathways, and person to environmental pathways, as a result of poor hygiene (Eisenberg et al., 2012).

The highest risks are borne by people accessing water through unsafe and untreated water sources. Contaminants in these water sources can often be attributed to open defecation or poor maintenance of pit latrines (Tsinda et al., 2013). As summarized by the Centers for Disease Control and Prevention (CDC) in Figure 2.3, there are several pathways related to WASH conditions that can help pathogenic agents spread and increase the risk of contracted diarrhoea (CDC, 2011). Unsafe drinking water, unimproved sanitation and poor hygiene practices are the most important risk factors, long associated with diarrhoeal illness particularly in low-income countries (Mausezahl et al., 2009; Cairncross et al., 2010a; Pullan et al., 2014; Wolf et al., 2014).

It has been estimated that 58% of all diarrhoeal cases in LMICs could be attributed to environmental factors, such as inadequate drinking water (34%; 502,000), sanitation (19%;

280,000 deaths) and hand hygiene (20%; 297,000 deaths) (Prüss-Üstun et al., 2014). According to Prüss et al., (2016), the predominant pathway of transmission depends on the pathogen's local infrastructure (e.g. whether the population has access to appropriate sanitation and safe water) and human behaviour (Prüss-Üstün et al., 2016). As show in Figure 2.4, if sanitation or related hygiene is poor, e.g. when handwashing facilities are inadequate or when faeces are disposed improperly, excreta may contaminate hands, which can then contaminate food or other humans (person-to-person transmission). In addition, faecal pathogens transferred to sewage systems that are not linked to treatment plants may subsequently contaminate surface and ground water. Human excreta can also directly contaminate the soil and surface, e.g. through open defecation, and come in contact with people; likewise, flies may carry pathogens from excreta to food. Through these pathways, drinking water, food and recreational water may be contaminated and cause diarrhoeal diseases following ingestion (Pruss et al., 2002; Moors et al., 2013). Moreover, pathogens in animal excreta may also contaminate drinking water sources (Dufour and Bartram, 2012).

Faecal contamination not only occurs in informal water supply services but also in centralised water supply networks (Boakye-Ansah et al., 2016; Rossiter et al., 2010). Risk of diarrhoeal diseases may therefore extend to the urban population served by the contaminated system. Recognizing the importance of safe drinking water and improved sanitation in reducing health risks, WHO has developed and supported the implementation of Water Safety Plans, which aim to assess and manage risk from catchment to consumer (Bartram, 2009). This approach has been extended to risk reduction along the sanitation chain with the Sanitation Safety Plans (WHO, 2015a).

Figure 2.3: Pathways to diarrhoea illustrating how contamination can occur (modified from CDC, 2011)

2.4.5.2 Climatic factors and diarrhoea transmission

Diarrhoeal disease transmission is also affected by weather and climate, like temperature and rainfall factors (Figure 2.4), thus highlighting yet an additional link of diarrhoea with the environment (Singh et al., 2001; Moors et al., 2013; WHO, 2014a; Levy et al., 2016). As the climate continues to change, a future increase in diarrhoea incidence is predicted.

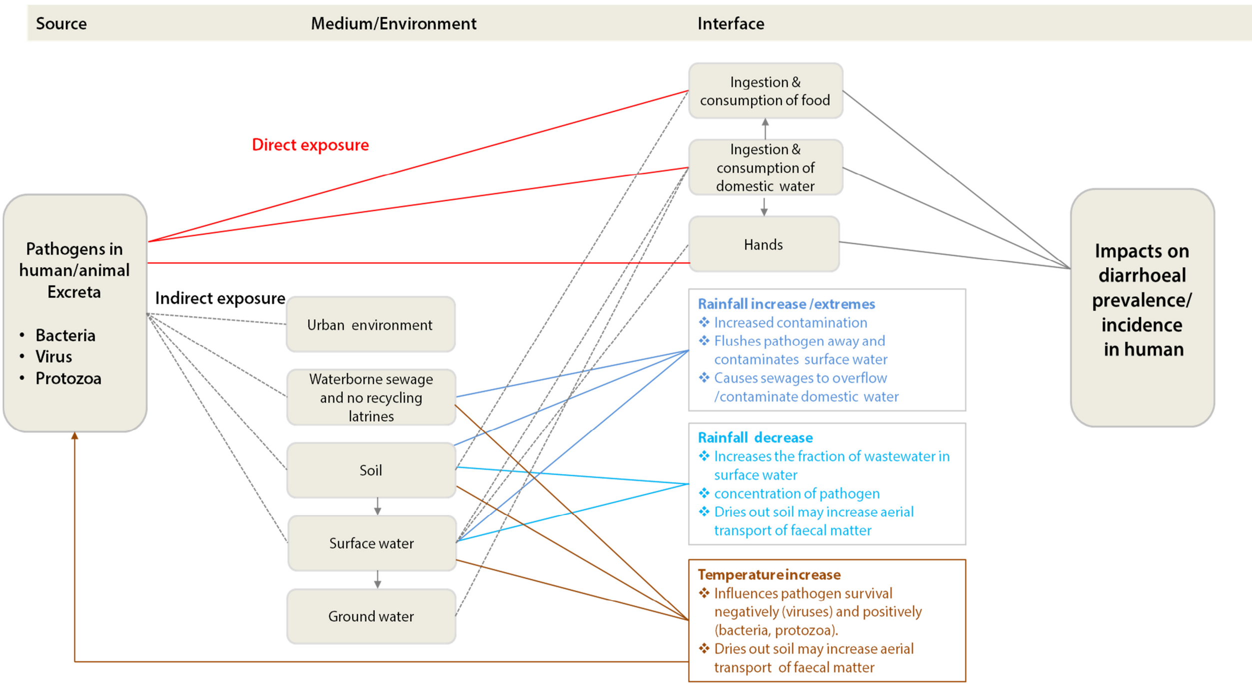


Figure 2.4: Example of potential transmission pathways of diarrhoea-causing pathogens through WASH and climatic factors (adapted from Prüss-Üstün et al., 2008 and Moors et al., 2013)

Temperature is the climate factors for which most exposure-response relationships have been described (Moors et al., 2013). Pathogens like bacteria favour warmer temperatures (Freeman et al., 2009; El-Fadel et al., 2012). Increased temperatures may increase the probability of food spoilage, and concurrent temperature-related changes in food storage and consumption practices may affect disease risk (D'Souza et al., 2004; Tirado et al., 2010). Water consumption rates may also increase during warmer periods of the year, increasing the risk of pathogen ingestion in regions with poor quality drinking water.

While ambient temperature may affect pathogen survival and host behaviour, increased or extreme rainfall can directly affect the transport of pathogens, and can affect the existing water and sanitation infrastructure, altering human exposure patterns (Levy et al., 2016). Transport of pathogens resulting from increased or extreme rainfall occurs in several ways, in which it can affect the risk of getting diarrhoea. If pathogens from human and/or animal excreta are present in soils and on environmental surfaces, rainfall can mobilize these pathogens and transport them to the surface water or to other areas, exposing individuals to pathogens. Several studies argue that floodwaters can spread pathogens within watersheds (Ferguson et al., 2003; Dorner et al., 2006) and that heavy rainfall events can lead to saturation of the subsurface, which facilitates water transport of pathogens to the surface or through groundwater (Auld et al., 2004; Fong et al., 2007). Heavy rainfall and flooding can increase the vulnerability of WASH systems, affecting pathogens transmission via sanitation and/or drinking water treatment infrastructures, for example (Cissé et al., 2016).

Decreased rainfall or drought, coupled with water scarcity, limits dilution and may, thus, increase the fraction of wastewater in surface water, leading to consumption of lower quality water due to increases in the concentration of pathogens in both drinking and irrigation water sources (Moors et al., 2013; Levy et al., 2016). Populations relying on these contaminated water resources experience increased outbreaks of waterborne diseases, including diarrhoea (Hashizume et al., 2007; Hofstra, 2011; El-Fadel et al., 2012). Water scarcity (which is a measure of per capita water availability) is associated with a range of health problems, including diarrhoea (Kovats and Lloyd, 2014). In periods of decreased water availability, people have to revert to poor quality water sources (Jofre et al., 2009). Furthermore, interrupted water availability contributes to poor hygiene, an important factor causing diarrhoea (Lloyd et al., 2007; Prüss-Üstun et al., 2008). In their study conducted in 2001 in 18 Pacific islands, Singh and colleagues, considered average weather conditions over a 10-year period and showed that all-cause diarrhoea (measured by hospital admissions) increased with decreasing water availability (Singh et al., 2001).

3 Senegal's urbanization trends, water and sanitation challenges

3.1 Urbanization trends and socio-economical profile of Senegal

Senegal is a low-income country located at the far West of Africa. It is bordering to the north with the Republic of Mauritania, to the east with Mali, to the south with Guinea Bissau and Guinea Conakry and to the west by the Atlantic Ocean. The country is crossed by the Gambia River, and its area is approximately 196,712 km^2 with a population density of 78 inhabitants per km^2.

Since its independence in 1960, Senegal experienced a rapid urbanization. With almost half of its population living in cities, Senegal is one of the most urbanizing countries in West Africa. Its urban population has almost doubled in the last few decades, rising from 23% in 1960 to 45% in 2015, and is expected to increase to almost 60% by 2030 (World Bank, 2016). Currently, 15 million people live in the country with highest population size living in the regions of Dakar (the capital of the country) and Thiès (where the study area Mbour is located) with 3,529,300 inhabitants (23.1% of the total population), 1,995,037 inhabitants (13.1%), respectively; moreover 40% of the urban population of the country live in the coastal cities (ANSD, 2014).

Regarding the weather, the climate is typically Sahelian with two main seasons: a hot dry season from November to June and a rainy season from July to October. Indeed, between the two seasons, there is a dry season of transition from December to March relatively cold called cold dry season. The annual mean temperature is between 22°C and 30°, with monthly average in the hottest seasons of up to 35°C, varying significantly between the coast and the interior of the country (World Bank, 2016; Faye, 2010). The relative humidity is high on the coast; it varies between 60 and 80%. The small coast of Senegal, where Mbour is located, is vulnerable to weather events particularly flooding, drought, sea level rise and coastal erosion associated with climate change (World Bank, 2016).

Even if the country is classified as a low-income country, the economy is growing. According to the National Agency of Statistic and Demography (ANSD; webpage), the country gross domestic product (GDP) and unemployment rate was respectively 6.4% and 12.5% in second quarter of 2017. The same institution argues that Senegal's economic growth is mainly attributable to the primary sector (such as agriculture, animal husbandry, fishing and handicrafts) and the secondary sector (such as construction and manufacturing industry).The portion of people living below the poverty line was 16.5% for woman and 13.9% for men.

Regarding the country demographic profile, the crude birth and the global fertility rate were 37.2 ‰ (with 4.7 children per woman in 2016) and 152‰ respectively; the average life-expectancy (years) at birth was 64.8 years (ANSD, 2014).
Regarding the health status of children under the age of five years, the under-five and infant mortality rates were 51‰ and 36‰ respectively in 2016 (ANSD and ICF International, 2017). The main causes of this mortality are diarrhoeal diseases, lower respiratory infections, neonatal preterm birth, encephalopathy and sepsis, malaria and protein-energy malnutrition, according to the GBD (Institute for Health Metric and Evaluation, 2016).

In the following section, we will focus in details on water, sanitation and hygiene challenges in Senegal, followed by a short section on diarrhoeal burden and control policies in the country.

3.2 Water, sanitation and hygiene challenges in Senegal

3.2.1 Drinking water challenges

Senegal has a huge potential hydraulic (surface water, groundwater). However, despite this potential, difficulties in accessing drinking water supply persist in some part of the country. These difficulties are linked to a lack of effective management and an important inequality in the spatial distribution of the resource. The demographic growth is driving the increasing need for drinking water access and other services. Indeed, urban centers where a significant portion of the population is concentrated are the most affected, especially urban slums. Given the recurrence of the water issues, the Senegalese's Government has been made several reforms in the water sector over two decades. Table 3.1 shows the chronological evolution of water policies reforms in Senegal since the 1980s.

The water distributed by the Senegalese Society of Water (Sénégalaise des Eaux (SDE)) comes from two sources: (i)- surface water (i.e. Lac de Guiers) which is alimented by the Senegalese river, and (ii)- groundwater (i.e. boring or drilling). The source of water supply, which is closely related to the socio-economic conditions of the households, is classified as an "improved" or "unimproved" source. The richest households are being much more likely to have improved sources than the poorest. "Improved sources" consist of a direct supply from the water network (i.e. private tap, use of neighbours tap or public tap connected to the water network), and "unimproved sources" are unprotected wells, boring with manual pumping and surface water, which are relatively more exposed to disease-causing contamination (Fewtrell et al., 2005).

According to the JMP, Senegal has met its MDG target on water, the proportion of people with improved water source rising from 60% in 1990, 62% in 2000 to 75% in 2015. Almost half of the population (48%) gained access from this period (WHO/UNICEF, 2015; WHO/UNICEF, 2017). However, the high proportion of access to drinking water hides important inter-regional disparities across the country and the place of residence. More than 90% of the urban population have access to improved water sources as opposed to 63% in rural areas in 2015 (WHO/UNICEF, 2017). The 2016 Demographic and Health Survey-continue (DHS-continue 2016) report showed that 82% of the Senegalese households have access to improved sources of water, mostly from private water connection in the house (53%) or from a public tap/fountain. In contrast, one in five households (18%) use water from unimproved source, mainly from an unprotected dug well (13%) (ANSD and ICF International, 2017).

Even if access to safe water has rapidly improved for urban centres, unplanned or informal settlements' continue to struggle to access to safe drinking water. Peri-urban households are often excluded from piped water services. In Senegal, the fact that a neighbourhood must be planned to be eligible for social connections on the water network excludes the populations who live in peri-urban areas or informal settlements, which have a more precarious socio-economic status (SENAGROSOL, 2009). For these neighbourhoods, the technical response from the National Water Agency (SDE) is the installation of standpipes (public tap/fountain), which certainly offer access to drinking water to the populations, but put them also at risk of water contamination due to transport and storage.

Table 3.1 Water policies in Senegal from the 1980s to today

Year	**Hydraulic policies**
1985	Canal du Cayor
1990	Bornes fontaines
1994	Branchements sociaux
1995	Projet Sectoriel Eau (PSE); contrat d'affermage SDE
2002	Projet Eau à Long Terme (PELT)
2006	Projet Eau potable Assainissment du Millénaire (PEPAM)
2008	Plan d'Action pour la Gestion Intégrée des Ressources en Eau (PAGIRE)

3.2.2 Sanitation and hygiene challenges

Although Senegal has met its water target, it lags behind on improved sanitation, although sanitation and hygiene are among the priorities for the government, as demonstrated by the creation of the National Senegal Sanitation Agency (ONAS, *Office National de l’Assainissement du Sénégal*) since 1996, as part of the Programme d’Eau Potable et d’Assainissment du Millénaire (PEPAM strategy of the *Millennium Drinking Water and Sanitation Program* to meet the MDGs target). ONAS is responsible for sanitation in urban areas throughout the country. However, despite its start, progress in terms of access to sanitation remains insufficient. The proportion of people with improved sanitation increased slightly from 36% in 1990 to 48% in 2015 with high disparities between urban and rural areas (WHO/UNICEF, 2015). Only 30% of the population gained access to improved sanitation between 1990 and 2015. It thus appears that the country missed the MDG target of 65% of the population utilizing improved sanitation. In 2015, 23% of the households still used open unimproved sanitation and 14% still practiced open defecation despite the multiplication of Community-Led Total Sanitation (CLTS) initiatives since 2009 (Hoang-Gia et al., 2004; WHO/UNICEF, 2015).

The last DHS-continued report showed that less than half (45%) of the Senegalese households use improved unshared sanitation facilities in 2016 (ANSD and ICF International, 2017). In addition, one in five households (23%) have access to improved shared sanitation, and there are significant variations depending on the place of residence (37% in urban vs 8% in rural areas). Hence, almost one-third of households (32%) still use unimproved sanitation, mostly traditional latrines (17%) and 15% have no sanitation facilities. Inter-regional disparities on access to improved sanitation are also prevalent in Senegal. For example, 64% of households in Greater Dakar have access to improved sanitation; 39% have on-site or semi-collective systems and 25% are connected to the sewer network compared to other regions (Scott et al., 2013). The most common sanitation technologies are on-site system, typically pit latrine or septic tank.

The availability of improved sanitation or water is closely related to socio-economic conditions, with wealthier households having a much higher chance of having access to improved sanitation or water than the poorest households. Therefore, socio-economic factor is probably the main determinant in explaining the inequalities observed in access to water and sanitation. The distribution of these inequalities at the regional level is evidenced by strong geographical inequalities in access to sanitation and sanitary practices. The availability of improved sanitation, which is much more favourable in Dakar, is linked to a population that is massively in the richest category. With regard to wastewater disposal, discharge into the environment is the main practice by more than 60% of the households (ANSD and ICF International, 2015).

Regarding hygiene issues, the last DHS report revealed that only 15% of the Senegalese household visited disposed a handwashing facility in their house. This report is similar with what is reported in the JMP report (ANSD and ICF International, 2017; WHO/UNICEF, 2017). This proportion, which is much higher in urban than in rural areas (23% vs 7%) is still very low (ANSD and ICF International, 2017). This situation in Senegal shows that the issues such as access to safe water, adequate sanitation and basic hygiene are major preoccupation for some categories of the population. Lack of basic urban services results in difficult living conditions, especially for people in precarious habitats, that expose them to multiple health risks for infectious diseases, such as diarrhoea (Salem, 1998; Sy et al., 2011b). Based on the idea that the occurrence and transmission of infectious diseases are closely linked to the neighbourhood environment (Wu et al., 2011), and that the environmental factors significantly affect the occurrence of disease like diarrhoea, it is therefore of high importance to investigate regularly and deeply the interactions between water, urban environment and health.

3.3 Diarrhoeal diseases burden and control policies in Senegal

Diarrhoeal diseases constitute one of the major health issues affecting mostly children under the age of five years in Senegal. The Senegalese's government, through the Ministry of Health (MoH) is according a high priority of improving child health by implementing several strategies to reduce the mortality and morbidity due to diarrhoea. Since the 1980s, the Government has implemented a program to fight diarrhoeal diseases (MSAS, 2013) and is working closely with several partners such as WHO, UNICEF, the Canadian Micronutrient Initiative (Mi) NGOs and Gavi Alliance. In 2008, the MoH, with the support of these partners, especially Micronutrients Initiative (MI), changed its national policy against diarrhoea, following the recommendations of the WHO/ UNICEF/USAID concerning the use of zinc supplementation combined with the low osmolality Oral Rehydration Solution (ORS) (WHO, 2006b). In this context, the MoH has developed a plan that focuses on three strategic objectives:

(i) increase the demand and use of ORS/ZINC for the management of diarrhoea by populations;

(ii) improve the quality of service provision and accessibility for the management of diarrhoea with the use of ORS / ZINC;

(iii) create an enabling environment for scaling up the management of diarrhoea with ORS/ZINC.

Moreover, in 2014, Senegal became the 33rd country supported by the GAVI Alliance to introduce rotavirus vaccine in its expanded program on vaccination (PEV) in the fight against diarrhoea. Other interventions such as improving water, sanitation and hygiene were also taken into account. In spite of the aforementioned interventions strategies, morbidity and mortality due to diarrhoea remain unacceptably high in the country.

According to the most recent estimates for diarrhoea associated deaths in children from the GBD, in Senegal, diarrhoea is the leading cause of death among children under the age of five years accounting for 13% (9.1% - 17.4%) of total child deaths; and responsible for 7% of death and 14% of the Disability-Adjusted-Life Years (DALYs) in this age group (GBD, 2016). Epidemiological studies conducted in the country estimated the prevalence of diarrhoea among children under five between 19% (ANSD and ICF International, 2015) and 26% (Thiam et al., 2017a). The last DHS-continued report, shows that the prevalence of diarrhoea among children under the age of five years has not decreased significantly between 2014 and 2016 and remained at almost the same level at 15% (ANSD and ICF International, 2017). The observed prevalence was particularly high among children aged 6 to 23 months (24% to 23%).

In Senegal, diarrhoea is mostly due to viral or bacterial pathogens with a high number of cases due to rotavirus in the cooler months and bacterial enteric pathogens in the warmer months (Sambe-Ba et al., 2013; Sire et al., 2013; PATH, 2014; Liu et al., 2015). About a third of all hospitalizations due to diarrhea in children under the age of five years in Senegal are caused by rotavirus (Tate et al., 2012). Morbidity due to diarrhoea is still high probably because risk factors (such as poor hygiene, lack of access to safe drinking water, insufficient promotion of breastfeeding and malnutrition) still prevail (Okeke, 2009). The continued growth of African secondary cities, like Mbour, with resulting overcrowding population in some areas may contribute to outbreaks of diarrhoea to which children are particularly vulnerable. In these cities, aggregates figures from statistics are often lacked of disaggregate data at small scale (e.g. neighbourhood level).

4 Background and objective of the PhD thesis

4.1 Identified research needs

Rapid urbanization, especially the ongoing and expected population growth in urban areas, coupled with the expected impact of climate change in these areas, feed a huge challenges to global health including the difficulties to control infectious diseases (UN, 2017). An important feature of the rapid urban growth is the disproportionate expansion of small and medium-sized cities" also known as "secondary cities" rather than big cities alone (Satterthwaite and Owen, 2006; Cissé et al., 2011).

As highlighted in previous chapters, there are heterogeneous environments and a lack of access to safe drinking water, sanitation and hygiene, as well as waste management in African cities, especially in secondary cities. Previous studies have shown that unplanned urbanization and unequal infrastructure of cities have many consequences on health by producing different health risk and uneven exposure to specific diseases (Vallée, 2009; Salem, 2013). Increased urban growth of secondary cities, like Mbour, coupled with their difficulties in accessing sufficient quantities and quality of water, and sanitation system, their weakness or inability to manage solid waste and wastewater produced lead to waterborne diseases like diarrhoeal diseases (Esrey and Habicht, 1986; Esrey et al., 1991; Bartram and Cairncross, 2010; Fuhrimann et al., 2016).

In Mbour, Senegal, the rapid urban population growth in a short time is characterized by the proliferation of precarious neighbourhoods and urban slums where poor people generally coming from rural areas settle in the city with lack of access to sufficient drinking water (49%), safe sanitation (4%), garbage collection services (25%), and others basic services (ONAS, 2008; Toure et al., 2011). This situation explains that these issues such as access to safe water, adequate sanitation and basic hygiene are major preoccupation for the population. An analysis of the routine health surveillance data of Mbour have shown that diseases related to poor hygiene and sanitation were the main reasons for visiting a health facility in 2012, with diarrhoeal diseases accounting for 19.40% of total consultation among children under the age five years. This diarrhoea prevalence may hide the fact that there are highest areas of the city most affected than others.

However, in secondary cities, health outcome as well as health related risk data aggregated at small scale (e.g. at neighbourhood level) are often not well documented or are unavailable (Dodman, 2017; Zeba et al., 2017; Brown, 2017). Little is known about urbanization and its health consequences in small and medium-sized cities. Most data on everyday health outcomes are aggregated at national or wide city scale. This hides important differences in how the impacts of different hazards and risks vary across different size of urban areas and locations, and between genders, ages, and human abilities (Osuteye et al., 2017). Few studies have been conducted on health and its determinants in these cities; most attention is given to big cities because of their strategic economic importance. For instance, in Mbour, the study area of the current study, scientific research has mainly been focusing on the urban growth of the city and coastal erosion that are affecting the city. The literature on this subject is still relatively poor. To our knowledge, no study has combined geographical, environmental, and epidemiological approaches to analyse the spatial patterns of diarrhoeal diseases and associated environmental risk factors in Senegal in general and particular in Mbour. It is rare to have spatial information at small scale for diarrhoea collected from the community (perceived morbidity) and from the health facilities (reported morbidity).

Against this background, disaggregated data are needed in these urban areas to establish the local epidemiology and implement appropriate preventive measures. In addition, due to the fact that city governments have an important role to play in managing urban growth and in the implementation of the SDGs more generally because they have the responsibilities for delivery of basic services (e.g. water, sanitation and many others) that are linked to many of the goals. To achieve the SDGs, local governments need comprehensive, detailed, socially and spatially disaggregated information to be on board. To address research gaps and information deficit in small and medium-sized cities, this PhD aims to provide further disaggregated evidence on diarrhoeal diseases prevalence and incidence among children under the age of five years as well as the associated environmental risk factors in the secondary city of Mbour, Senegal in West Africa. A thorough understanding of the spatial patterns of diarrhoea risk within city is important in order to develop appropriate interventions and preventive measures to reduce risk and burden of the diseases. Hence, the current PhD thesis pursues the following objectives.

4.2 Goals and objectives of the thesis

4.2.1 Goals

The overall goal of this PhD thesis was to provide further disaggregated evidence on diarrhoeal diseases prevalence and incidence among children under the age of five years as well as the associated environmental risk factors in order to improve the control of the disease through the implementation of targeted preventive measures in the secondary city of Mbour, Senegal, West Africa. The future interventions are expected to contribute to improving the health status of children by reducing the burden of the disease in the secondary city Mbour.

4.2.2 Specific objectives

Five specific objectives are linked to the overall goal.

1. To provide an overview of the urbanization trends of Mbour and its effect on childhood diarrhoea associated risk factors (e.g. water supply, sanitation, wastewater and solid waste management);
2. To determine the prevalence of diarrhoea among children under the age of five and its associated risk factors in four different zones of the city;
3. To investigate the relationship between childhood diarrhoeal incidence and climatic factors such as temperature and rainfall;
4. To map the spatial pattern of diarrhoea and estimate the effect of sociodemographic and climatic factors on diarrhoea morbidity using a Bayesian CAR model;
5. To assess mothers/caregivers knowledge and management practice of diarrhoea among children under the age five years.

4.3 Conceptual framework

The current PhD thesis aims, therefore, to analyse the spatial patterns of diarrhoea risk among children under the age of five years and its associated risk factors in the secondary cities of Mbour, Senegal based on the following conceptual framework.

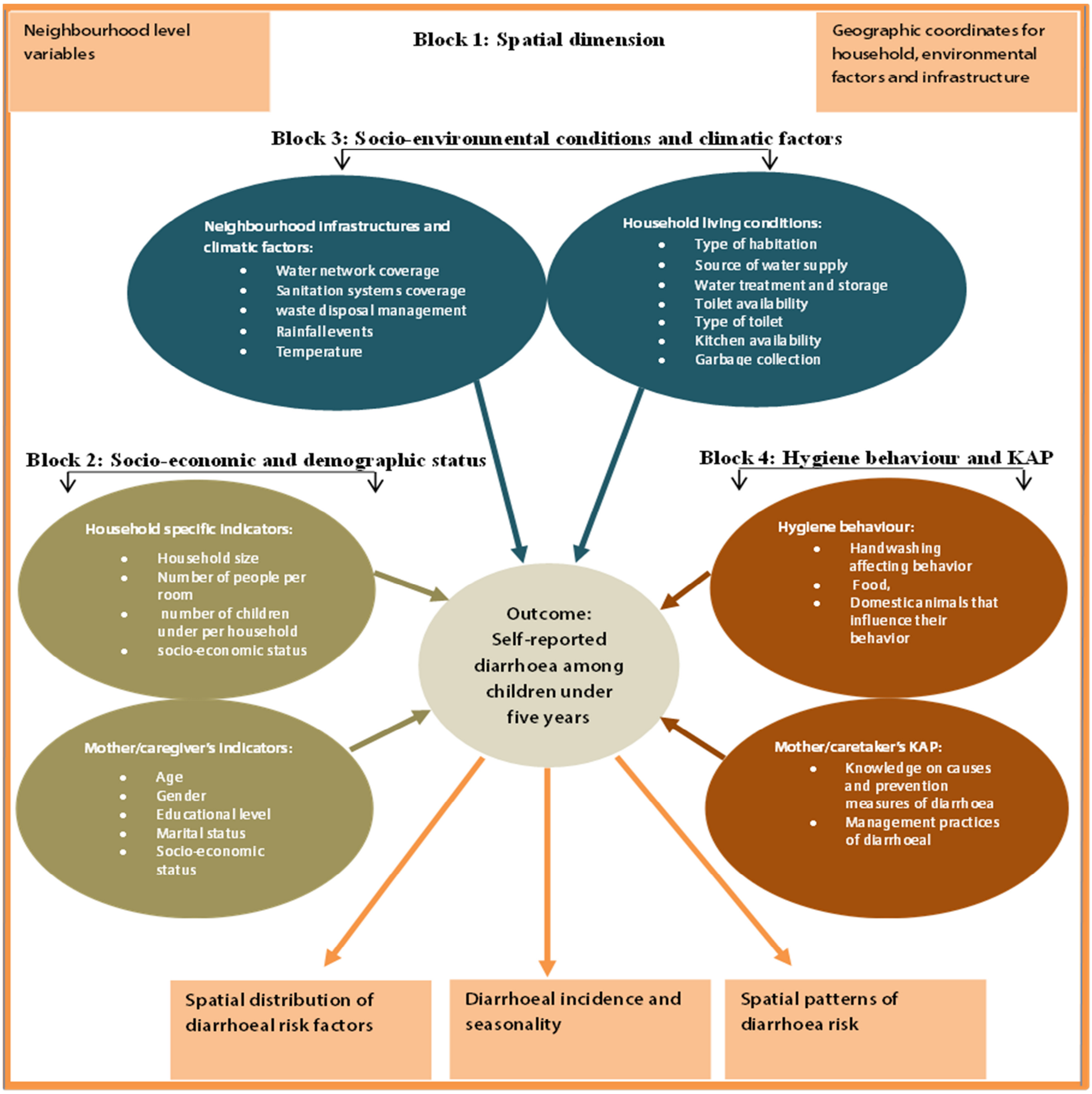


Figure 4.1: Conceptual framework of the PhD thesis

5 Methodology

5.1 Multidisciplinary approach

In order, to assess the environmental risk factors, and deepen the understanding of the spatial patterns of diarrhoea risk among children in an urban context, the nature and diversity of the data to be collected push to build multidisciplinary approaches. Therefore, the methodology developed in this PhD thesis combined three complementary methodological approaches (Figure 5.1). These include: (i)- a geographical approach (mapping), (ii)- an epidemiological approach (household surveys), and (iii)- a microbial analysis of drinking water samples derived from water sources and households as described below. The present chapter describes the study area and provides an overview of the methodology applied in this thesis.

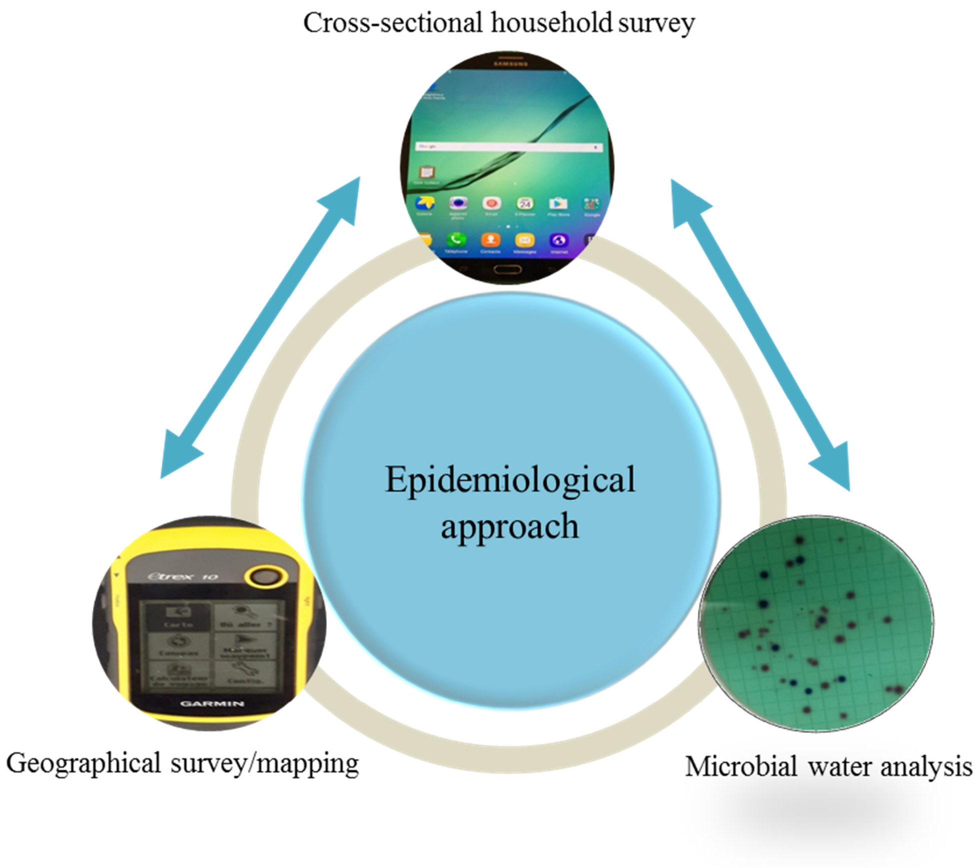


Figure 5.1: Multidisciplinary epidemiological approach

5.2 Study area, Mbour, a rapidly growing secondary coastal city of Senegal

5.2.1 Location and neighborhoods

Mbour is the third largest city of Senegal. It is located in the southwestern part of Senegal, neighbouring the Atlantic Ocean on the small coast, at 45 km from Thiès, its regional capital, and 80 km from Dakar, the capital of the Senegal. Mbour serves as an intermediate city to the capital and the south of the country. Administratively, the city is divided into 25 neighbourhoods.

5.2.2 Population and spatial growth of the city

The city grew rapidly and has been shown constant growth rates (6.3% per year, on average exceeding the national average which is 2.7%) since its creation as a colonial trading port in 1926 by settlers (Figure 5.2). Colonization was a determining factor in the evolution of most of the coastal cities in Senegal, including Mbour. The European presence and the establishment of administrative services and market equipment, intended to commercialize the agricultural production of the hinterland have generated a strong migratory flow in this part of the country. The rapid urbanization of the city is mainly due to the migration of people from rural areas, other urban areas, and the neighbouring countries. The city was characterized by some constructions of fishermen along the coast in 1978.

According to statistical data from yearbook Afrique Occidentale Francophone (AOF) and ANSD, the population of Mbour was 1,700 inhabitants in 1926, with a demographic growth of 11.8% between 1926 and 1936, due to a strong migration during the first years of its erection as a municipality. After the independence of the country in 1960, precisely in 1961 the population increased to 16,000 inhabitants, and the city became quickly an agglomeration. The population rose from 26,750 inhabitants in 1972 to 37,896 inhabitants in 1976 and from 76,751 inhabitants in 1988 to 170,436 inhabitants in 2002. The last population census estimated the population at 232,777 inhabitants in 2013, but the local authorities claim that the population has exceeded 500,000 inhabitants since 2000.

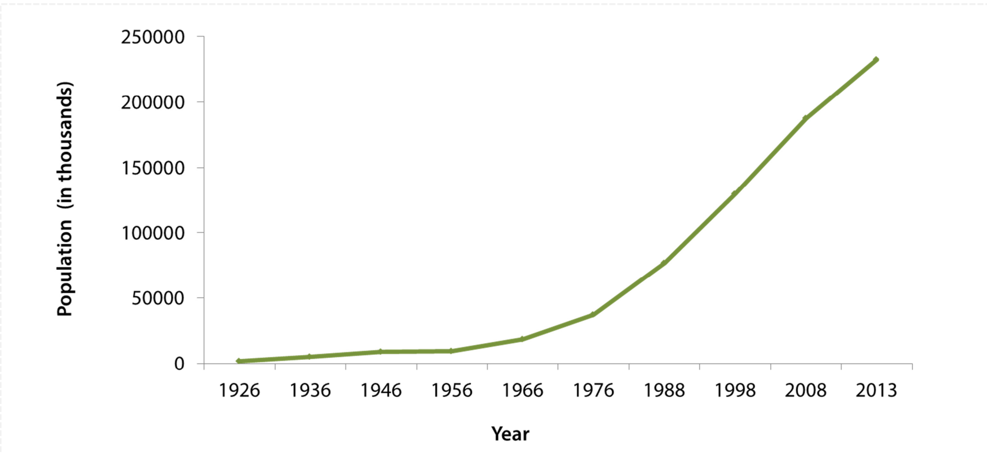


Figure 5.2: Demographic growth of Mbour

This rapid growth in Mbour's population has resulted in a rapid spatial expansion of the city (Figure 5.3) which was made from the traditional village or the historical centre. Three main steps must be taken into account in the spatial expansion: the period from 1922 to 1945, from 1945 to 1976, and from 1995 to 2009. The first step of growth 1922-1945 corresponded with the creation of five neighbourhoods especially Escale, Tefess, Mbour Sérère, Onze Novembre, Santessou. These neighbourhoods were settled by the settlers and constituted the historical centre of Mbour. The second step, between 1945 and 1976, corresponded to the creation of the first peripheral neighbourhoods of the city, which were created after the 1950s by the State: Château d'eau nord, Château d'eau sud, Darou Salam, Diamaguene 1, Diamaguene 2, Mbour Sérère Kaw, Mbour Toucouleur, Thiocé Est, Thioce Ouest, Zone Résidentielle, Golf and Mbour Maure. And the last step corresponded to the creation of the new peripheral neighbourhoods created by the municipality between 1995 and 2009, which are divided into two parts: Grand Mbour, Liberté, Médine, Santhie, ONCAD, Gouye Mouride, Zone Sonatel and Baye Deuk. The peripheral neighbourhoods are divided into: North peripheral neighbourhoods and south peripheral neighbourhoods.

Mbour is distinguished by its remarkable spatial evolution (Table 5.1). Between the years 1966 and 1978 Mbour experienced a spatial evolution rate of 3.8%, with an extension by 18.93 ha/year. This situation is explained by the fact that the beginning of the 1960s corresponds to a significant increase of the population.

The period from 1978 to the end of the 1980s corresponds to an increase in the area of 29.3 ha/year, i.e. an estimated spatial growth of 4.5%. This phase corresponds to an unprecedented increase in the population of Mbour that resulted in a further pressure on the space. From 1989 to 1999, the city experienced an even stronger spatial growth of 7.4%, with an increase in the area of 88.0 ha /year (Gadal, 2011). From the 1999 up to 2010, the spatial growth went slowly down with a rate of 0.4%, i.e. an evolution of 7.9 ha/year.

The limits of the city's spatial expansion in recent years put pressure on land needs, which creates a strong internal heterogeneity with a clear opposition between the old and new neighbourhoods in terms of access to basic services. The city face a huge challenge of urban infrastructure and basic services such as affordable housing, access to safe drinking water and improved sanitation, as well as domestic solid and wastewater management, and access to health care. The lacks of these variables affect the health and well-being of many population groups mostly children and lead to increase the transmission of infectious diseases, including diarrhoea.

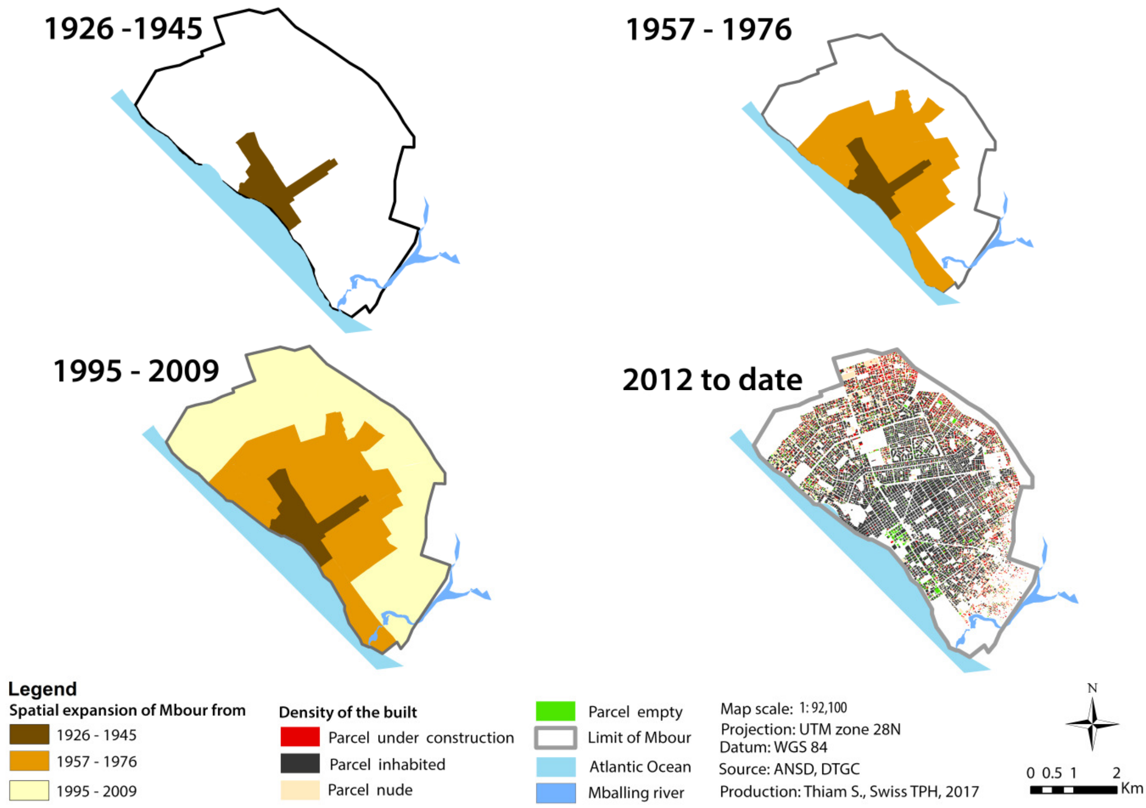


Figure 5.3: Spatial expansion of Mbour, from 1926 to 2012

Table 5.1 Evolution of the surface area of Mbour from 1966 to 2010

Période	Durée	Evolution de la superficie(en ha)	croît annuel	Taux de croissance spatiale
1966 - 1978	12 ans	189.3	18.93 ha/an	3.81%
1978 - 1989	11 ans	322.6	29.32 ha /an	4.46%
1989 - 1999	10 ans	879.5	87.95 ha/an	7.39%
1999 - 2010	11 ans	87	7.90 ha/an	0.44%

Source: Service d'Urbanisme et de l'Habitat (SDUH) de Mbour, 2010

5.2.3 Drinking water and sanitation network coverage

The city in its majority gets mainly the water supply from the SDE, and is served by two water reservoirs (towers): the R1 located in Mbour Escale and the R2 in ONCAD. The R1 which supplies exclusively the city of Mbour has a capacity of 1000 m³; the R2, which supplies a part of the city and the all other cities located between Mbour and Joal, has a capacity of 3200 m³. Although the most common source of water supply in the city remains the private connection to the SDE network, there is a persistence of traditional modes of water supply. This is due to the fact that the water network does not cover the entire city and some populations have not the means to afford an access to the distribution network (Figure 5.4). The peripheral neighbourhoods are less covered by the network and the mode of supply varies from one neighbourhood to another. Only 48.7% of the population are connected to the SDE network (Toure et al., 2011). The populations not connected to the network are obliged to use water from the public tap located along the pipeline of the network or from traditional wells often untreated and potentially polluted.

The city has no functional sewerage system. One-site sanitation facilities (such as pit latrines and septic tanks) are the main ones of for the majority of the inhabitants. The only existing networks are those for the drainage of storm water and wastewater. These networks, which are no longer functional, have been created by the settlers with the aim of health prevention to protect the colonial district from bad hygienic conditions in the neighbouring districts.

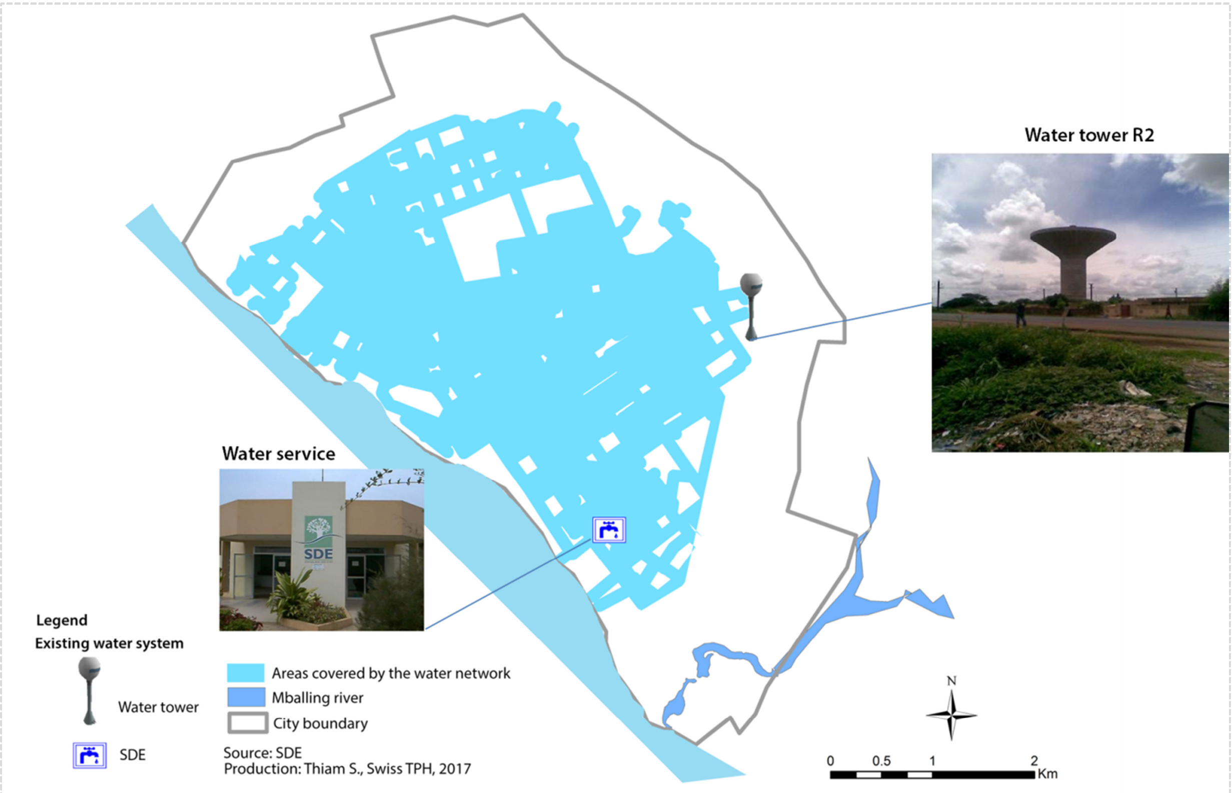


Figure 5.4: Water network coverage and rate of connection to the network by neighbourhood in 2016

These infrastructures were planned for a small colonial town (Figure 5.5). It is only in 2012 that the government, through the National Office of Sanitation (ONAS), has initiated a sanitation program for the city; this program concerns three other secondary cities of Senegal. The program includes the installation of a conventional collective sewerage network in four neighbourhoods of the city: Onze Novembre, Thioce Est, Thioce Ouest and Tefess. Currently, the initiated sanitation plan by the central authorities has not been fully implemented. The topography of the city is relatively flat and the proximity to the sea put the city at risk of seasonal urban floods.

Concerning solid waste management, the increased urbanization of the city, coupled with the difficulty of the local authorities to fully manage the flows of solid waste and wastewater due to limited material, technical and financial resources, the population use several self-managed methods (e.g. incineration, dumping of wastes in the street, in or around the sea) to evacuate their waste. The existing collection and transport service of the municipality covers only the central neighbourhoods of the city. The bad sanitation conditions of the city are well illustrated by the high number of stagnant rainwater points, stagnant wastewater points, seasonal flooding events, and solid waste deposits in the streets.

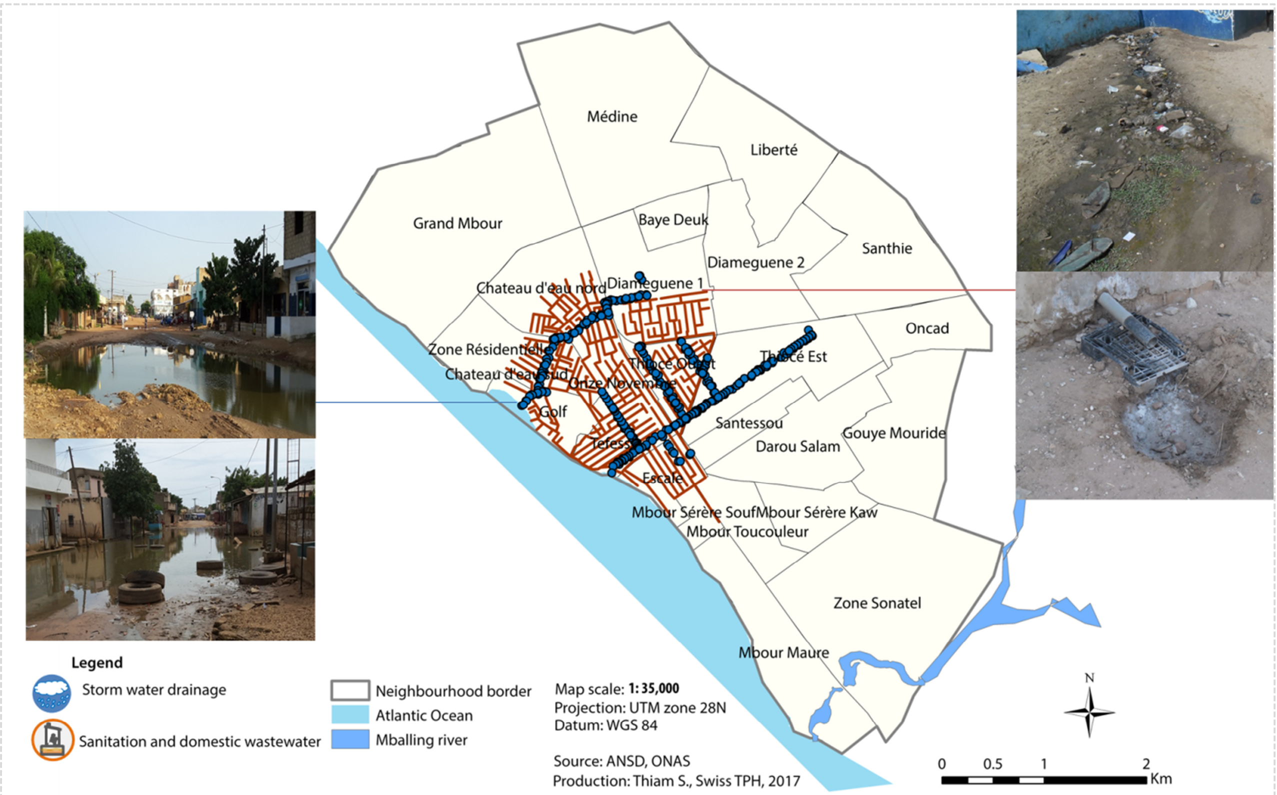


Figure 5.5: Storm water, sanitation and domestic wastewater drain network in Mbour

5.2.4 Health conditions

The majority of disease burden in the city among children under-five is caused mainly by communicable infectious diseases such as acute respiratory infections (35,385 visits, 32.0%) and diarrhoeal diseases (23,543 visits, 21.1%) according to the routine health surveillance data from 2011 to 2014 (Thiam et al., 2017b).

5.3 Data collection

5.3.1 Overview

The methodology developed in this thesis combines several types of data collection, as data were to be obtained from various sources. We collected some data from available secondary sources from local services (e.g. routine health facility data on diarrhoeal incidence, demographic and mapping data), available remote sensing sources for the climatic data (e.g. temperature and rainfall), and others from primary (original) data from combined field surveys conducted in Mbour: cross-sectional epidemiological household surveys, drinking water sampling and analysis, mapping of environmental risk factors at city and household level and observations.

5.3.2 Study population

The study population is children under the age of 5 years and their caregivers, which included the child's father, mother or any other caregivers with sufficient information on the child and household characteristics.

5.3.3 Secondary data collection

5.3.3.1 Demographic, health surveillance and climatic data

The demographic data used in this thesis come from the national census of population and housing (RGPH) of the year 2013. In order to have an idea of the epidemiological situation of diarrhoea in Mbour, we first collected routine health data at health facility level in the health district of Mbour, namely, monthly diarrhoeal case records among children under the age of 5 years from 24 health facilities over a 4-year period (2011-2014) from the District Health Information System (DHIS2) of the Ministry of Health of Senegal. All the patients who consulted the health facilities and all diagnosed diseases were reported to the DHIS2. A total of 72 diseases were recorded, including diarrhoea, which is the main outcome of interest in this study. The data are classified by health facilities, year and month, and by age groups and sex.

Children were classified into three groups: 0-11 months, 12 -59 months and 5-14 years. The DHIS2 did not report the patient's place of residence.

Climatic data, specifically land surface temperature day (LST_{Day}), land surface temperature night (LST_{Night}) and rainfall estimate were obtained from readily available remote sensing for the same 4-year period (Chapter 8). We extracted day and night land surface temperature (LST_{Day} and LST_{Night}) as a proxy of minimum/maximum air surface temperature from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite, and rainfall estimate (RFE) from the Africa Data Dissemination Service, covering the period 2011 to 2014

5.3.3.2 Mapping data

Advances in information technology have revolutionized the use of mapping techniques to analyse and present information on vulnerability and risk in order to facilitate their understanding and decision making. In the current PhD thesis, a spatial approach was an essential part of the study in order to analyse diarrhoea pattern and associated risk factors in Mbour, including the use of spatial analysis tools such as Geographic Information Systems (GIS). Knowing that cartography is an indispensable tool for interventions in a geographical area, the Senegalese authorities, in the context of the implementation of its fourth census initiated by the United Nations Population Fund (UNFPA), used the best method of meeting the census requirement; recording each individual at the level of his/her place of residence for his/her interview. The project of digitalizing the census districts was implemented to identify the location of each inhabitant over the entire national territory. The entire country was divided into small areas called Census Districts and all plots were digitalized. The spatial data used in this PhD thesis were obtained from the database of the census mapping of the RGPH. The 2012 cadastral map of the city with the location and number of each household plot was obtained from the National Agency of Statistic and Demographic (ANSD). This map allowed identifying and eliminating the inhabited houses, under construction houses, and those dedicated to administrative and commercial usage.

Specifically, there are “shapefiles” presenting three types of representation: polygon (e.g. administrative boundary of Mbour, boundary of each neighbourhood), line (e.g. road network) and point (e.g. health and education infrastructures, administrative building, economic and commercial infrastructures, etc.) as illustrated in Figure 5.6.

The shapefiles of the existing drinking water network in the city, wastewater and rainwater drainage network were obtained respectively from SDE and ONAS.

After collecting all these data, mapping were performed at the city and household levels. At the city level, this was applied for the visualization of the infrastructure related to water and sanitation system including public taps and wells and the major environmental risk factors such as solid waste dumping, stagnant wastewater points, flood-prone areas and stagnant rainwater points in the city. At the household level, the mapping was used to characterise the location of the interviewed households during the survey. A hand held global positioning system (GPS) device eTrex10 (GARMIN, Kansas, USA) was used in the field for the data collection and to locate major environmental risk factors mentioned above at the community level using Universal Transverse Mercator (UTM).

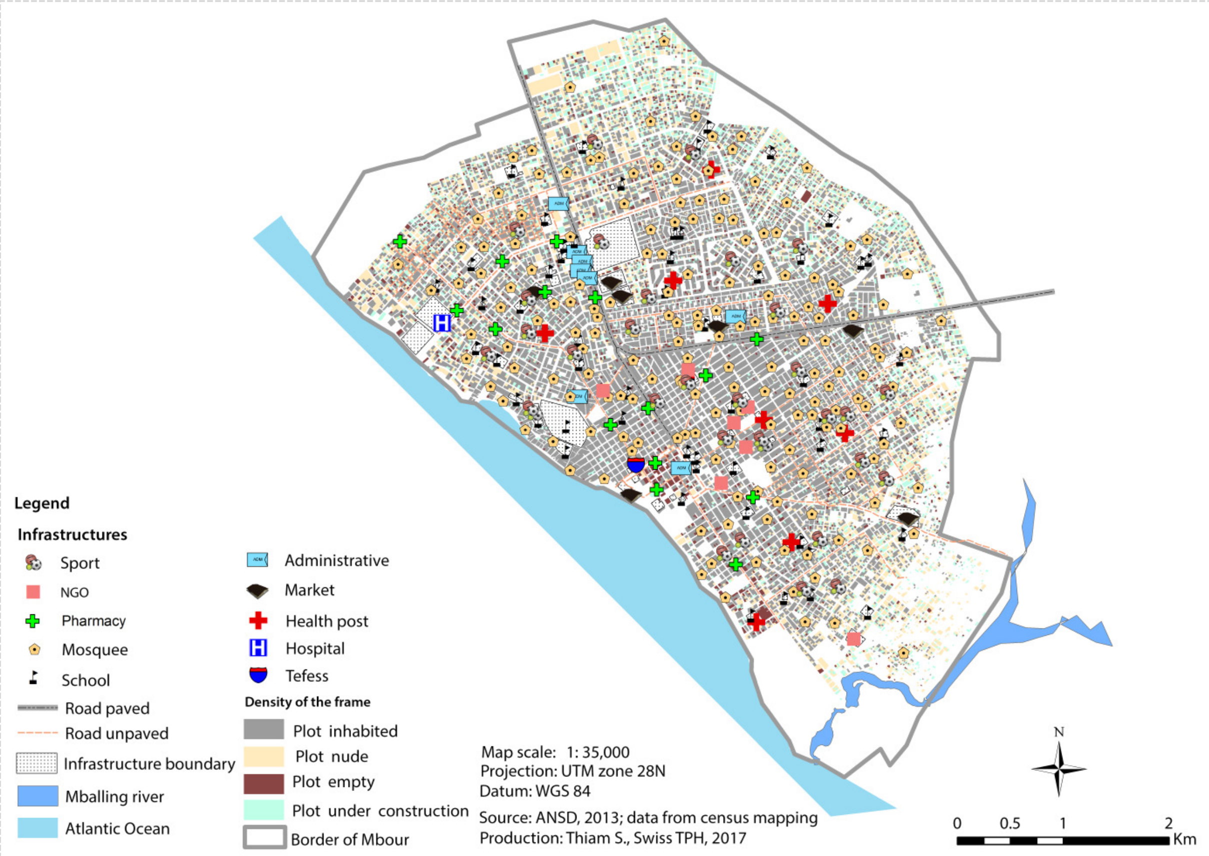


Figure 5.6: Map showing the plot of Mbour and the location of the major infrastructures

5.3.4 Primary data collection

5.3.4.1 Cross-sectional epidemiological household surveys

Two cross-sectional household surveys were conducted in Mbour. The first survey was carried out in dry season, between February and March 2014, in eight (8) neighbourhoods randomly selected in four different zones which represent the socio-spatial heterogeneity of the city, namely: (i)-urban central area (UCA); (ii)-peri-central area (PCA); (iii)-north peripheral area (NPA); and (iv)-south peripheral area (SPA). The second survey was conducted at the end of the rainy season, between September and October 2016, and covered all the twenty-five (25) neighbourhoods of city, including the eight neighbourhoods sampled in 2014, within the four aforementioned zones.

5.3.4.2 Demographic and spatial sampling strategy for the surveys

For both surveys, a spatial multi-stage cluster sampling approach was adopted to select target households and neighbourhoods within each zone (Figure 5.7). The aim of the spatial sampling was to compare the health disparities and diarrhoea risk factors between the different zones of Mbour.

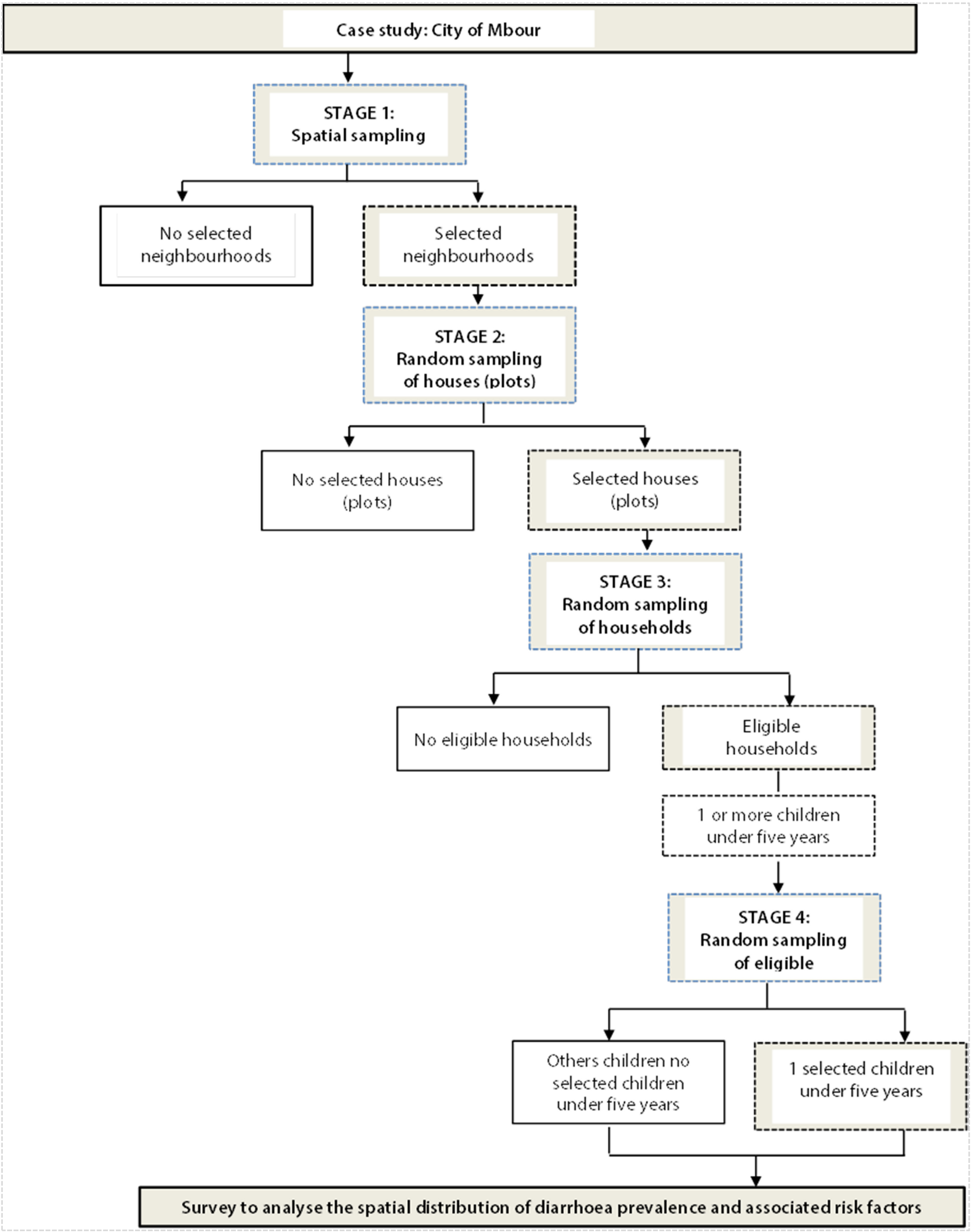


Figure 5.7: Flowchart of the survey carried out in Mbour in 2014 and 2016

In both surveys, the sample size were calculated based on the formula for normal approximation to binomial distribution with 95% confidence, an estimated prevalence of diarrhoea among children under the age of 5 years of 26%, and a margin of error of 5%. The calculated sample size was 600 households for the first survey and 800 households for the second survey. At each stage (zone and neighbourhood units), we first selected the number of sampling units and then allocated the targeted sample among these units according to the two following procedures: first, we allocated the targeted sample to each zone in proportion to its population, using the last population census data (2013); second, for each neighbourhood, we allocated the targeted sample of the zone where it is located in proportion to the population of that neighbourhood. Household were randomly selected within zone and neighbourhood using the “Sampling Design Tool” of ArcGIS 10.

5.3.4.3 Household inclusion criteria

The eligible criteria for this study were: (i) being mothers/caregivers of at least one child under the age of 5 years; (ii) provided written informed consent to participate to the survey. If an eligible household contained more than one mothers/caregivers of a child under five, the surveyors randomly selected one of the caregivers for the survey using Kish grid, which is a method that involves constructing a list of eligible individuals at a particular address and then selecting based on the number of the address itself (Kish L., 1949). This method gives all the individuals in a household an equal chance of selection. The same approach was also applied if the selected mother/caregiver had more than one child to randomly select one of them for the survey.

5.3.4.4 Mapping of selected households

The geographical coordinates of the randomly selected household were integrated in Garmin eTrex 10 a hand-help Global Positioning System (GPS). Surveyors had to find the selected houses and identify those with at least one caregivers of children under the age of 5 years by using the procedure “Go to” of the GPS system, the detailed map on which the randomly selected household were shown and the location of major infrastructures like (mosque, school, administrative building etc.). This approach avoided having all the selected households in a single part of the study area and allowed to cover the entire city in order to better analyse the health disparities. In case of absence the surveyor took an appointment. After two unsuccessful appointments, the household was replaced by another household in the sampling list of the zone. For more details about the sample size calculation see paper 1, 2 and 4 for the respective surveys. The final randomly selected households in the two surveys are presented in Figure 5.8.

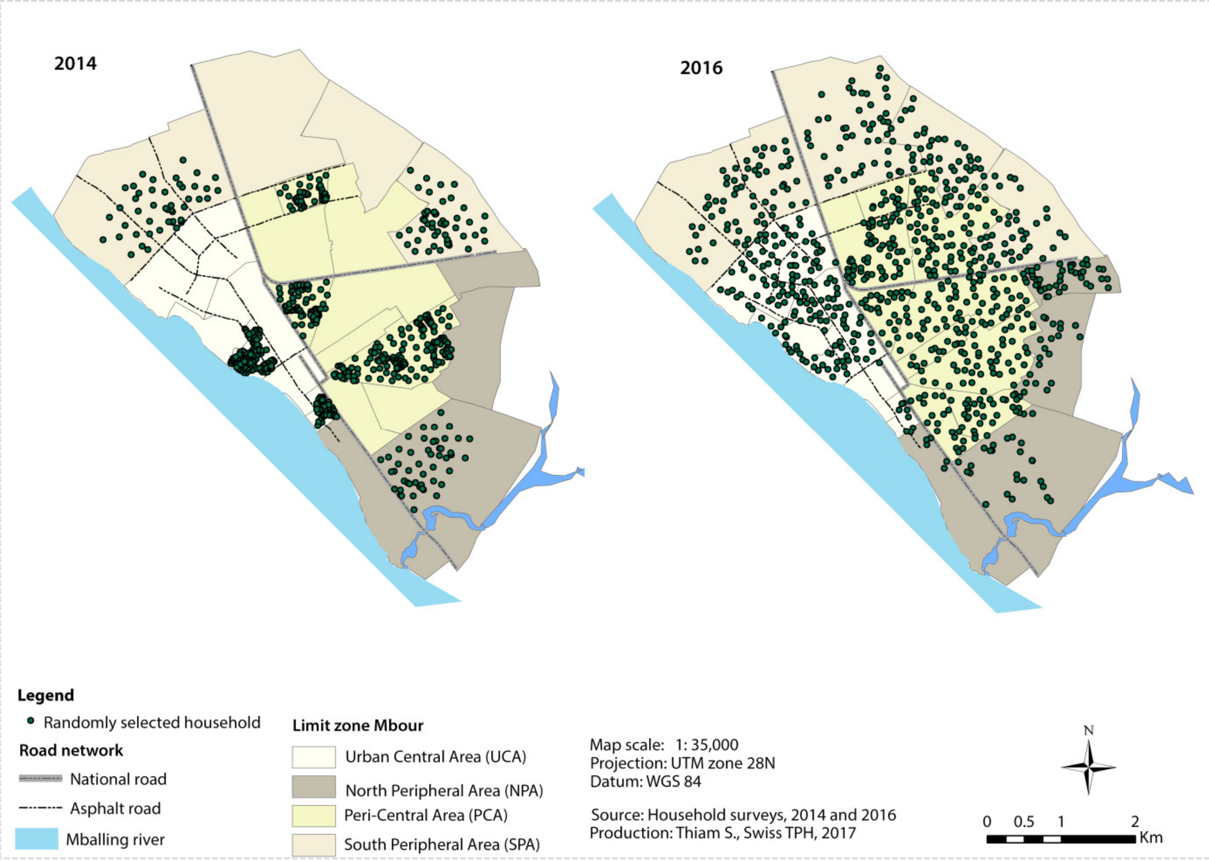


Figure 5.8: Map of Mbour showing the spatial distribution of the randomly selected households for the surveys carried out in 2014 and 2016 in Mbour

5.3.4.5 Drinking water analysis

Drinking water was analysed at household and city level for faecal contamination during the second survey in 2016. Collecting data on microbial drinking water contamination at two levels allowed characterizing the risk profiles of the different zones and describing the quality of the existing drinking water sources besides their geographic characteristics and, beyond that, to examine the possible effect of the transportation and storage on drinking water quality at the household level. Water samples were collected in sterile 100 ml borosilicate glass bottles. At the city level, water was taken directly from the tap or wells; at the household level mothers or caregivers of selected households were asked for water from the stored container into a cup before transferring it into the sample bottles.

In order to assess recent faecal contamination of the drinking water, water sample were analysed for two bacterial indicators, namely faecal coliform and *Escherichia coli* by using membrane filtration technique. Culture on semi-solid medium using the VRBA medium

(Green Red Bile Agar) was used to detect faecal coliform and fluorescence in situ hybridization (FISH) for *E.coli*. A detailed description of the methods can be found elsewhere (Wallner et al., 1993; Poppert et al., 2005).

5.4 Data analysis

All collected data (geographical coordinates of environmental risk factors and households surveys) were integrated in a geodatabase with a map Datum projection WGS84 UTM 30 N (Figure 5.9). ArcGIS software version 10 (ESRI, Redlands, USA) was used for data visualization. The detailed methods used for data analysis are explained in the respective manuscripts presented in chapters 4 to 7.

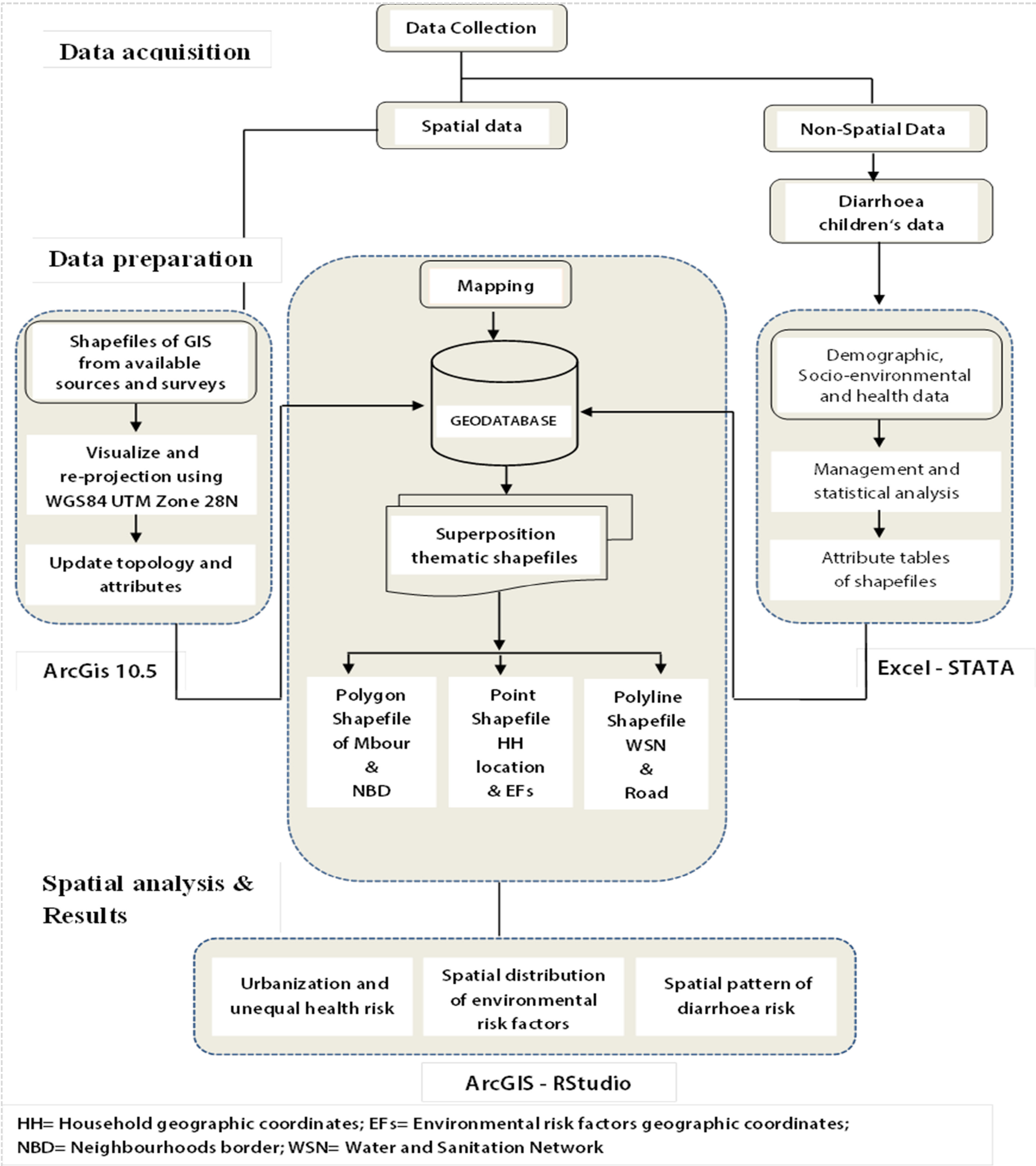
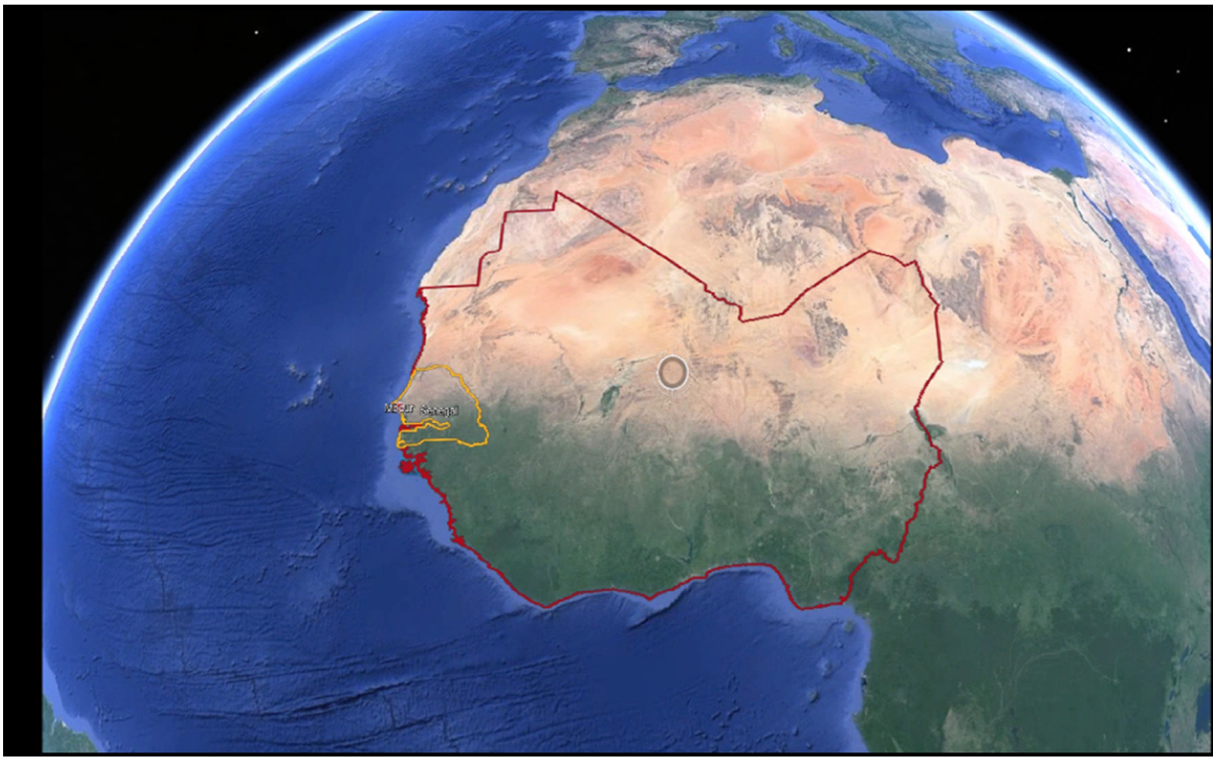


Figure 5.9: Flowchart of the mapping database construction adapted (adapted from Kassie et al, 2017)

5.5 Ethical considerations

The study protocol was approved by the Comité National d’Ethique de la Recherche (CER) of Senegal (reference no. 0l06/2015/CER/UCAD). As we used secondary health data on children under the age of five years from the district health information system (DHIS2), written informed consent was obtained from the Director of the Division du Système d’Information Sanitaire et Sociale and the Direction de la Planification, de la Recherche et des Statstiques at the Ministry of Health of Senegal and from the chief medical officer of the health district of Mbour. An interview was conducted only if the respondent provided their consent in response to being read and informed consent statement by the reviewer. Verbal informed consent was conducted by the interviewer reading a prescribed statement to the respondent and recording in the questionnaire whether or not the respondent consented or assent was provided. The interviewer signed his or her name attesting to the fact that he/she read the consent statement to the respondent. All information gathered was handled confidentially.

6 ARTICLE 1: Urbanization and its effect on risk factors associated with childhood diarrhoea in Mbour, Senegal: a visualization



Map: Location of the mid-sized city of Mbour in Senegal, West Africa (©S. Thiam, 2017)

Video link:

https://www.youtube.com/watch?v=DRQJgu2WiXg&t=5s

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Urbanisation and its effect on risk factors associated with childhood diarrhoea in Mbour, Senegal: A visualisation

Sokhna Thiam,[1,2] Samuel Fuhrimann,[1-3] Aminata Niang-Diène,[4] Ibrahima Sy,[4,5] Ousmane Faye,[6] Jürg Utzinger,[1,2] Guéladio Cissé[1,2]

[1]Swiss Tropical and Public Health Institute, Basel; [2]University of Basel, Basel, Switzerland; [3]School of Public Health and Family Medicine, University of Cape Town, Cape Town, South Africa; [4]Department of Geography, Université Cheikh Anta Diop de Dakar, Dakar; [5]Centre de Suivi Ecologique, Dakar; [6]Department of Animal Biology, Université Cheikh Anta Diop de Dakar, Dakar, Senegal

Abstract

Rapid urbanisation, particularly in secondary cities in Africa, brings along specific challenges for global health, including the prevention and control of infectious diseases such as diarrhoea. Our purpose was to visualise urbanisation trends and its effect on risk factors associated with childhood diarrhoea, *e.g.* water supply, sanitation, wastewater and solid waste management in Mbour, a secondary city in south-western Senegal. Our visualisation is facilitated by epidemiological and geographical surveys carried out in 2016. A deeper spatial and visual understanding of the urbanisation trends and the disparities of diarrhoea-associated risk factors might lead to the implementation of suitable health interventions and preventive measures. Our visualisation is aimed to serve as a basis for discussion and as a decision support tool for policymakers, municipal officials and local communities to prioritise interventions related to water, sanitation and waste management with a view to reduce the environmental and health risks in the rapidly growing city of Mbour, which is set as an example for other similar secondary cities across low- and middle-income countries in Africa.

Correspondence: Guéladio Cissé, Swiss Tropical and Public Health Institute, P.O. Box, CH-4002 Basel, Switzerland.
Tel: +41-61-284-8304 - Fax: +41-61-284-8105.
E-mail: gueladio.cisse@swisstph.ch

Key words: Visualisation; Urbanisation; Childhood; Diarrhoea; Senegal.

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Video link: https://www.youtube.com/watch?v=DRQJgu2WiXg&t=5s

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Introduction

The world is becoming increasingly urban, a process that has accelerated since the industrial revolution that commenced in the late 18th century (Neiderud, 2015). For instance, in 2016, 3.8 billion people were concentrated in urban settings, thus accounting for approximately 54% of the world's population (UN, 2015). A further increase in urban population growth is expected in the coming decades, particularly in Africa and Asia (UN, 2015). Africa's population might rise to 2.4 billion by 2050 and 56% of this population is expected to live in urban settings (UN, 2015). In West Africa, the second fastest growing part after East Africa on this continent, two-third of the population are expected to be urban dwellers by 2050 (UN-HABITAT, 2014).

An important feature of rapid, urban growth is the disproportionate expansion of secondary cities, which are also known as medium-sized cities, a term popularised by Rondinelli in the 1980s and now commonly used to describe the second level in the hierarchy of cities below the primary level (*i.e.* big city) (Rondinelli, 1983). The definition of a secondary city is contextual: it can relate to population size, function, urban hierarchy as well as its economic and social structure. Rondinelli's definition has secondary cities as urban settlements with a population of at least 100,000 that does not include the big cities in a country, while UN-HABITAT defines it as an urban area with a population of between 100,000 and 500,000 (UN-HABITAT, 1996; Rondinelli, 1983). Today, secondary cities range in population size from a few hundred thousand to several million. There are more than 4,000 cities in the world with a population exceeding 100,000 people and this number is expected to increase to 6,000 by 2050 (Angel, 2012). Nearly two-thirds of the world's secondary cities are currently located in Africa and Asia (World Bank, 2009).

African cities pose particular challenges to global health not only due to the high rates of urbanisation, but also because of unplanned settlements. As a result, environmental risks and health disparities are widening, both in terms of infectious diseases (*e.g.* diarrhoeal diseases) and non-communicable diseases. Risks to human health are accentuated in the urban environment where population density is high and the likelihood of exposure to disease equally high (Satterthwaite and Bartlett, 2017). For many of the rapidly growing secondary African cities, the absence of basic services, such as access to safe drinking water and sanitation, affordable housing and waste management, is particularly severe for the poorest and most marginalised communities (UN-HABITAT, 2014). In 2015, it was estimated that 319 and 695 million people in sub-Saharan African still used below-standard sources of drinking water and unimproved sanitation, respectively (WHO/UNICEF, 2015). This is a particularly pressing problem where the urban informal settlements are growing faster than the ability of administrations to provide the basic services can cope. Lack of such services affects the health and wellbeing of people, mostly children under the age of 5 years leading to increased health risks and vulnerability. Resulting global health challenges include the control of infectious diseases such as diarrhoeal diseases (GBD 2015 DALYs and HALE Collaborators, 2016).

According to the World Health Organization (WHO, 2017), infectious diseases are still a major public health problem in African cities. The three main causes of death in these settings are infectious diseases, namely lower respiratory infections, diarrhoeal diseases and tuberculosis (TB) (WHO). Diarrhoea is one of the infectious diseases most responsive to environmental and socio-sanitary risk factors. Globally, diarrhoea caused 1.4 million deaths in 2015, and children under the age of 5 years are the most affected age group with one in 10 childhood deaths due to diarrhoea (WHO, 2017). Nearly half of this diarrhoeal burden occurs in Africa and Asia, classified at the same time as the most rapidly urbanising settings (WHO, 2017).

In Senegal, a country where secondary cities struggle to provide basic services, diarrhoea is the leading cause of death among children under the age of 5 years, responsible for 14% of total disability-adjusted life years (DALYs) in this age group (GBD 2015 Child Mortality Collaborators, 2016; GBD 2015 DALYs and HALE Collaborators, 2016). Of note, Senegal's urban population has doubled in the past 60 years; it was 23% in 1960, 45% in 2013 and is projected to reach 60% by 2030 (World Bank, 2016). In the Senegalese context, urban is defined as a city of 10,000 people or more.

Although prior research has investigated the interactions between urbanisation, environment and health, little is known regarding urbanisation and its health effects in secondary cities since most of this research was conducted in big cities. Hence, the aim of the present study was to expand our understanding of urbanisation trends and its effect on risk factors for diarrhoea in the secondary coastal city of Mbour in south-western Senegal. The following questions guided our vHealth contribution: i) what are typical urbanisation trends and how does urbanisation affect risk factors for childhood diarrhoea? ii) Are risk factors for diarrhoea among children below the age of 5 years in Mbour spatially clustered? iii) What are the priority interventions that can reduce the burden of childhood diarrhoea and which are the high-risk areas?

Our study was carried out in the Senegalese city of Mbour located near the Atlantic Ocean in the region of Thiès (Figure 1). We employed a multidisciplinary approach, including a literature review, a cross-sectional epidemiological household survey, microbial water sampling and a geographical survey facilitated by global positioning system (GPS) data collection to locate the major environmental risk factors and a questionnaire interview with urban planners on the spatial expansion of the city. We carried out a cross-sectional epidemiological survey with spatial random sampling between September and October 2016. A total of 800 households were sampled and distributed in the four zones, which represent the socio-spatial heterogeneity of the city: Urban Central Areas (UCA), Peri-Central Areas (PCA), Northern Peripheral Areas (NPA) and Southern Peripheral Areas (SPA). Households were randomly selected within the aforementioned zones. A two-stage procedure was used to identify households with children under the age of 5 years. We allocated the targeted sample to each zone in proportion to its population and allocated the targeted sample of each zone in the entire neighbourhood, which allowed covering the whole city in order to better analyse the disparities. The survey comprised two components: i) a tablet-based questionnaire yielding information on water, sanitation and hygiene (WASH) and diarrhoea occurrence among children; and ii) collection of water samples to determine microbial contamination of stored drinking water at home. A membrane filtration method was used to detect *Escherichia coli* and faecal coliform bacteria in households that stored drinking water. For the geographical survey, a Garmin GPS device (eTrex® 30; Garmin Ltd, Olathe, KS, USA) was used to locate environmental factors at the community level, such as wells, stagnant wastewater points, solid-waste dumping, potential flood areas and stagnant rainwater points. Applied software packages were: Microsoft Power Point 2010 (Microsoft Corporation; Edmond, WA, USA) for content visualisation including geospatial components; ArcGIS version 10.2.1 (ArcMap; ESRI; Redlands, CA, USA) for map production; Camtasia Studio version 9 (TechSmith Corporation; Okemos, MI, USA) for production of video for Internet streaming (Goolge Earth Pro, version 7.1.2.2041; Google Inc.; Mountain View, CA, USA).

The demographic and spatial data showed an exponential population growth followed by a rapid spatial expansion of the city from 1922 to date resulting in the creation of neighbourhoods with poor environmental conditions with regard to safe water and sanitation. Since its creation in 1926 as a colonial trading port by colonialists, the population of Mbour has grown rapidly and steadily increasing from 1,700 in 1926 to 18,600 in 1966 and from 170,436 inhabitant in 2002 to 232,777 inhabitants in 2013 (ANSD, 2014). This rapid growth resulted in an important spatial expansion, which increased the city surface from 175 ha in 1945 to 894 ha in 1976 and on to more than 1,300 ha in 2012. This expansion had considerable consequences with respect to urban planning. The city is facing a deficit of urban infrastructure and poor service delivery, such as affordable housing, access to safe drinking water and improved sanitation, as well as domestic wastewater and solid-waste management. An important unequal distribution of urban basic services in space and time was observed. Differences concerning the access to drinking water were observed, with very low rates of connection in the new neighbourhoods with an inexistent rate of connection in Baye Deuk, and variable rates in other neighbourhoods located in the peri-central area.

The findings from the cross-sectional household survey showed an insufficiency in clean water access, hygiene and sanitary systems in Mbour that foster diarrhoea transmission pathways.

It showed that only 58.6% of the surveyed household were connected to water networks with significant disparities between zones and neighbourhoods. Less than half (40.5%) were connected to the water network in NPA with only 17.8% in Medine and 21.7% in Liberte. In SPA only 12.0% were connected to the network with zero percent in Gouye Mouride, 7.5% in Oncad and 14.3% in Zone Sonatel. Our study revealed a persistence of traditional modes of water supply in the peripheral neighbourhoods and showed a high use of wells in NPA and SPA with 77.9% of the visited household in Medine, 71.4% in Zone Sonatel and 33.9% in Grand Mbour. The wells are used in spite of being untreated and polluted since the water network does not reach these neighbourhoods. The city has no functional sewerage system and dwellers are mainly using on-site sanitation facilities. The topography is relatively flat and the proximity to the sea puts the city at risk of seasonal urban floods. The findings also revealed that 72% of the study population empty their wastewater in the street, which might contaminate drinking water source and increase the diarrhoea risk among children, a practice common all over the city with more than 80% in some neighbourhoods.

Our study showed that 44.5% of the visited household had at least one child with diarrhoea in the two weeks prior to the interview. The two-week point prevalence rate was 33.9% with a significant difference between zones. The highest prevalence was found among children living in UCA (38.3%), followed by those living in SPA (37.2%) and the lowest prevalence was observed in NPA with 26.9%. We also looked at the prevalence by neighbourhood and found that in UCA, the highest prevalence was observed in the following neighbourhoods: Tefess (57.1%), Zone Residentielle (54.3%); in PCA, diarrhoea prevalence was highest in Baye Deuk (57.9%); in SPA the prevalence was higher in Zone Sonatel (46.1%). Descriptive and analytical mapping revealed that the spatial distribution of diarrhoeal diseases prevalence was governed by specific environmental and socio-sanitary risk factors. Environmental factors such as unimproved water sources, sanitation, wastewater and solid waste management, and bacteriological aspects (*e.g.* water contamination with *E. coli* and other faecal coliform bacteria, which indicate faecal contamination) are the main drivers explaining the spatial distribution of diarrhoea in the city. Diarrhoeal prevalence was higher in the neighbourhoods with the largest number of contaminated water especially in the most densely populated neighbourhoods of the city (*e.g.* Tefess, Golf and

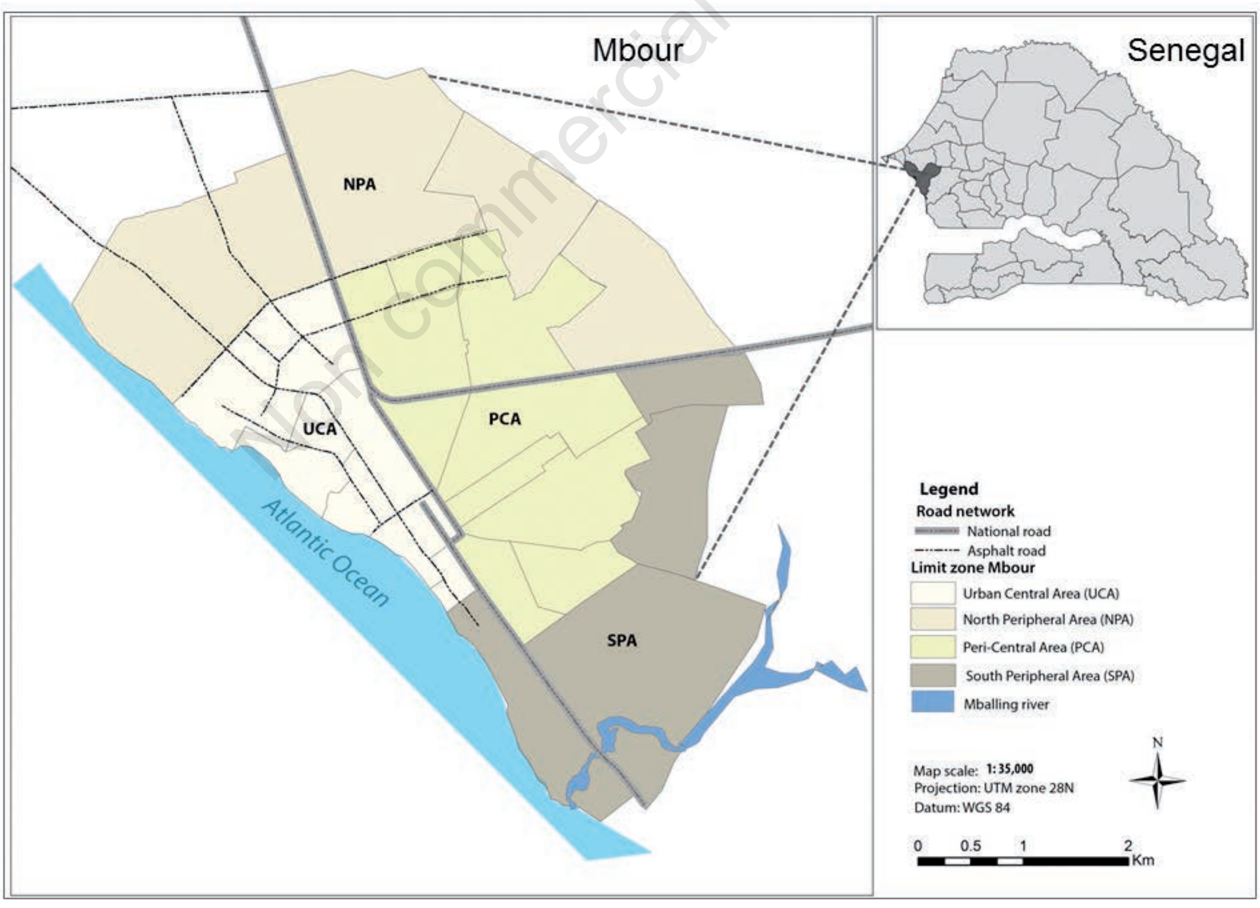

Figure 1. Map showing Mbour in Senegal stratified in the four different research zones (based on Thiam *et al.*, 2017: Prevalence of diarrhoea and risk factors among children under five years old in Mbour, Senegal: a cross-sectional study. Infect Dis Poverty 6:109).

Baye Deuk). Our data show that there is considerable spatial heterogeneity of vulnerability and risk for diarrhoeal transmission.

Visualisation and outlook

The purpose of our study was to visually characterise the trends of urbanisation and highlight disparities of environmental risk factors associated with diarrhoeal diseases in a secondary city of West Africa to help policymakers and city officials to better plan their action. Our visualisation is structured as follows. First, we provide a general overview of the urbanisation trends in Mbour by highlighting the demographic growth and the spatial expansion of the city boundaries over the past 60 years. Second, we highlight risk factors for childhood diarrhoea. These include the urban infrastructures related to drinking water and sanitation coverage, wastewater and solid waste management. Third, we show how our work can help urban planners, public-health experts and other relevant stakeholders to better prioritise interventions and preventive measures in order to reduce the burden of diarrhoea in Mbour.

Conclusions

Our visualisation emphasises important heterogeneity in terms of access to clean water, improved sanitation and hygiene and its effect on childhood diarrhoea. We believe that our contribution in the series of short video presentations put forth by the international journal Geospatial Health, which are readily accessible by policymakers, local communities and others stakeholders, further underscores the value and potential of this format (Fuhrimann *et al.*, 2014; Krieger *et al.*, 2012). Indeed, our visualisation can serve as a decision support tool to policymakers and municipal officials for implementation and policy development related to safe drinking water, sanitation infrastructures (including wastewater and solid waste management) and can support spatial and temporal targeted interventions designed to reduce risk factors in the population. It can also be used to geographically support accurate future implementation of preventive measures against diarrhoea in children below the age of 5 years through community education on the importance of WASH, household and community systems for treating and storing water, rotavirus vaccination, *etc*. in the rapidly growing secondary city of Mbour. Our methods and approaches might be applicable to others cities in West Africa and elsewhere.

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7. ARTICLE 2: Prevalence of diarrhoea and risk factors among under 5-year-old children in Mbour, Senegal: a cross-sectional study

Photo: Sanitation conditions with higher exposure to environmental pollution in Mbour, Senegal (©S. Thiam, 2014)

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Prevalence of diarrhoea and risk factors among children under five years old in Mbour, Senegal: a cross-sectional study

Sokhna Thiam[1,2,3], Aminata N. Diène[3], Samuel Fuhrimann[1,2], Mirko S. Winkler[1,2], Ibrahima Sy[4], Jacques A. Ndione[4], Christian Schindler[1,2], Penelope Vounatsou[1,2], Jürg Utzinger[1,2], Ousmane Faye[5] and Guéladio Cissé[1,2*]

Abstract

Background: Diarrhoeal diseases remain an important cause of mortality and morbidity among children, particularly in low- and middle-income countries. In Senegal, diarrhoea is responsible for 15% of all deaths in children under the age of five and is the third leading cause of childhood deaths. For targeted planning and implementation of prevention strategies, a context-specific understanding of the determinants of diarrhoeal diseases is needed. The aim of this study was to identify risk factors of diarrhoeal diseases in children under the age of five in Mbour, Senegal.

Methods: Between February and March 2014, a cross-sectional survey was conducted in four zones of Mbour to estimate the burden of diarrhoeal diseases (i.e. diarrhoea episodes in the 2 weeks preceding the survey) and associated risk factors. The zones covered urban central, peri-central, north peripheral and south peripheral areas. Overall, 596 households were surveyed by a questionnaire, yielding information on sociodemographic, environmental and hygiene behavioural factors. Univariable and multivariable logistic regression analyses were used to identify risk factors associated with the occurrence of diarrhoea.

Results: The reported prevalence of diarrhoea among children under the age of five during the 2 weeks preceding the survey was 26%. Without adjustment, the highest diarrhoea prevalence rates were observed in the peri-central (44.8%) and urban central zones (36.3%). Multivariable regression revealed significant associations between diarrhoeal diseases and unemployment of mothers (adjusted odds ratio [a*OR*] = 1.62, 95% confidence interval [*CI*]: 1.18–2.23), use of open bags for storing household waste (a*OR* = 1.75, 95% *CI*: 1.00–3.02), evacuation of household waste in public streets (a*OR* = 2.07, 95% *CI*: 1.20–3.55), no treatment of stored drinking water (a*OR* = 1.69, 95% *CI*: 1.11–2.56) and use of shared toilets (a*OR* = 1.69, 95% *CI*: 1.11–2.56).

Conclusion: We found a high prevalence of diarrhoea in children under the age of five in Mbour, with the highest prevalence occurring in the central and peri-central areas. These findings underscore the need for public health interventions to alleviate the burden of diarrhoea among vulnerable groups. Promotion of solid waste disposal and reduction of wastewater exposure should be implemented without delay.

Keywords: Children under five year-old, Cross-sectional survey, Diarrhoea, Multivariable logistic regression, Risk factor, Senegal

* Correspondence: gueladio.cisse@unibas.ch
[1]Swiss Tropical and Public Health Institute, P.O. BoxCH-4002 Basel, Switzerland
[2]University of Basel, P.O. BoxCH-4003 Basel, Switzerland
Full list of author information is available at the end of the article

Multilingual abstracts

Please see Additional file 1 for translations of the abstract into the five official working languages of the United Nations.

Background

Diarrhoeal diseases remain among the most common causes of mortality and morbidity in children, particularly in low- and middle-income countries (LMICs). In 2013, of the 6.3 million children worldwide who died before they reached their fifth birthday, about half (3.2 million) died from infectious diseases, with diarrhoea killing more than 500,000 children [1]. By 2030, it is estimated that 4.4 million children under the age of five will die from infectious diseases annually and that 60% of those deaths will occur in sub-Saharan Africa [1]. Diarrhoea accounts for an estimated 3.6% of the global burden of disease, as expressed in disability-adjusted life years (DALYs) [2]. Although mortality from diarrhoea has declined considerably over the past 25 years globally, morbidity from diarrhoea in sub-Saharan Africa has not, as risk factors related to inadequate water, sanitation and hygiene (WASH), insufficient promotion of breastfeeding and malnutrition remain unacceptably high [3]. The rapid growth of African cities and associated overcrowding has been linked to outbreaks of diarrhoea, with children under the age of five among the most affected [4].

In Senegal, the Ministry of Health (MoH) lists diarrhoea as the third leading cause of mortality and the second leading cause driving caregivers of children under 5 years old to seek medical consultation [5]. In 2013, according to Liu and colleagues, the total number of deaths among children under the age of five in the country was 28,648, with 1866 deaths (15%) due to diarrhoeal diseases [1, 6]. In 2011, the Senegalese Demographic and Health Survey (DHS) reported that one in five children under the age of five suffered from diarrhoea during the 2 weeks preceding the survey (21%) [7]. The 2014 DHS showed that prevalence of diarrhoea in this age group remained at the same level (19%) [8].

Lack of access to clean water and improved sanitation is a major issue in the urban coastal area of Senegal, where 13.5 million people reside, accounting for 45% of the national population [9]. Rapid urbanisation in sub-Saharan Africa (including Senegal) over the past few decades has resulted in disorganised urban landscapes, where populations live in crowded conditions [10, 11]. Urbanisation not only occurs in capital cities of LMICs, but also in secondary cities [12]. Indeed, half of the anticipated urban population increase in the coming years is expected to occur in secondary African cities and in smaller cities that connect the rural hinterlands of the sub-region [13–15]. The urbanisation trends in secondary cities merit focused attention due to the particular weaknesses and vulnerabilities of those contexts.

In Mbour, a secondary coastal city in Senegal, the population has grown from approximately 100,000 in 1988 to more than 220,000 in 2014 [16]. However, unofficial estimations by Mbour municipality leaders suggest that the current population might be as high as 700,000, which is far above the projection for 2014 made by the National Agency of Statistics and Demography (ANSD) on the basis of 2002 census data. This massive increase in Mbour's population has also resulted in a spatial extension of 56% [17], the spread of urban slums and a lack of basic services pertaining to WASH and solid waste removal [18, 19]. These conditions create a high risk of water-borne and gastrointestinal diseases, including diarrhoea [20]. Not surprisingly, Mbour was among the ten health districts in Senegal characterised by high numbers of diarrhoeal cases. To better understand the determinants of diarrhoea in this urban setting, data are needed to better understand the local epidemiology. Such data will be valuable for designing and implementing intervention and prevention strategies to reduce morbidity due to diarrhoea at the community level.

Here, we provide an overview of diarrhoea prevalence and risk factors among children under 5 years old in Mbour. Specifically, we determined the prevalence of self-reported diarrhoea and identified key risk factors among young children in this secondary city of Senegal.

Methods

Study area

The study was conducted in Mbour, a secondary coastal city in Senegal on the edge of the Atlantic Ocean (Fig. 1). The city lies approximately 19 m above sea level in the region of Thiès in western Senegal (latitude 14°41′6″N and longitude 16°96′9″W), about 80 km south of the capital, Dakar. Administratively, the city is divided into 25 neighbourhoods. Mbour's health system consists of a hospital, a health centre and 10 health posts. The study area was stratified into four zones according to specific characteristics, namely: (i) urban central area (UCA); (ii) peri-central area (PCA); (iii) north peripheral area (NPA); and (iv) south peripheral area (SPA). The PCA, UCA, NPA and SPA cover areas of 7, 4, 8 and 6 km^2, respectively. The respective population sizes are 98,126, 48,011, 53,894 and 28,259.

The UCA is the original core of the city and includes the central neighbourhoods, the historic district and commercial centre, all with a type of traditional habitat. It is characterised by poor sanitation, high population density and overcrowding and is inhabited mostly by fishermen. The PCA is the first peri-urban area of the city, composed of regular and irregular neighbourhoods like *Baye Deuk,* an informal neighbourhood surrounding the core. The NPA and SPA comprise new neighbourhoods or peripheral

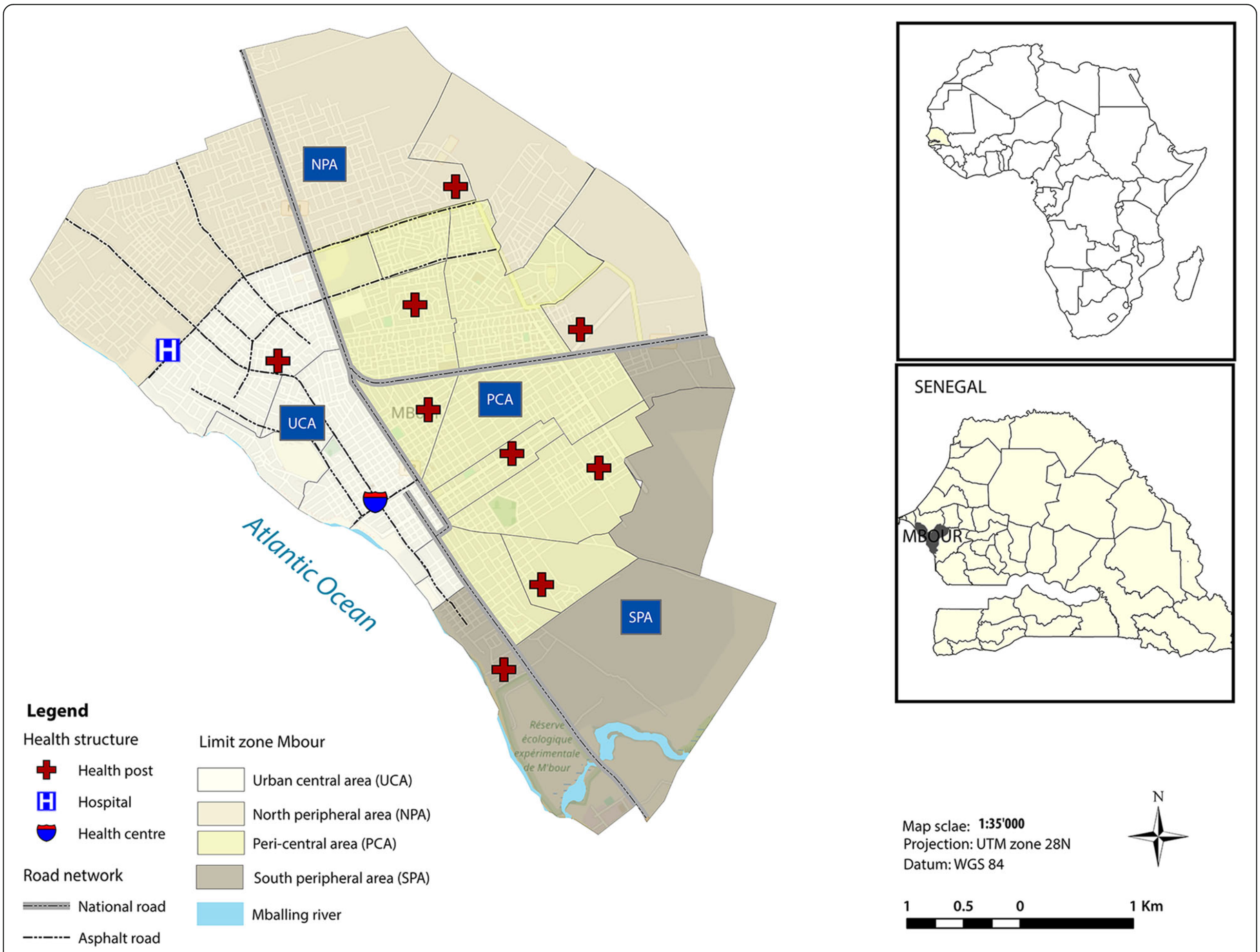

Fig. 1 Map showing Mbour in Senegal and the location of the four different zones

neighbourhoods. The NPA is marked by a modern habitat and better access to basic social services in some neighbourhoods, while the SPA is characterised by straw houses, a precarious socioeconomic status and a lack of access to safe drinking water. Most of the population in the SPA and NPA use water from traditional wells. These four zones were chosen to compare the prevalence and risk factors of diarrhoea related to living conditions, socioeconomic status, drinking water sources, sanitation facilities, hygiene and education levels.

Outcome definition

The primary outcome variable was the occurrence of diarrhoea during the 2-week period preceding the survey interview. For this purpose, the DHS definition of diarrhoea was applied, i.e. having three or more loose or liquid bowel movements over a 24-h period, as reported by the mother or caregiver of the child, at any point during the 2 weeks preceding the interview [8]. This definition is in line with that of the World Health Organization (WHO) [21].

Household survey and study population

A cross-sectional study was carried out between 2 February and 8 March 2014. As the prevalence of diarrhoea in Mbour had not been investigated in previous studies, we assumed an average prevalence rate of 26%, based on data obtained from the DHS and National Survey on Food Security and Nutrition (ENSAN), representing the Thiès region where Mbour is located [7, 22]. The sample size (n) was calculated to achieve sufficient precision in estimating the prevalence of diarrhoea among children under 5 years, using the following formula: $n = Z^2 \times \mathrm{p} \times (1 - \mathrm{p}) \times c/r^2$ where: Z equals 1.96, p is the estimated prevalence of diarrhoea among children under 5 years (assumed to be 26%), r is the accepted margin of error (assumed to be 5%) and c is the design effect accounting for clustering of the data within households. Assuming $c = 2$, a sample size of 600 households was calculated. Having divided the city into four zones (i.e. PCA, UCA, NPA and SPA), we determined the sample size of households proportionally to the population for each zone. We randomly selected clusters of equal size (25 households) within each zone. Overall, we surveyed

24 clusters. These clusters were defined by the smallest administrative units, known as "district census". The final sample size was 596 households.

Households were eligible for inclusion in the survey if the following criteria were met: (i) presence of mother or caregiver; and (ii) presence of at least one child under the age of five. A structured questionnaire was administered for data collection. The questionnaire was inspired by the Multiple Indicators Cluster Survey (MICS) and by DHS questionnaires related to diarrhoea. The French language version of the questionnaire was translated into local language and then translated back into French to ensure accuracy. Four experienced investigators conducted interviews in the local language or in French, using a paper-based questionnaire. Investigators were trained to administer the interview, to follow data quality assurance procedures and to adhere to principles of ethical conduct in human research. The survey questionnaire was pre-tested in a neighbourhood of Mbour that was not otherwise considered, to ensure that questions were properly understood by the local communities. In the pilot study, ten households were interviewed and any observed shortcomings in the instruments were corrected before the start of data collection. The pre-test also provided crucial information on the validity and usefulness of the data collected.

Independent variables included the following: (i) sociodemographic information (zone, mother's age, family size, number of children under the age of five in the household, mother's or caregiver's educational level); (ii) socioeconomic status (occupation); (iii) environmental and behavioural indicators (availability of a toilet, type of toilet, drinking water source, solid waste and wastewater disposal, personal hygiene); and (iv) occurrence of diarrhoea. Socioeconomic status of the households was classified as either "richest", "middle" or "poorest", based on a cumulative standardised assets score, which was calculated using principal component analysis. All asset variables considered were dichotomous (e.g. presence or absence of radio).

Statistical analysis

Statistical analysis was performed in Stata version 13.0 (Stata Corporation; College Station, United States of America). Descriptive statistics were used to summarise the study variables. Associations between outcome and independent variables were expressed by their odds ratios (*OR*s) and 95% confidence intervals (*CI*s). Mixed univariable and multivariable logistic regression models with random intercepts for households were used to quantify the effects of the risk factors on the diarrhoea outcome and to compare differences in diarrhoea prevalence between the zones. Models were compared using likelihood ratio tests (LRTs). To reduce the number of parameters and to improve precision of the estimates of the final models, we only considered variables that had a *P*-value below 0.2 in the univariable analysis (using LRT) for the multivariable analysis. Statistical significance was defined at the level of 5%.

Results

Sociodemographic characteristics of the surveyed households

A total of 1136 children under the age of five (50.8% males) from 596 households participated in the survey conducted in four zones of Mbour, in early 2014 (Fig. 2). Demographic and socioeconomic characteristics of the surveyed households are summarised in Table 1. The median age of the respondents was 30 years. Parental ages presented in Table 1 are for those parents with complete questionnaire results. Most of the mothers were married (93.5%; n = 275). The primary occupation was housewife (56.6%; n = 167). Almost half of the mothers had no formal education (45.6%; n = 272). The mean household size was 8.7 (standard deviation (*SD*): 4.8) individuals.

Access to water and sanitation

As shown in Table 1, tap water at home was the most commonly used drinking water source (61.7%; n = 368), followed by water from public taps (25.5%; n = 152), well water (8.6%; n = 51) and other sources (4.2%; n = 25). In the UCA, 83.4% (n = 146) had their own tap water at home, followed by the NPA (64.9%, n = 63), PCA (55.8%, n = 153) and SPA (12.0%, n = 6).

Two thirds of the households (69.6%; n = 415) stored drinking water and 16.4% of them (n = 98) treated the stored water prior to consumption. Among the households that treated their water prior to storing, 69 (70.4%) used chlorination, 22 (22.4%) used filtration, and 7 (7.1%) employed other methods. Most households (97.3%; n = 580) had a toilet facility at home, while the remaining 16 households had no access to sanitation facilities (2.7%). Among households with a toilet, 522 (90.0%) had a septic tank, 222 (38.3%) shared toilet facilities and only 7 (1.2%) households were connected to a sewer. Two hundred and one households (33.7%) reported no kitchen at home. Most of them (63.7%; n = 128) prepared their food in the yard of the house, while 18.9% (n = 38) prepared food in a covered space provided for cooking in the yard of the house and 17.4% (n = 35) in a corridor in the residence.

Reported prevalence of diarrhoea among children under the age of five

Diarrhoea prevalence among children under the age of five was estimated based on the number of children who reportedly had diarrhoea during the 2 weeks preceding the interview as the numerator and the overall number of children in the sample as the denominator. Diarrhoeal cases occurring within the 2 weeks preceding the interview were reported for one in four children, giving an overall prevalence of 26.1% (n = 295). Prevalence was

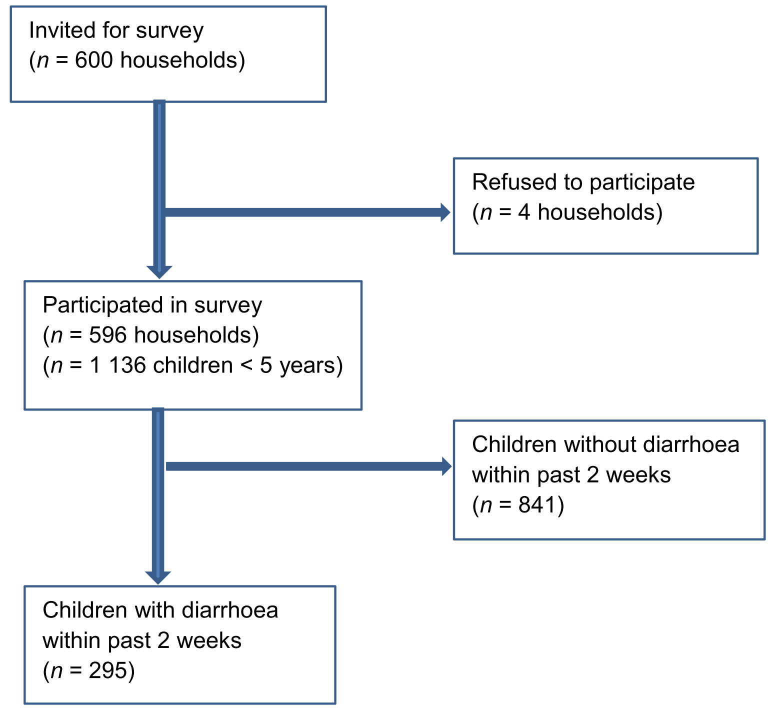

Fig. 2 Summary of surveyed household and results of reported diarrhoea cases by age categories in Mbour, Senegal, 2014

slightly higher among girls than boys (27.6% and 24.4%, respectively), but this difference was not statistically significant (P = 0.22). Adjusted diarrhoea prevalence among children under the age of five did not show a significant difference between zones, with the highest rate observed in the UCA (26.9%) and the lowest rate in the SPA (17.1%). Without adjusting for other variables, the highest diarrhoea prevalence was observed in the PCA (44.8%) and the second highest in the UCA (36.3%), as shown in Figs. 3 and 4. The analysis stratified by age group showed a higher prevalence of diarrhoea in the oldest age group (24–59 months), while the lowest diarrhoea prevalence was observed among children under 12 months (Fig. 3). Diarrhoea prevalence, stratified by age group and zone, is shown in Fig. 5. In this analysis, the highest prevalence was observed among children 12–23 months in the PCA. The highest prevalence among children <12 months was observed in the UCA and NPA. The proportion of children having more than one diarrhoea event during the 2 weeks immediately preceding the survey was 30%.

Household risk factors associated with diarrhoea

The results from the univariable and multivariable logistic regression analyses are presented in Tables 2 and 3. After adjustment for potential confounders, diarrhoea among children under the age of five was significantly associated with: (i) mother's unemployment (adjusted (a*OR*) = 1.62, 95% *CI*: 1.18–2.23); (ii) sharing the toilet with other households (a*OR* = 1.69, 95% *CI*: 1.11–2.56); (iii) use of unconventional bag (open bag) for storing household solid waste (a*OR* = 1.75, 95% *CI*: 1.00–3.02); note that solid waste comprises garbage originating from private homes or apartments (also called domestic waste or residential waste); (iv) households with more than one child under the age of five (a*OR* = 2.86, 95% *CI*: 1.70–4.80 and a*OR* = 1.55, 95% *CI*: 1.00–2.40); (v) evacuation of household domestic wastewater in public street (a*OR* = 2.07, 95% *CI*: 1.20–3.55); and (vi) no treatment of stored drinking water (a*OR* = 1.69, 95% *CI*: 1.11–2.56). Conversely, mother's above 40 years (a*OR* = 0.38, 95% *CI*: 0.22–0.65) and "middle" (a*OR* = 0.64, 95% *CI*: 0.41–0.98) and "richest" (a*OR* = 0.62, 95% *CI*: 0.42–0.90) socioeconomic status were negatively associated with the occurrence of diarrhoea.

Discussion

In this study, we compared diarrhoea prevalence (recall period: 2 weeks) and risk factors among children under the age of five in four zones of Mbour, a medium-size town in Senegal. We found that the 2-week, caregiver-reported prevalence of diarrhoea among children under 5 years was 26%, which is slightly above the rate reported for the same age group in the 2014 Senegalese DHS (19%) [7]. However, our rate is below that reported in the ENSAN 2013 survey report (32%) for the Thiès region [22]. It is also lower than the 35% prevalence among children under 5 years previously reported in Kaédi, Mauritania by Touray and colleagues (2012) [23]. Other studies in secondary cities of

Table 1 Characteristics of the households surveyed (n = 596) in four zones of Mbour, Senegal, in early 2014

Variables	UCA (N = 175) n (%)	PCA (N = 324) n (%)	NPA (N = 47) n (%)	SPA (N = 50) n (%)	Overall (N = 596) n (%)	P-value
Caretaker characteristics						
Age in years						0.065
< 25	24 (15.9)	47 (18.9)	20 (22.5)	8 (19.5)	99 (18.7)	
25–29	39 (25.8)	52 (20.9)	13 (14.6)	2 (4.9)	106 (20.0)	
30–39	55 (36.4)	100 (40.1)	34 (38.2)	15 (36.6)	204 (38.5)	
≥ 40	33 (21.8)	50 (20.1)	22 (24.7)	16 (39.0)	121 (22.8)	
Educational level						**<0.001**
Never went to school	67 (38.3)	133 (48.5)	43 (44.3)	29 (58.0)	272 (45.6)	
Primary school	81 (46.3)	70 (25.6)	32 (33.0)	9 (18.0)	192 (32.2)	
Secondary education or higher[a]	27 (15.4)	71 (25.9)	22 (22.7)	12 (24.0)	132 (22.2)	
Household characteristics						
Number of household members						**<0.001**
< 5 members	25 (14.3)	43 (15.7)	20 (20.6)	6 (12.0)	94 (15.7)	
5–7 members	31 (17.7)	103 (37.6)	48 (49.5)	14 (28.0)	196 (32.9)	
8–10 members	40 (22.9)	70 (25.5)	19 (19.6)	15 (30.0)	144 (24.2)	
≥ 11 members	79 (45.1)	58 (21.2)	10 (10.3)	15 (30.0)	162 (27.2)	
Number of children <5 years in the house						**<0.001**
< 2	64 (36.6)	129 (47.1)	52 (53.6)	24 (48.0)	269 (45.1)	
2 to 3	77 (44.0)	126 (46.0)	42 (43.3)	25 (50.0)	270 (45.3)	
4+	34 (19.4)	19 (6.9)	3 (3.1)	1 (2.0)	57 (9.6)	
Socio-economic status						**<0.001**
Poorest	9 (5.2)	89 (32.5)	24 (24.7)	26 (52.0)	148 (24.9)	
Middle	55 (31.6)	54 (19.7)	24 (24.7)	16 (32.0)	149 (25.0)	
Richest	110 (63.2)	131 (47.8)	49 (50.5)	8 (16.0)	298 (50.1)	
Drinking water sources						**<0.001**
Tap water in the house	146 (83.4)	153 (55.8)	63 (64.9)	6 (12.0)	368 (61.7)	
Public tap	24 (13.7)	95 (34.7)	20 (20.6)	13 (26.0)	152 (25.5)	
Well water	2 (1.1)	9 (3.2)	13 (13.4)	27 (54.0)	51 (8.6)	
Others[b]	3 (1.7)	17 (6.2)	1 (1.0)	4 (8.0)	25 (4.2)	
Water storage						**<0.001**
No	67 (38.3)	58 (21.2)	38 (39.2)	18 (36.0)	181 (30.4)	
Yes	108 (61.7)	216 (78.8)	59 (60.8)	32 (64.0)	415 (69.6)	
Toilet availability						<0.001
No	2 (1.1)	6 (2.2)	1 (1.0)	7 (14.0)	16 (2.7)	
Yes	173 (98.9)	268 (97.8)	96 (99.0)	43 (86.0)	580 (97.3)	
Type of toilet facilities						<0.001
Sewer	4 (2.3)	2 (0.7)	1 (1.0)	0	7 (1.2)	
Toilet with pit	166 (94.9)	227 (84.7)	91 (94.8)	38 (88.4)	522 (90.0)	
Traditional latrine	3 (1.7)	39 (14.6)	4 (4.2)	5 (11.6)	51 (8.8)	
Toilet shared with others households						**<0.001**
No	112 (64.7)	145 (54.1)	66 (68.8)	35 (81.4)	358 (61.7)	
Yes	61 (35.3)	123 (45.9)	30 (31.2)	8 (18.6)	222 (38.3)	

Table 1 Characteristics of the households surveyed (n = 596) in four zones of Mbour, Senegal, in early 2014 *(Continued)*

No kitchen available in the house	52 (29.7)	102 (37.2)	21 (21.6)	26 (52.0)	201 (33.7)	**<0.001**
Behavioural characteristics						
Duration of storage						0.233
One day	54 (57.5)	108 (54.5)	32 (56.1)	14 (43.7)	208 (54.6)	
Two days	22 (23.4)	45 (22.7)	12 (21.1)	15 (46.9)	94 (24.7)	
Three days	10 (10.6)	32 (16.2)	8 (14.0)	1 (3.1)	51 (13.4)	
More than four three days	8 (8.5)	13 (6.6)	5 8.8)	2 (6.2)	28 (7.3)	
Treatment water stored						**<0.001**
Yes	21 (12.0)	36 (13.1)	18 (18.6)	23 (46.7)	98 (16.4)	

Bold p-value means significant difference between zones
[a]carter water seller and at the neighbour
[b]UCA = Urban central area
[c]PCA = Peri-central area
[d]NPA = North peripheral area
[e]SPA = South peripheral area

sub-Saharan Africa reported lower rates: 23.6% in a 2008 survey in Nouakchott, Mauritania; 14% in 2006 in Yopougon, Côte d'Ivoire; and 13.5% in 2010 in other districts of Nouakchott, Mauritania [23–27]. The high prevalence of diarrhoea in urban Senegal found in the present study was observed in the cold, dry season between February and March, the period of the harmattan, during which most diarrhoea cases and deaths due to rotavirus infection had previously been reported [10]. A study conducted in Burkina Faso during the cold, dry season (December 2009–February 2010) found a rotavirus prevalence of 63.8% among children under the age of five. The same study showed that up to 90% of all diarrhoea cases in this population group were related to rotavirus [28]. In view of these findings, more attention should be given to exploring diarrhoea seasonality and the influence of climatic parameters, in order to more effectively prevent and manage diarrhoea in urban settings in Senegal and elsewhere in sub-Saharan Africa.

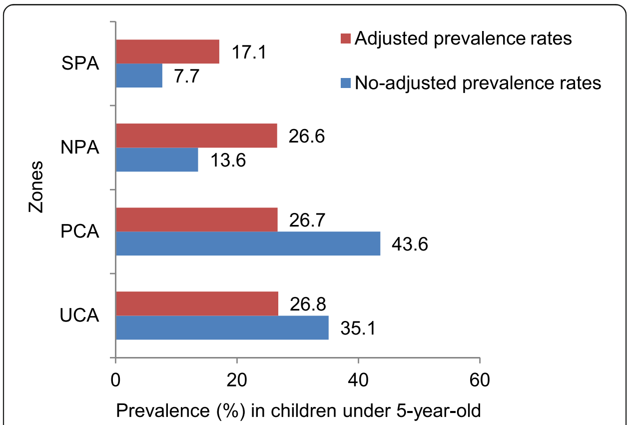

Fig. 3 Diarrhoeal prevalence rates by zone before and after adjustment for individual factors in Mbour, Senegal, 2014

According to our study, diarrhoeal prevalence was highest in the PCA (44.8%), which was almost nine times higher than that in the SPA (5.1%). Hence, there is considerable spatial heterogeneity of diarrhoea prevalence, which might partially be explained by differences in the distribution of risk factors across zones, such as living conditions, population density, socioeconomic status and WASH conditions.

We also found that diarrhoea was reported slightly more often among girls compared to boys. In contrast, diarrhoea was more frequent among boys in a study from Sudan [29]. Our finding might be explained by the cultural practices in Senegal, where there is an overt preference for boys over girls that might also affect how mothers or caregivers take care of children. For example, the 2014 Senegalese DHS indicates that care for diarrhoea concerns was sought more frequently for boys (36%) than for girls (29%) [8]. This suggests that boys suffer more frequently from diarrhoea compared to girls, unless there is a tendency to take girls to the doctor less often.

In our study, the prevalence of diarrhoea was highest in the age group 24–59 months (51.5%). This finding is in contrast to results from a study in Burkina Faso, where children under the age of 12 months had the highest rate of diarrhoea (44%) [28, 30]. However, in the urban slums of Senegal, children aged 2–5 years are likely to have a high risk of exposure to diarrhoeal pathogens because they have considerable independence. They are often highly mobile and play unsupervised within the community environment, where there is a high level of contamination.

Our study showed that the risk of diarrhoea was significantly associated with the mother's occupation (i.e. housewife was associated with higher diarrhoea risk compared to those working in the private or public sector). This finding is consistent with other reports, which found that parental occupation was associated

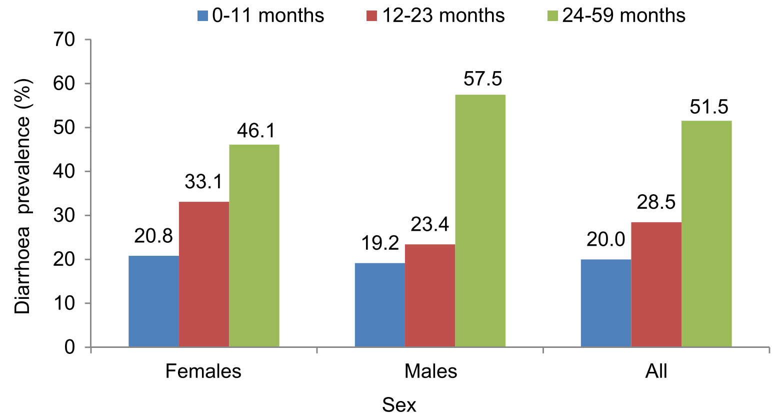

Fig. 4 Diarrhoea prevalence among children under 5-years-old by age and gender in Mbour, Senegal, 2014

with diarrhoeal occurrence [31, 32]. Although socioeconomic status (middle and poorest) showed a significant association with the occurrence of diarrhoea in the bivariate analysis, it was not significant when other variables were included. In the multivariate analyses, we found that children living in better off households were less likely to have diarrhoea compared to their lower wealth counterparts. A likely explanation of this observation is that wealth is associated with better access to household amenities and facilities, including those related to better hygiene and environmental health, which might reduce the risk of diarrhoea. In addition, wealth allows parents to use health services more frequently [33, 34]. However, Root suggested that wealthy parents may be unable to reduce the risk of diarrhoea due to factors beyond their control, such as contaminated community environment or lack of water [35]. However, many other studies indicate that socioeconomic factors are strongly associated with the occurrence of diarrhoea; this appears to confirm the social determinants of health [36, 37].

The presence of two or more children under the age of five living in the same household was significantly associated with the occurrence of diarrhoea. This observation is consistent with a number of cross-sectional studies conducted in Nigeria and Cameroon [38–40]. These findings indicate that a large number of children residing in the same household is a predictor of diarrhoea among children under the age of five. More than two children in this age range in a single household probably means that contact with potential pathogens is more frequent than in households with only one or two young children [38]. This difference could be due to the challenges of taking care of multiple young children. It follows, then, that longer spacing between births and exclusive breastfeeding in the first 2 years of life might have a positive impact on diarrhoea prevention.

We did not find a significant association between drinking water sources and the occurrence of diarrhoea. This might be explained by the very small differences across the sampled households in terms of drinking water sources. In urban Africa, there are multiple sources of drinking water (e.g. well, tap water at home and public taps). Even if a household has a water connection at home, an inhabitant might need to go to the public tap or use

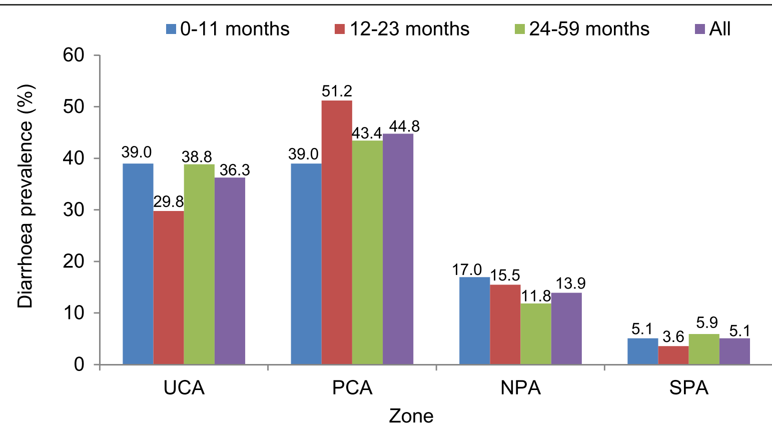

Fig. 5 Diarrhoea prevalence among children under 5-year-old by age and zone in Mbour, Senegal, 2014

Table 2 Results of univariate logistic regression for diarrhoea risk factors in Mbour, Senegal, 2014

Two weeks diarrhoea prevalence *N*(total) = 1136 / *N*(cases) = 295		Diarrhoea *N* (%)	Healthy *N* (%)	Univariate logistic regression*		
				OR	95% *CI*	*P*-value
1.Socio-demographic and socioeconomic determinants of diarrhoea						
Age (in years)	< 25	62 (22.3)	127 (17.1)	Reference		**<0.001**
	25–29	71 (26.7)	159 (21.4)	0.91	0.61–1.38	0.672
	30–39	106 (39.8)	232 (39.3)	0.74	0.51–1.08	0.123
	≥ 40	27 (10.1)	165 (22.2)	0.33	0.20–0.56	**<0.001**
Household's socioeconomic status	Richest	148 (50.3)	438 (52.1)	1.20	0.85–1.69	0.301
	Middle	58 (19.7)	206 (24.5)	Reference		**>0.053**
	Poorest	88 (30.0)	197 (23.4)	1.58	1.07–2.33	**0.019**
Occupational status	Employed	128 (43.4)	482 (57.3)	Reference		
	Unemployed	167 (56.6)	359 (42.7)	1.75	1.34–2.29	**<0.001**
Marital status	Married	275 (93.5)	765 (91.2)	Reference		0.194
	Unmarried	19 (6.5)	74 (8.8)	0.71	0.42–1.20	0.207
Number of household members	< 5	45 (15.3)	86 (10.2)	1.78	1.17–2.73	**0.008**
	5 to 7	87 (29.5)	224 (26.6)	1.32	0.95–1.85	0.101
	8 to 10	65 (22.0)	197 (23.4)	1.12	0.78–1.61	0.522
	≥ 11	98 (33.2)	334 (39.7)	Reference		**0.049**
Number of children <5 years in the house	< 2	92 (31.2)	177 (21.0)	2.13	1.44–3.15	**<0.001**
	2 to 3	150 (50.8)	447 (53.2)	1.37	0.97–1.95	0.077
	≥ 4	53 (18.0)	217 (25.8	Reference		**<0.001**
2.Environmental exposure variables associated with diarrhoea						
Type of toilet in the house	Toilet with pit	254 (88.2)	744 (90.7)	Reference		**0.035**
	Latrine traditional	25 (8.7)	69 (8.4)	1.06	0.66–1.71	0.808
	Sewer network	9 (3.1)	7 (0.8)	3.76	1.38–10.21	**0.009**
Storage of household solid waste	Others**	24 (8.1)	99 (11.8)	Reference		**0.058**
	Pail/basin	104 (35.3)	326 (38.8)	1.32	0.80–2.16	0.279
	Open bag	167 (56.6)	416 (49.4)	1.66	1.02–2.68	**0.040**
Toilet shared with others households	Yes	119 (41.3)	270 (32.9)	1.43	1.09–1.89	**<0.001**
	No	169 (58.68)	550 (67.1)	Reference		**<0.001**
Duration of storage	Two days	38 (20.0)	157 (28.7)	Reference		**<0.001**
	One day	113 (59.4)	290 (53.1)	1.61	1.06–2.44	**0.025**
	Three days	29 (15.3)	64 (11.7)	1.87	1.07–3.29	**0.029**
	More than three days.	10 (5.3)	35 (6.4)	1.18	0.54–2.59	0.689
3.Behavioural related risk factor for diarrhoea						
Handwashing after work	No	243 (82.4)	613 (72.9)	Reference		
	Yes	52 (17.6)	228 (27.1)	0.57	0.41–0.80	**<0.001**

Bold significant *p*-value <0.05 derived from the multivariate regression
*Odds ratio (*OR*), confidence interval (*CI*) and *P*-value derived from univariate logistic regression based on likelihood ratio test, overall significant *P*-value of the models are indicated in bold letter. **Others including half metal drum, plastic vacant lost or illegal dumping etc

well water due to recurrent cuts in the network. A study in southwest Ethiopia did not find a significant association between drinking water sources and the risk of diarrhoea either [41]. In contrast, two different studies from Ethiopia found that water sources are an important environmental predictor of diarrhoea morbidity [42, 43]. We found that the lack of treatment of stored drinking water was positively associated with the prevalence of diarrhoea.

We found that diarrhoea occurrence was not significantly associated with the presence of a toilet. This finding is in line with a recent study from Ethiopia, where no association was found between sanitary facilities and

Table 3 Multivariate analysis of risk factors of diarrhoea among children <5 years old in Mbour, Senegal, 2014

Two weeks diarrhoea prevalence *N*(total) = 1136/*N*(cases) = 295		Multivariate logistic regression*		
		a*OR*	95% *CI*	*P*-value
Age (in years)	<25	1.00		
	25–29	0.95	0.62–1.43	0.802
	30–39	0.73	0.46-1.15	0.178
	≥ 40	0.38	0.22–0.65	**<0.001****
Occupational status	Employed	1.00		
	Unemployed	1.62	1.18–2.23	**0.003****
Household's socioeconomic status	Richest	0.62	0.42–0.90	**0.013****
	Middle	0.64	0.41–0. 98	**0.041****
	Poorest	1.00		
Number of children <5 years in the house	<2	2.86	1.70–4.80	**<0.001****
	2 to 3	1.55	1.00–2.40	**0.035****
	≥ 4	1.00		
Toilet shared with others households	Yes	1.69	1.11–2.56	**0.014****
	No	1.00		
Domestic wastewater disposal	Dustbin	1.00		
	Pit	0.96	0.62–1.49	0.868
	Public street	2.07	1.20–3.55	**0.009****
Storage of household solid waste	Others	1.00		
	Pail/basin	1.67	0.94–2.97	0.080
	Open bag	1.75	1.00–3.02	**0.046****
Treatment of drinking water stored	Yes	1.00		
	No	1.69	1.11–2.56	**0.014****

*Adjusted odds ratio (a*OR*), confidence interval (*CI*) and Wald *P*-value in the multivariable mixed regression model including random household intercepts.
**Significant *P*-value <0.05 derived from the multivariable regression.The multivariable model was defined including the variables sex, age, educational level, socioeconomic status, number of people per household and number of children under 5 years per household. In addition, all risk factors that had a *P*-value lower than 0.2 in the univariable analyses were included into the multivariable regression models (as indicated in the Table 3)

the occurrence of diarrhoea [41]. Conversely, another study from Ethiopia found that the availability of a latrine was negatively associated with diarrhoea after controlling for potential confounding factors [44]. The type of toilet showed a significant association with the occurrence of diarrhoea in our bivariate analyses. Rather unexpectedly, the association became insignificant when other variables were included in the multivariate analyses. We found that sharing a toilet with other households was associated with a high risk of diarrhoea.

Our study showed that the use of open bags for storing household solid waste was significantly associated with the prevalence of diarrhoea. In a study carried out in Ibadan, Nigeria, indiscriminate disposal of solid waste was significantly associated with a high rate of diarrhoea [45]. Studies in Ethiopia also revealed that open disposal of waste around the house was a risk factor for diarrhoea [26, 46]. We also found that evacuation of domestic wastewater from households into public streets was significantly associated with the risk of diarrhoea. The likely explanation for these results is that inappropriate disposal of solid waste and evacuation of wastewater in public streets create breeding sites for insects, which may spread diarrhoeal pathogens from the open waste to water or food.

Evacuation of human excreta into septic tanks conferred an increased risk of diarrhoea but these associations were not statistically significant, which may be due to its rare occurrence. We also found that mother's age (i.e. 40 years and above) significantly reduced the risk of children's diarrhoea. This finding might be explained by greater experience in childcare, hygiene and feeding practices with age.

Our findings support the 'urban health penalty' hypothesis, which posits that the poor in urban areas are pushed to marginal areas, where environmental health conditions are not suitable for health. This issue is particularly pronounced in secondary cities, where access to clean water and improved sanitation, and socioeconomic conditions more broadly, have been compromised by populations moving into urban areas that are unregulated and poorly managed. Such conditions might result in urban slums that are characterised by inadequate safe water supply, lack of drainage and sewage networks and the absence of sanitation and solid waste removal.

Limitations

Our study has several limitations that are offered for consideration. First, we pursued a cross-sectional survey; hence, caution is required regarding causality, as the results presented here are related to the cold, dry season (February and March). To better understand seasonal variability, we are in the process of conducting a survey in the same area in the hot, wet season (July and August). Second, the assessment of diarrhoea prevalence was based on caregivers' reports, which may have introduced some recall bias, despite the relatively short recall period of 2 weeks. Third, we did not undertake microbiological analysis of stool samples and drinking water samples, mainly due to budget limitations. Microbiological analysis of drinking water at source and household levels will be conducted in subsequent follow-up studies in the study area.

Despite these limitations, our study provides new insight into the extent of diarrhoea among children under five in Mbour. Our results might be helpful for designing appropriate interventions for preventing childhood diarrhoea in the study area.

Conclusions

Our study showed that the reported prevalence of diarrhoea among children under the age of five is high in Mbour (26%), which is similar to previous estimates obtained from DHS. The disaggregated findings provide a useful baseline for more targeted interventions and future studies in more vulnerable urban settings in the area. The study indicates that there is a need for effective preventive measures to reduce the high prevalence of diarrhoea in secondary cities in Senegal. Health intervention programmes, including increasing priority of solid waste and wastewater management, should be introduced and tested, particularly in the PCA and UCA, where diarrhoeal diseases are most common, in order to reduce the prevalence and burden of diarrhoea. The findings also provide useful information to the existing national programme for the fight against diarrhoea and to all other actors developing targeted interventions for preventing childhood diarrhoea.

Additional file

Additional file 1 Multilingual abstracts in the five official working languages of the United Nations. (PDF 749 kb)

Abbreviations

ANSD: National Agency of Statistics and Demography; a*OR*: Adjusted odds ratio; *CI*: Confidence interval; DALY: Disability-adjusted life year; DHS: Demographic and Health Survey; ENSAN: National Survey on Food Security and Nutrition; NPA: North peripheral area; *OR*: Odds ratio; PCA: Pericentral area; SPA: South peripheral area; UCA: Urban central area; WASH: water, sanitation and hygiene; WHO: World Health Organization

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Availability of data and materials

The dataset supporting the conclusions of this article are included within the article and its additional files. Moreover, the current dataset contains information not presented here, which might be used for additional analyses. Excerpts from the dataset are available upon request from the corresponding author.

Authors' contributions

ST, AND, IS, JAN and OF participated in the study conception and design. AND, PV, JU, OF and GC supervised the study. ST is the principal investigator and conducted the data collection activities, managed data entry, cleaned and prepared the database for statistical analysis. ST performed statistical analysis, interpreted the data supported by SF and CS and drafted the manuscript. SF, MSW, JAN, JU and GC revised the manuscript. All authors read and approved the final submitted version of the manuscript.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Ethical clearance was obtained from the *Comité National d'Ethique de la Recherche* (CER) of Senegal (reference number 0 l06/2015/CER/UCAD). As the focus of this study was on children under the age of five, written informed consent was obtained from the parents/guardians before commencing the interviews. Participants were free not to answer specific questions or to cease the interview at any time without further obligations. All information gathered was handled confidentially. No biological specimens (stool, urine or blood samples) were collected.

Author details

[1]Swiss Tropical and Public Health Institute, P.O. BoxCH-4002 Basel, Switzerland. [2]University of Basel, P.O. BoxCH-4003 Basel, Switzerland. [3]Département de Géographie, Université Cheikh Anta Diop de Dakar, BP 5005 Dakar, Senegal. [4]Centre de Suivi Ecologique, BP 15 532 Dakar-Fann, Senegal. [5]Département de Biologie Animale, Université Cheikh Anta Diop de Dakar, BP 5005 Dakar, Senegal.

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8. ARTICLE 3: Association between childhood diarrhoeal incidence and climatic factors in urban and rural settings in the health district of Mbour, Senegal

Photo: Health post in the health district of Mbour, Senegal (©S. Thiam, 2016)

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Association between Childhood Diarrhoeal Incidence and Climatic Factors in Urban and Rural Settings in the Health District of Mbour, Senegal

Sokhna Thiam [1,2,3], Aminata N. Diène [3], Ibrahima Sy [4], Mirko S. Winkler [1,2], Christian Schindler [1,2], Jacques A. Ndione [4], Ousmane Faye [5], Penelope Vounatsou [1,2], Jürg Utzinger [1,2] and Guéladio Cissé [1,2,*]

1. Department of Epidemiology and Public Health, Swiss Tropical and Public Health Institute, P.O. Box, CH-4002 Basel, Switzerland; sokhna.thiam@swisstph.ch (S.T.); mirko.winkler@swisstph.ch (M.S.W.); christian.schindler@swisstph.ch (C.S.); penelope.vounatsou@swisstph.ch (P.V.); juerg.utzinger@swisstph.ch (J.U.)
2. University of Basel, P.O. Box, CH-4003 Basel, Switzerland
3. Département de Géographie, Université Cheikh Anta Diop de Dakar, Dakar-Fann BP 25405, Senegal; aminaniang@orange.sn
4. Centre de Suivi Ecologique, Dakar-Fann BP 15532, Senegal; ibrahima.sy@cse.sn (I.S.); jacques-andre.ndione@cse.sn (J.A.N.)
5. Département de Biologie Animale, Université Cheikh Anta Diop de Dakar, Dakar-Fann BP 25405, Senegal; fayeo@orange.sn

* Correspondence: gueladio.cisse@swisstph.ch; Tel.: +41-61-284-8304; Fax: +41-61-284-8105

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Abstract: We assessed the association between childhood diarrhoeal incidence and climatic factors in rural and urban settings in the health district of Mbour in western Senegal. We used monthly diarrhoeal case records among children under five years registered in 24 health facilities over a four-year period (2011–2014). Climatic data (i.e., daily temperature, night temperature and rainfall) for the same four-year period were obtained. We performed a negative binomial regression model to establish the relationship between monthly diarrhoeal incidence and climatic factors of the same and the previous month. There were two annual peaks in diarrhoeal incidence: one during the cold dry season and one during the rainy season. We observed a positive association between diarrhoeal incidence and high average temperature of 36 °C and above and high cumulative monthly rainfall at 57 mm and above. The association between diarrhoeal incidence and temperature was stronger in rural compared to urban settings, while higher rainfall was associated with higher diarrhoeal incidence in the urban settings. Concluding, this study identified significant health–climate interactions and calls for effective preventive measures in the health district of Mbour. Particular attention should be paid to urban settings where diarrhoea was most common in order to reduce the high incidence in the context of climatic variability, which is expected to increase in urban areas in the face of global warming.

Keywords: diarrhoea; negative binomial regression; rainfall; seasonality; temperature; Senegal

1. Introduction

Diarrhoea is one of the major causes of child morbidity and mortality. For example, in 2015, it was estimated that more than half a million children under the age of five died from diarrhoeal diseases [1]. Nearly half of these deaths occurred in sub-Saharan Africa. Although child mortality due to diarrhoeal diseases has declined annually by 6.5% since the establishment of the UN Millennium Development Goal 4 (MDG4) in 2000, in 2015, 9% of all child deaths were still due to diarrhoeal diseases, and morbidity from diarrhoea remains unacceptably high [2]. Climate change impacts and will increasingly influence human health, and is expected to affect waterborne diseases, including diarrhoeal diseases [3]. Environmental change is a major risk factor for public and global health, including children's health [4]. Children may experience greater risk of infectious diseases like diarrhoea due to rise in the average global surface temperature and rainfall. Diarrhoea is an important disease to study in this context because of its sensitivity to climatic parameters, and because children are particularly vulnerable to temperature variability as their immune system is not yet fully developed [5,6]. The primary impact of climate on society results from extreme weather events which are linked to changes in climatic variability to a greater extent than to changes in the mean values of climatic variables [7]. In the specific case of diarrhoea, climatic variability, especially rainfall and temperature variation, more generally impact diarrhoeal incidence through their effects on the growth of the various bacteria, protozoa, viruses and helminths that cause the infections of which diarrhoea is a symptom [6]. The effects of variation in rainfall and temperature on diarrhoea depend on the season in which the variation occurs [8,9].

The relationship between climate and diarrhoeal diseases is complex because of the myriad confounding variables and transmission routes that can affect the disease incidence and the fact that diarrhoea is caused by different pathogens [10–13]. Despite this complexity, evidence suggests that climatic factors, such as temperature and rainfall, are associated with the occurrence of diarrhoea; indeed an increase in temperature is associated with an increase in the incidence of diarrhoea [14–19]. However, previous studies exploring the effects of climatic factors on diarrhoea are inconclusive. One reason is that climatic data obtained from observing stations might contain measurement bias, as most of these monitoring sites are located in or in close proximity to urban areas, while temperature may show considerable variation even within cities [20]. Satellite remote sensing technologies offer new opportunities because of the broad spatial coverage [21]. To our knowledge only few studies used satellite remote sensing data to assess the effects of climatic factors on childhood diarrhoea. However, there is little evidence to support the hypothesis that the association between climatic factors and diarrhoeal incidence differs between rural and urban areas. Also, to date, no studies have assessed the relationship between climatic factors and diarrhoeal incidence using satellite remote sensing data in Senegal. This study aimed to fill these knowledge gaps. Moreover, the relationship between temperature variability and childhood diarrhoea remains to be explored, even though large temperature variability may stress children's immune system and compromise their resistance to intestinal aetiological agents [22].

Results from a recent study conducted in Senegal showed that there is an increase in temperature during the cool season with significant inter-annual variation (–1.8 °C to 1.7 °C) and also during the warm season with a somewhat lower inter-annual variation (–1.7 °C to 1.0 °C) [23]. The study also showed that the variation in temperatures and heavy rainfall observed in Senegal matched scenarios put forward by the Intergovernmental Panel on Climate Change (IPCC). Hence, it is important to understand climate variability as a risk factor for infectious diseases, particularly diarrhoea. Against this background, Senegal remains a vulnerable country in view of the high presence of climate-sensitive diseases, including diarrhoea, but also because of rapid urbanization and an increasing frequency of extreme whether events, such as flooding in urban areas. This means that climatic variations particularly extreme events, must be considered when safeguarding people's health and wellbeing.

The current study focusses on the coastal secondary city of Mbour and explores the association between childhood diarrhoeal incidence and climatic factors. In this part of Senegal, the cold dry season extends from December to March and is characterized by a high diarrhoea burden. This season offers conditions that favour the rapid spread of pathogens or viruses causing diarrhoea. The objectives of the study were, firstly, to determine the incidence of diarrhoea in children under the age of five years in urban and rural settings of Mbour; secondly, to examine the seasonal patterns of diarrhoea in both areas; thirdly, to statistically assess the relationship between diarrhoea incidence and daily land surface temperature (LST_{Day}) and night land surface temperature (LST_{Night}), average temperature (LST), temperature variability (defined as the difference between temperature LST_{Day} and LST_{Night}), and rainfall; and, fourthly, to examine if the relationship with diarrhoea incidence and climatic factors differ between urban and rural settings using health surveillance data for childhood diarrhoea and satellite remote sensing data for the climate over a four-year period (January 2011 to December 2014).

2. Methods

2.1. Ethics Statement

The study protocol was approved by the *Comité National d'Ethique de la Recherche* (CER) of Senegal (reference no. 0l06/2015/CER/UCAD). As we used secondary health data on children under the age of five years from the government health facilities, written informed consent was obtained from the Director of the *Division du Système d'Information Sanitaire et Sociale* and the *Direction de la Planification, de la Recherche et des Statstiques* at the Ministry of Health of Senegal and from the chief medical officer of the health district of Mbour. All information gathered was handled confidentially. No biological specimens (stool, urine or blood samples) were collected.

2.2. Study Site and Associated Datasets

Mbour is located in the western part of Senegal on the small coast, approximately 80 km south of the capital Dakar (Figure 1). The health district of Mbour consists of 23 posts and one health centre, which provide first-line health care services. Additionally, there is one hospital located in Mbour town.

Senegal has two main seasons: the rainy season (July–October with a peak in August–September) and the dry season (November–June). The dry season is divided in two seasons: the cold dry season (December–March) and the hot dry season (April–June and November). The mean annual temperature is between 22 °C and 30 °C, with monthly average in the hottest seasons of up to 35 °C, varying significantly between the coast and the interior of the country [24,25]. The relative humidity is high on the coast; it varies between 60% and 80%. The small coast of Senegal is vulnerable to weather events particularly flood-related health epidemics, drought, sea level rise and coastal erosion associated with climate change [25].

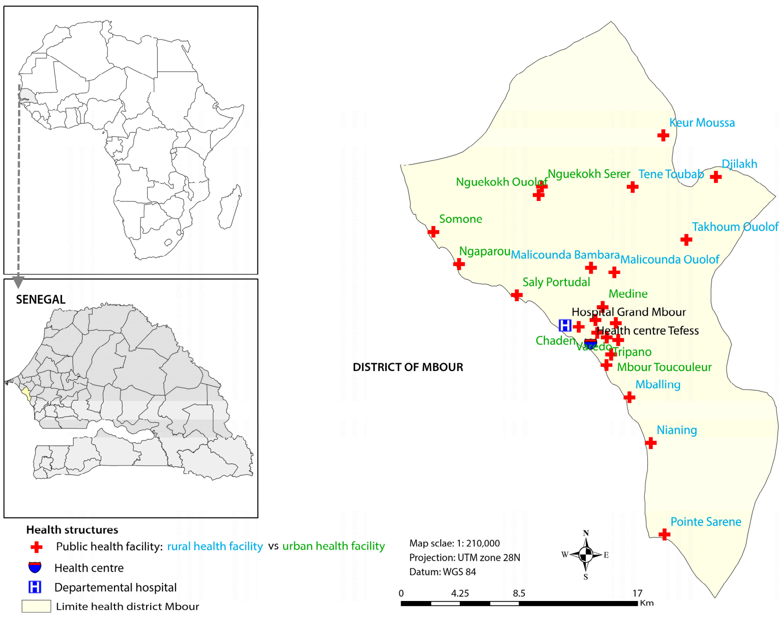


Figure 1. Map showing the study area and the location of the health facilities in the district of Mbour, Senegal.

In Mbour, the climate is tropical with an average annual precipitation of 496 mm. Figure 2 depicts key climate variables in the four-year study period. In brief, the monthly mean LST_{Day} and LST_{Night} were 32.6 °C and 19.5 °C, respectively. The mean monthly precipitation in the years 2011–2014 was 37.3 mm.

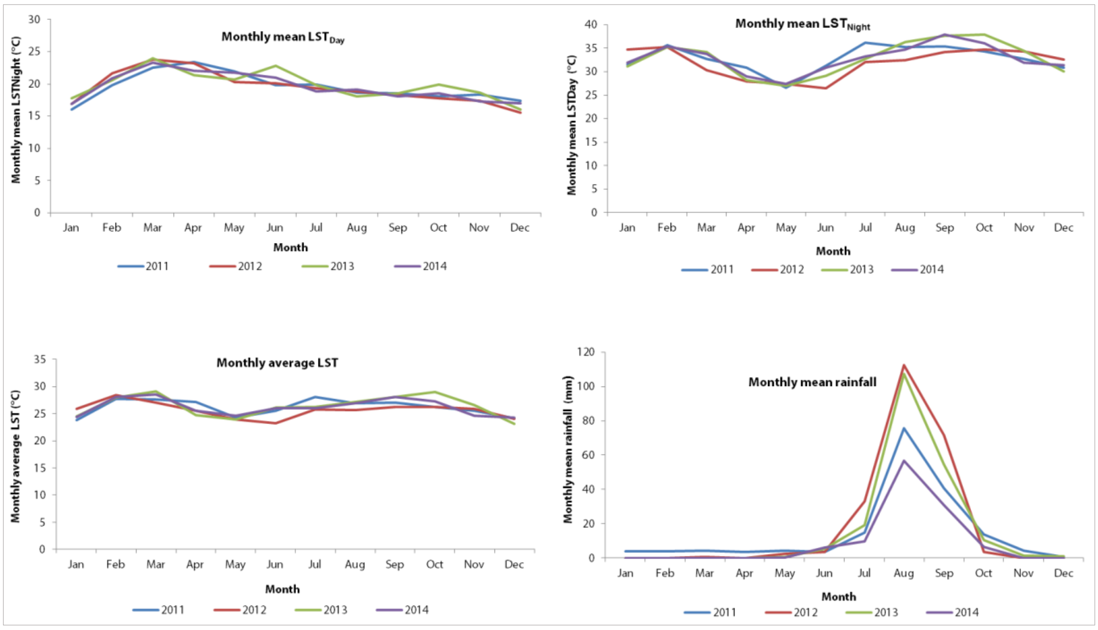


Figure 2. Distribution of mean monthly climatic variables in Mbour, Senegal over a four-year period from January 2011 to December 2014. Upper row: Distribution of mean monthly land surface temperature (LST_{Day}) and Night (LST_{Night}), by month and year, over the period 2011–2014. Lower row: Distribution of monthly average land surface temperature and monthly mean cumulative rainfall, by month and year, over the period 2011–2014.

2.3. Data Sources

Table 1 summarizes the key health data (reported diarrhoea) and climatic variables, including reporting period and spatial resolution. Monthly records of diarrhoeal cases among children under the age of five presenting to government health facilities of the district of Mbour were obtained through the District Health Information System of the Ministry of Health of Senegal ($DHIS_2$) from January 2011 to December 2014. For each child, information on age, sex, date of admission, name of the health facility visited and cause of the visit were provided. Diarrhoeal cases were aggregated by sex and age into two groups (<12 months and 12–59 months), as categorized by the $DHIS_2$, and location of the health facility (urban and rural area). We were granted access to diarrhoea data through the District Data Manager of Mbour.

Monthly climatic data were obtained from readily available remote sensing data sources. In particular, we extracted day and night land surface temperature (LST_{Day} and LST_{Night}) as a proxy of minimum/maximum air surface temperature from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite, and rainfall estimate (RFE) from the Africa Data Dissemination Service, covering the period 2011 to 2014. We validated these remote sensing data using an exploratory analysis provided as a supplementary file (Figure S1). We compared satellite data extracted from the health facility location that is closer to the single meteorological station present in our study area. The results showed that estimated LST_{Day}, LST_{Night} and RFE were quite consistent and have similar pattern with the observed ground data from the meteorological station of Mbour.

Table 1. Health data and remote sensing data sources, including reporting period and spatial resolution.

Data Source	Type	Period	Spatial Resolution
	Health Data		
$DHIS_2$	Number of visit to a health facility due to diarrhoea	1/2011–12/2014	
	Climatic Variables		
MODIS	LST_{Day}	1/2011–12/2014	1 × 1 km
MODIS	LST_{Night}	1/2011–12/2014	1 × 1 km
USGS/Decadal RFE	RFE	1/2011–12/2014	80 × 80 km
SRTM-Altitude	-	-	90 × 90 m

$DHIS_2$, District Health Information System of the Ministry of Health of Senegal; LST, land surface temperature; MODIS, Moderate Resolution Imaging Spectroradiometer (http://modis.gsfc.nasa.gov); SRTM-Altitude, Shuttle Radar Topography Mission (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1); USGS/RFE, United States Geographical Survey/Rainfall estimates (http://earlywarning.usgs.gov).

2.4. Statistical Analysis

We analysed monthly health and climatic data from 24 health facilities (15 in urban and nine in rural settings) in the health district of Mbour for the period 2011–2014. A short-term time series analysis approach was first used to assess the seasonal pattern of diarrhoea and, secondly, to explore the association between diarrhoea and climatic variables. Several steps were involved in analysing the data in order to addresses our study objectives.

In a first step, a descriptive analysis was conducted to explore seasonal patterns of the climatic data and the number of diarrhoeal cases over time, as shown in Table 2. The proportions of diarrhoeal cases, means and standard deviations of climatic variables were compared across three seasons and by setting (urban vs. rural) according to a locally used seasonal calendar in Senegal, as shown in Table 1. Secondly, raw plots of mean monthly climate factors and monthly counts of diarrhoeal cases per health facility were generated and superimposed in order to visually check the seasonal pattern of climate-diarrhoea association over the four-year study period. Thirdly, to estimate effects of climatic parameters on monthly incidence of diarrhoea, we developed negative binomial regression models for monthly counts of diarrhoeal cases by health facility. These models included fixed intercepts for the different health facilities, for the calendar years and terms for seasonality, and they provided estimates of the incidence rate ratios (IRR) associated with the different predictor variables studied. To remove serial correlation of residuals, we added the lag 1 Pearson residual as further covariate to the model [26]. We conducted preliminary analyses to verify whether the climate–diarrhoea association was influenced by specifying climatic variables through different ways. We performed two separate models; one with continuous climatic variables and another one with categorical climatic variables to examine associations with diarrhoeal incidence.

Climatic variables such as LST, LST_{Day} and LST_{Night} were categorized into four groups defined by the quartiles of their values and indicating low, moderate, high and very high levels. Cumulative monthly rainfall was categorized into the following classes: $\leq$12 mm, 12–56 mm and $\geq$57 mm. Modification of the association between climatic variables and diarrhoea by location was evaluated, stratifying regression analyses between urban and rural areas. The quality of model fit was assessed based on the Akaike information criterion (AIC).

Negative binomial regression analyses were conducted separately in urban and rural areas and in both settings combined. All models were adjusted by using the number of under 5-year-old children outpatient of a given month as an offset. Moreover, they contained a calendar years trend, an indicator variable for type of setting (urban vs. rural) as well as terms describing seasonality. Seasonal patterns were described in two ways: (i) by considering three categories indicating cold dry season, hot dry season and rainy season, and (ii) by considering a cosine function: $f(t) = \alpha \sin(2\pi t/12) + \beta \cos(2\pi t/12)$ where t is time measured in months. In addition to the values of temperature and rainfall of the same month, we also included the respective value of the preceding month to account for potential delays in the effect of temperature and rainfall on diarrhoeal incidence [6,27–30]. The reason for lagged climatic variables is to assess the sensitivity of diarrhoeal incidence to the potential delayed impact of weather event, as we expected diarrhoeal incidence to respond quickly to changes in rainfall and temperature due to the ubiquitous presence of bacteria [6]. Delayed effects are likely to be of lesser important for diarrhoea than, for example, malaria. Results are reported as IRR with 95% confidence intervals (CI) indicating the estimated relative change in incidence per unit increment in the respective predictor variable. All analyses were performed using Stata version 13.0 (Stata Corporation, College Station, TX, USA).

3. Results

3.1. Descriptive Analysis of Diarrhoeal Incidence and Climatic Data

A total of 111,302 child-visits were recorded in the 24 health facilities in the health district of Mbour in the four-year study period. The predominant cause for children under the age of five years visiting a health facility was acute respiratory infections (35,385 visits, 32.0%). Diarrhoea was the second most important cause for visiting a health facility (23,543 visits, 21.1%). Diarrhoeal cases ranged from 0 to 1306 cases with a mean of 20 cases per month. More than half of the cases (53.4%) were male. More than two-thirds of the cases were in the age group range of 12–59 months (69.1%). The incidence of diarrhoeal cases was higher in urban compared to rural settings (24.4% vs. 19.9%). The plots of monthly number of diarrhoeal cases indicated that diarrhoea peaked at the beginning of the year and after the mid-part of the year. The monthly average LST was 20.1 °C with monthly mean LST_{Day} of 32.6 °C (standard deviation (SD) 5.6 °C) and monthly mean LST_{Night} of 19.5 °C (SD 2.5 °C). A quarter (25.0%) of monthly observations had an LST_{Day} of 36 °C and above. The mean monthly cumulative rainfall was 14.8 mm (SD 28.5 mm) and 75.0% of the observations recorded less than 12 mm, whereas 10.0% of observations recorded more than 57 mm (Table 2).

Table 2. Study parameters summarized for both areas combined (U/R), urban (U) and rural (R) in the health district of Mbour, Senegal and seasonal calendars extracted for the study period 2011–2014.

Climatic Variables * (Mean ± SD)		Cold Dry Season (December–March)	Hot Dry Season (April–June and November)	Rainy Season (July–October)	Overall
Monthly mean temperature					
LST_{Day} (°C)	U/R	32.49 ± 3.89	29.78 ± 4.98	34.57 ± 5.71	32.64 ± 5.64
	Urban	32.45 ± 3.72	28.98 ± 4.26	33.89 ± 5.15	31.82 ± 4.87
	Rural	33.65 ± 5.18	31.11 ± 5.76	36.99 ± 7.07	33.97 ± 6.50
LST_{Night} (°C)	U/R	19.44 ± 2.79	20.62 ± 2.21	18.66 ± 0.98	19.59 ± 2.51
	Urban	19.84 ± 2.88	20.58 ± 1.89	18.64 ± 0.79	19.68 ± 2.19
	Rural	18.65 ± 3.38	20.70 ± 2.64	19.01 ± 2.28	19.45 ± 2.94
Average LST	U/R	26.15 ± 2.66	25.20 ± 2.52	26.93 ± 3.27	26.11 ± 2.92
	Urban	26.15 ± 2.43	24.77 ± 1.95	26.27 ± 2.60	25.74 ± 2.43
	Rural	26.16 ± 3.00	25.91 ± 3.13	28.00 ± 3.91	26.70 ± 3.49
Difference mean LST_{Day} and LST_{Night}	U/R	13.54 ± 5.45	9.17 ± 5.86	16.29 ± 6.11	13.06 ± 6.50
	Urban	12.62 ± 4.56	8.42 ± 5.33	15.26 ± 5.21	12.15 ± 5.76
	Rural	15.00 ± 6.37	10.39 ± 6.48	17.98 ± 7.03	14.54 ± 7.30
Cumulative rainfall (mm)	U/R	1.00 ± 7.89	2.75 ± 6.62	37.30 ± 34.57	14.80 ± 28.51
	Urban	0.60 ± 4.35	1.78 ± 3.91	41.75 ± 36.81	14.71 ± 28.78
	Rural	1.52 ± 8.52	2.99 ± 8.11	40.42 ± 35.42	14.98 ± 28.05
Diarrhoea proportion (%)					
Proportion of diarrhoeal cases in outpatient children	U/R	30.67	15.11	18.49	21.10
	Urban	30.50	14.98	19.19	21.41
	Rural	31.46	15.72	15.40	19.95

* Monthly mean LST_{Day}, LST_{Night}, LST, difference LST and cumulative rainfall per health facility are presented; Urban = health facilities located in urban area; Rural = health facilities located in rural area; U/R = both areas combined; SD = standard deviation.

3.2. Seasonal Patterns of Diarrhoeal Incidence in Urban and Rural Mbour

Figure 3 shows the seasonal patterns of the mean numbers of diarrhoeal cases per month and facility from January 2011 to December 2014 in urban and rural settings of Mbour. A consistent pattern of seasonality in diarrhoeal incidence among children under the age of five years was observed in both areas.

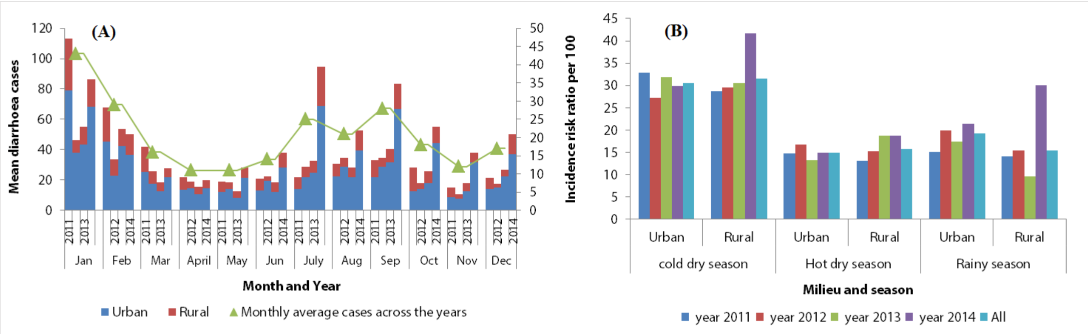


Figure 3. Distribution of mean monthly count of diarrhoeal cases per health facility in urban and rural settings in the health district of Mbour, Senegal over a four-year study period from 2011 to 2014. (**A**) Distribution of mean monthly diarrhoeal cases per health facility, by year, over the study period 2011–2014. (**B**) Distribution of diarrhoeal incidence (number of cases/population at risk times 100) across health facilities in urban and rural settings, and combined in Mbour over the three seasons.

There were two relative peaks in the number of diarrhoeal cases, as shown in Table 3 and Figure 3; one in the cold dry season with 42.7% of the reported diarrhoeal cases (10,048 cases), corresponding to the lowest mean temperature and lowest amount of rainfall; and another one in the rainy season, characterized by relatively warm temperature with 37.8% of the reported diarrhoeal cases (n = 8913). Throughout the study period, the burden of diarrhoeal disease was highest during the cold dry season with an average proportion of 30.5%. There was a corresponding trend in the rainy season with an average proportion of 17.9%. In the cold dry season, diarrhoeal cases were most likely to occur in January (17.6% of the cases) and February (11.8% of the cases) for the entire four-year period.

Table 3. Seasonal distribution of diarrhoeal cases for the period 2011–2014 in the health district of Mbour, Senegal.

Seasonal Calendar	Number of Diarrhoeal Case Visits	Percent (%)
Cold dry season (December–March)	10,048	42.7
Hot dry season (April–June and November)	4582	19.5
Rainy season (July–October)	8913	37.8
Overall	23,534	100.0

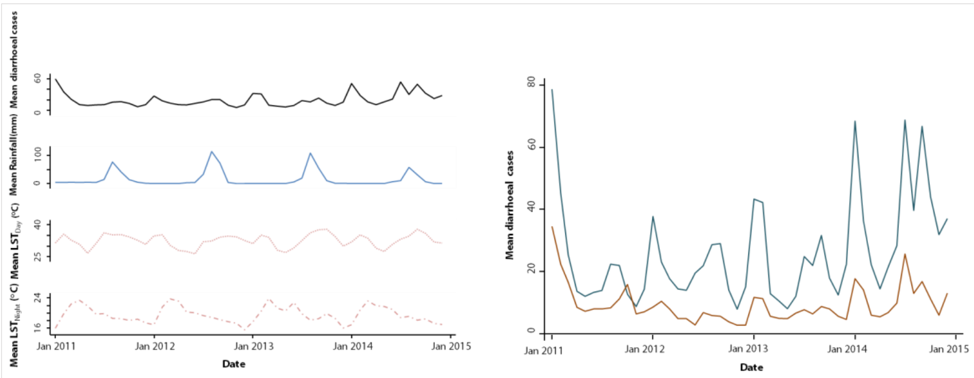
Table 4 and Figure 4 show that the numbers of diarrhoeal cases in rural settings were approximately five times lower than in urban settings (3895 vs. 19,648 cases). In 2014, an increase in the number of diarrhoeal cases was observed in the rural settings, both in the cold and rainy seasons, while this increase was only seen in the rainy season in the urban settings (Figure 4B). The overall incidence rate in both areas combined showed a significant difference by season ($p < 0.001$), age ($p < 0.024$) and sex ($p < 0.001$). Moreover, we observed a positive time trend in diarrhoeal cases.

Diarrhoeal incidence was found to be considerably higher in the cold dry season and in the rainy season (IRR: 2.03; 95% CI: 1.79–2.31; IRR: 1.84; 95% CI: 1.62–2.09, respectively), as illustrated in Table 5. In these two seasons, the risk of diarrhoea among children under the age of five years was higher compared to the hot dry season.

Table 4. Number of diarrhoeal cases and population at-risk among children under the age of five years per year extracted for the study period 2011–2014.

Year	Urban		Rural		Overall	
	Cases	Pop. At-Risk +	Cases	Pop. At-Risk +	Cases	Pop. At-Risk +
2011	3947	14,053	1531	6511	5478	20,564
2012	3880	14,391	528	2181	4408	16,572
2013	4154	15,915	679	4186	4833	20,101
2014	7667	27,767	1157	2755	8824	30,522
Overall	19,648	72,126	3895	15,633	23,543	87,759

Urban = health facilities located in urban area; Rural = health facilities located in urban area; + The population at-risk as well as the number of cases was high in the last year of observation compared to the three earlier years based on the data received from the $DHIS_2$.



(**A**) (**B**)

Figure 4. Trend in mean monthly mean diarrhoeal cases per health facility and climatic factors in the health district of Mbour over a four-year period from 2011 to 2014. (**A**) Trend in monthly mean diarrhoeal cases per health facility with mean rainfall, mean LST_{Day} and LST_{Night}; (**B**) Trend in mean monthly diarrhoeal cases per health facility in urban and rural settings.

Table 5. Effect of season on the number of visits of health care centred due to diarrhoea in the health district of Mbour, Senegal from 2011–2014.

Areas	Cold Dry Season		Rainy Season	
	IRR (95% CI)	*p*-Value	IRR (95% CI)	*p*-Value
Both areas combined	2.03 (1.79–2.31)	<0.001	1.84 (1.62–2.09)	<0.001
Urban	2.07 (1.80–2.37)	<0.001	1.91 (1.67–2.20)	<0.001
Rural	1.98 (1.50–2.632)	<0.001	1.70 (1.29–2.24)	<0.001

IRR: Incidence-rate ratio; 95% CI: Confidence interval, adjusted for clustering at the level of health facility.

3.3. Association between Diarrhoea and Climatic Factors

The results of the unadjusted regression models are provided as a supplementary file (Table S1). The unadjusted analysis revealed significant positive associations between diarrhoeal cases and LST_{Day}, average LST, LST variability and moderate rainfall in the same month (lag 0). It was found that a very high $LST_{Day} \geq 36$ °C, average LST ≥ 28 °C and high LST variability ≥ 12 °C were significantly associated with higher number of monthly diarrhoeal cases (+25–95%), while moderate (13–56 mm) rainfall was associated with a somewhat higher number of diarrhoea (+18%). The unadjusted analysis revealed that moderate LST_{Night} at lag 0 showed a significant positive association with diarrhoeal incidence.

The results from the lagged models showed a significant negative associations between diarrhoeal incidence and high average LST ≥ 26 °C (IRR: 0.70, 95% CI: 0.58–0.86) and $LST_{Night} \geq 18$ °C at one-month lag. High LST variability and high rainfall were also significantly positively associated with diarrhoeal incidence at one-month lag (IRR: 1.42, 95% CI: 1.16–1.75; IRR: 1.21, 95% CI: 1.01–1.45, respectively). In the multivariable analysis, association of diarrhoeal incidence with higher levels of LST_{Day}, LST_{Night} and average LST of the same month (Table 6 and Table S2, respectively) were positive, while we did not find any evidence of an association. High $LST_{Day} \geq 32$ °C and high LST ≥ 26 °C showed a significant negative association with diarrhoeal incidence of the following month (IRR: 0.78, 95% CI: 0.66–0.91; IRR: 0.76, 95% CI: 0.66–0.87, respectively).The corresponding results for LST_{Night} were even stronger. Compared to the lowest level, all other levels of LST_{Night} were associated with significantly lower diarrhoeal incidence in the following month. Moderate and high rainfall showed a significant positive association with diarrhoeal incidence in the same month (IRR: 1.23, 95% CI: 1.08–1.42; IRR: 1.34, 95% CI: 1.16–1.56, respectively).

Table 6. Results from the multivariate negative binomial regression models with climatic variables of the same and the preceding month, in the health district of Mbour, Senegal (January 2011–December 2014).

Adjusted Model			
Parameter		**IRR (95% CI)**	***p*-Value**
Residual lag 1		1.04 (1.03–1.06)	<0.001
Areas			
	Rural	Ref.	
	Urban	1.53 (1.18–1.99)	<0.001
Season			
	Hot dry season	Ref.	
	Cold dry season	1.73 (1.55–1.92)	<0.001
	Rainy season	1.05 (0.90–1.22)	0.525
Mean LST_{Day} (°C)			
Lag 0	Low	Ref.	
	Moderate	1.02 (0.91–1.14)	0.734
	High	1.00 (0.87–1.16)	0.962
	Very high	1.00 (0.85–1.19)	0.968
Lag 1	Low	Ref.	
	Moderate	0.98 (0.88–1.10)	0.795
	High	0.87 (0.76–0.99)	0.043
	Very high	0.78 (0.66–0.91)	0.002
Mean LST_{Night} (°C)			
Lag 0	Low	Ref.	
	Moderate	1.13 (1.02–1.25)	0.014
	High	1.05 (0.94–1.17)	0.388
	Very high	1.11 (0.98–1.25)	0.089
Lag 1	Low	Ref.	
	Moderate	0.78 (0.71–0.87)	<0.001
	High	0.77 (0.69–0.87)	<0.001
	Very high	0.78 (0.68–0.91)	<0.001
Mean cumulative rainfall (mm)			
Lag 0	Low	Ref.	
	Moderate	1.23 (1.08–1.42)	0.003
	High	1.34 (1.16–1.56)	<0.001
lag 1	Low	Ref.	
	Moderate	1.03 (0.89–1.18)	0.716
	High	0.90 (0.77–1.05)	0.169
Annual trend			
	2011	Ref.	
	2012	1.21 (1.09–1.34)	<0.001
	2013	1.26 (1.14–1.39)	<0.001
	2014	1.38 (1.25–1.53)	<0.001

IRR: Incidence rate ratio; LST: Land surface temperature. Rainfall—low (≤12 mm), moderate (13–56 mm), high (≥57 mm); LST_{Day}—low (<27 °C), moderate (27–32 °C), high (32–36 °C), very high (≥36 °C); LST_{Night}—low (<18 °C), moderate (18–19 °C), high (19–21 °C), very high (≥21 °C); In this table, monthly mean LST_{Day}, LST_{Night} and mean monthly cumulative rainfall in the same month (lag 0) and the previous month (lag 1) are presented. In addition to the variables presented, the model also included health facility and type of setting (i.e., urban vs. rural) as fixed factors and the lag 1 Pearson residual as further covariate.

We conducted a separate analysis to determine whether the relationship between diarrhoeal incidence and climatic factors differed in urban and rural settings (Tables S3 and S4). We found that in both settings, diarrhoeal incidence was positively associated with average LST $\geq$ 24 °C in the current month but not statistically significant when controlled for others variables; whereas in urban settings, a significant negative association was found between diarrhoeal incidence and average high levels of LST in the previous month (IRR: 0.79; 95% CI: 0.70–0.89; IRR: 0.73; 95% CI: 0.63–0.85) (Tables S3 and S4). We also found that high rainfall had a significant positive effect on diarrhoeal incidence in urban areas at lag 0 (IRR: 1.31; 95% CI: 1.12–1.54), while we found no such association in the rural setting. This suggests that the effect of climatic factors on diarrhoeal incidence differ between urban and rural settings in the health district of Mbour.

4. Discussion

To our knowledge, this is the first study using a time-series approach to quantify the association between diarrhoeal incidence in children under five years of age and climatic factors in an entire health district of Senegal. Health-related data were readily available from the $DHIS_2$ for the four-year study period commencing in January 2011, while remotely sensed climatic data were obtained for the same time period from various data sources. Our study allowed examining the seasonal patterns of diarrhoeal incidence in the health district of Mbour.

We found two annual peaks in diarrhoeal incidence; a first peak occurred during the cold dry season (December–March), while a second peak was observed in the rainy season (July–October). The high number of diarrhoeal cases in the cold dry season is consistent with previous studies in Senegal [31,32]. Indeed, prior work in Senegal revealed that the cold dry season offers conditions that favour the rapid spread of pathogens or viruses causing diarrhoea [31,33]. Our findings are also in line with observations made in neighbouring Guinea Bissau [9] and Burkina Faso [34]. Viral infections causing diarrhoea were identified in previous studies during the cold dry season in children under the age of five years across large parts of sub-Saharan Africa, including Senegal [31,35–40]. These prior studies have reported prevalence rates due to rotavirus ranging from 18% to 41%. Importantly, rotaviral infections show the seasonal patterns in tropical climates [41,42]. Rotavirus is often the predominant aetiology of diarrhoea in infants and young children [43], with particularly high yields of isolation during the cooler months [44,45]. Although this may be an important explanation for the observed higher incidence of diarrhoeal illness during the cool dry season, the present study has not specifically investigated this association.

The second peak coincided with the rainy season and generally high temperatures, which mirrors the seasonal pattern of bacterial enteric infections [31]. We therefore speculate that during the rainy season, from July to October, the high number of diarrhoeal of infections might be driven by bacterial infection [31,34,38]. In Mbour, the rainy season includes the warmest months of the year, often coupled with floods, like in other parts of Senegal. The floods are partially explained by a poor drainage system. As a result, there is enhanced human contact with wastewater, which has been associated with cholera outbreaks [33]. Hence, it is conceivable that a large number of diarrhoeal cases during the rainy season results from an increased exposure to environmental pathogens and contaminated food due to high temperatures associated with accelerated bacterial growth [45]. However, there might be other reasons explaining the high rates of diarrhoea in these two seasons not investigated in the current study.

We found consistent diarrhoea seasonality in children under the age of five years in both urban and rural settings of Mbour, which calls for interventions and mitigation strategies of specific times of the year. The generally higher number of diarrhoeal cases found in the urban compared to rural settings, might be explained by overcrowding and lack of timely access to quality health care services.

The study revealed that, apart from seasonality, independent effects of temperature and rainfall were also associated with diarrhoeal incidence. Previous studies already reported positive associations between diarrhoeal incidence and temperature; indeed, an increase of temperature in the short-term (monthly or weekly) was associated with an increased risk of diarrhoea [6,46–48]. As reported in a prior study, pathogens causing diarrhoeal diseases respond differently to temperature variability [49]. The effect of high temperature on diarrhoeal incidence of the same month observed in the health district of Mbour may result from many factors. For instance, high temperature may lead to increased exposure to bacteria, parasites and other agents causing diarrhoea, implying that gastrointestinal diseases are more likely to occur during the hottest months of the year [14,50]. The associations of monthly temperatures (LST_{Day}, LST_{Night}, LST and LST variability) with diarrhoea incidence of the following month in the health district of Mbour were negative in the multivariate analyses. This suggests that the incubation period of the causative pathogen agent was shorter than one month.

Furthermore, our results from the multivariate analysis indicated that monthly mean cumulative rainfall has a positive effect on diarrhoeal incidence in the same month. Studies on the association between the risk of diarrhoea and rainfall have found contradictory results. In some cases, studies indicated that rainfall increases the risk of diarrhoea, which is in line with our observations [18,51,52]. Our findings are consistent with the results of Bandyopadhya et al., who found that rainfall and the prevalence of diarrhoea were positively associated across sub-Saharan Africa [6]. Other studies observed no association between rainfall and diarrhoea risk [16,19,53], even though a US study found that any rainfall four days prior was significantly associated with an 11% increase in acute gastrointestinal illness [54]. The positive association we found between diarrhoea and rainfall in the health district of Mbour could be explained by the fact that high rainfall can directly affect the transport of pathogens, and can affect the existing water and sanitation infrastructure, altering human exposure patterns [55]. The transport of pathogens resulting from heavy rainfall occurs in different ways. For example, if pathogens from animal or human excreta are present in soils and on environmental surface, rainfall can mobilize theses pathogens and transport them to surface water, exposing people to pathogens [56].

Our results showed that the effect of temperature (average LST) on diarrhoeal incidence was higher in rural compared to urban settings in the health district of Mbour but the difference was not statistically significant. In contrast, high rainfall was associated with a 31% increased risk of diarrhoea in urban settings, while there was no such association in rural settings. The reason why rainfall is a risk factor for diarrhoea in the urban setting may be due to higher levels of faecal contamination with higher exposure during the rainy season due to inexistent or unimproved sanitation system. Furthermore, in urban settings, the effects of overcrowding on diarrhoea may be exacerbated by high temperature associated with lower water availability for hygiene and sanitation. In the rural settings, high temperatures were associated with increased diarrhoeal risk, while rainfall showed no association. The negative association of LST_{Day} and average LST with diarrhoeal incidence of the following month observed in the urban settings is consistent with rotavirus seasonality studies [41].

This study provides evidence that the influence of temperature on diarrhoeal risk is more pronounced in rural than in urban settings, and rainfall is more likely to increase diarrhoeal risk in urban settings of Mbour. This may be explained by the interaction between climatic factors and differences in hygiene behaviour and sanitation status in urban and rural settings. The identification of climatic factors associated with diarrhoeal seasonality in this study sheds new light on the possible role of climatic variability in the occurrence of diarrhoea. Further, the potential factors of diarrhoeal seasonality we identified will facilitate future studies assessing the impact of social and economic development on diarrhoeal diseases in Senegal.

Several limitations should be acknowledged in this study. Firstly, our analysis relies on diagnosed diarrhoeal cases at health facilities, which, we assume, were mostly moderate or severe cases. Mild diarrhoeal episodes were more likely to go unreported. It follows that the trends reported here are only applicable to moderate and severe diarrhoeal cases. Secondly, our diagnostic work-up did not allow specific diagnosis of the pathogenic agents, which restrict us to examine the seasonality of specific pathogens, which might be necessary for future vaccine programmes. Given this shortcoming, we could not specifically analyse the association between climatic factors and the causative agents of diarrhoea. Characterizing the role of climatic factors in diarrhoeal risk is challenging due to a general lack of pathogen-specific diagnoses, with "all-causes" diarrhoeal data reflecting a combination of viral, parasitic and bacterial pathogens, which vary in transmission dynamics and sensitivities to environmental conditions [57]. With the mentioned limitations, the main strength of the current study is the use of an existing dataset (surveillance data) collected at 24 health facilities, coupled with remotely sensed climate data specific for health facility levels to assess the association between diarrhoeal diseases and climatic factors for a four-year period.

5. Conclusions

We found a seasonal fluctuation of diarrhoeal incidence in Mbour, western Senegal, characterized by a significant positive association of diarrhoeal incidence with rainfall and LST_{Night} in the same month among children under the age of five years, and a negative association between diarrhoeal risk and temperatures of the preceding month. We also found that diarrhoea is more associated with temperature in rural than in urban settings; while rainfall had no effect on diarrhoeal risk in the rural settings. Future studies should deepen our understanding of the association between diarrhoea and climatic factors, which is one of the main contributors to child mortality and morbidity in Senegal. Such knowledge will guide prevention and can lead programmes against diarrhoea. Our study indeed indicates that there is a need for effective preventive measures to reduce the high burden of diarrhoea in the health district of Mbour. Health intervention programmes in the cold dry season and in the rainy season focusing on morbidity control and prevention should be launched, particularly in urban settings where diarrhoea is most common, in order to reduce the incidence of diarrhoea in this context of climatic variability. We recommend that future studies should integrate detailed behavioural, climatic and socioeconomic factors, including relative humidity, access to water and sanitation, and more detailed surveillance data, including individual child data on diarrhoeal causation agents in order to improve the accuracy of predicting diarrhoeal morbidity in space and time. These factors should be included in the models to better explain the peak and trends in diarrhoeal occurrence as observed in Mbour.

Supplementary Materials: The following are available online at www.mdpi.com/1660-4601/14/9/1049/s1, Figure S1: Comparison of satellite remote sensing data of monthly temperatures and rainfall extracted at the health facility location closest to the meteorological station with measured data from this station; Table S1: Results from the unadjusted negative binomial regression models with climatic variables of the same and the preceding month, in the health district of Mbour, Senegal (January 2011–December 2014); Table S2: Results from the adjusted negative binomial regression model with climatic variables of the same and preceding month, in the health district of Mbour, Senegal (January 2011–December 2014); Table S3: Results from the adjusted negative binomial regression model with climatic variables of the same and preceding month, in urban areas of district of Mbour, Senegal (January 2011–December 2014); Table S4: Results from the adjusted negative binomial regression model with climatic variables of the same and preceding month, in rural areas of the health district of Mbour, Senegal (January 2011–December 2014).

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9. ARTICLE 4: Spatial patterns of diarrhoea among children under five: assessing the effects of sociodemographic and climatic factors using Bayesian CAR model

Sokhna Thiam[1,2], Aminata Niang-Diène[3], Christian Schindler[1,2], Anna-Sofie Stensgaard[4,5], Jürg Utzinger[1,2], Guéladio Cissé[1,2], Penelope Vounatsou[1,2]

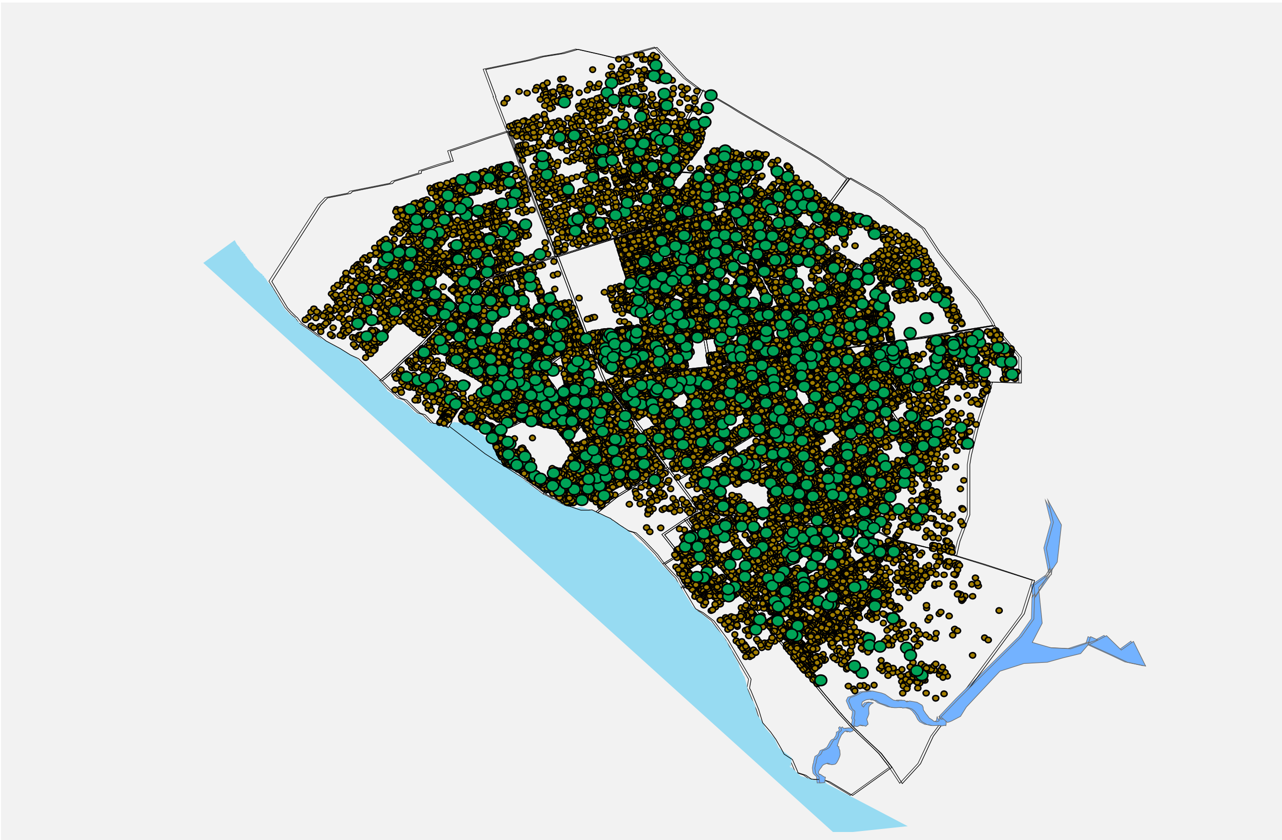
[1]Swiss Tropical and Public Health Institute, Basel, Switzerland

[2]University of Basel, Basel, Switzerland

[3]Department of geography, University Cheikh Anta Diop de Dakar, Senegal

[4]University of Copenhagen, Copenhagen, Denmark

[5]Center for Macroecology, Evolution and Climate, Copenhagen, Denmark



Map: All and surveyed household location (green) in Mbour, Senegal (©S. Thiam, 2016)

This article is a working paper

Spatial patterns of diarrhoea risk among children under five: assessing the effects of sociodemographic and climatic factors using Bayesian CAR model

Sokhna Thiam[1,2], Aminata Niang-Diène[3], Christian Schindler[1,2], Anna-Sofie Stensgaard[4,5], Jürg Utzinger[1,2], Guéladio Cissé[1,2,], Penelope Vounatsou[1,2]

[1]Swiss Tropical and Public Health Institute, Basel, Switzerland; [2]University of Basel, Basel, Switzerland; [3]Department of geography, University Cheikh Anta Diop de Dakar, Dakar; [4]University of Copenhagen, Copenhagen, Denmark; [5]Center for Macroecology, Evolution and Climate, Copenhagen, Denmark

Abstract

Background/objectives: Diarrhoeal disease remains a major public health menace causing for more than half a million children die every year globally. Nearly half of this diarrhoeal burden is borne by Asia and Africa, including Senegal. However, there is knowledge on the aetiologies and causes, but little is known about its spatial patterns in low- and middle-income countries like Senegal. In the present study, data from a cross-sectional study carried out in 2016 were analysed to describe the spatial pattern of diarrhoeal prevalence in children under the age of 5 years in Mbour, and assess the effect of sociodemographic/economic and climatic factors on distribution of diarrhoea prevalence.

Materials and methods: Bayesian conditional regressive (CAR) model with spatially varying coefficients were used to determine the effect of sociodemographic/economic and climatic factors on diarrhoeal prevalence.

Results: The findings highlighted substantial spatial heterogeneities in diarrhoea prevalence. The stratified maps by age group showed that diarrhoeal prevalence was higher in the age group 25 to 59 months, which were more prevailed in the north and south peripheral neighbourhoods, especially in Grand Mbour, Médine, Liberté and Zone Sonatel. The posterior relative risk estimate obtained from the Bayesian CAR model indicated that a unit increase in the proportion of people with untreated stored drinking water increased diarrhoea risk by 29%. A unit increase in rainfall was also found to increase diarrhoea risk.

Conclusion: The findings suggest that public health officials should integrate disease mapping and cluster analyses and consider the varying effects of socio-demographic factors in developing and implementing area-specific interventions for reducing diarrhoea.

Keywords: Diarrhoea; Spatial pattern; Bayesian CAR; relative risk; Mbour; Senegal

1.1 Introduction

Diarrhoea is an ongoing important health problem globally, associated with high childhood mortality and morbidity (GBD 2015 Child Mortality Collaborators, 2016; GBD, 2017). In 2015, diarrhoea caused more than 1.3 million deaths globally and was the second leading infectious cause of death among children under five years, only second lower respiratory infections (Liu et al., 2015; GBD 2015, 2016). The Global Burden of Diseases (diarrhoeal diseases collaborators), estimated that in 2015, 449,000 children under the age of five years deaths died due to diarrhoea (95% uncertainty range 447,000-558,000), although, the number of deaths due to diarrhoea decreased by an estimated 20.8% (95% uncertainty range 15.4-26.1) from 2005 to 2015, morbidity, however, has declined moderately (Fischer Walker et al., 2012; GBD, 2017). Most of those deaths were in LMICs, particularly in sub-Saharan Africa with 54%. There are nearly 1.7 billion episodes of diarrhoea globally every year (Walker et al., 2013; WHO, 2017a). Most of diarrhoea-related deaths are attributable to unsafe water, inadequate sanitation, and insufficient hygiene (Black et al., 2003; GBD, 2017). WHO estimated that 58% of all cases of diarrhoea in Low-and Middle-Income Countries (LMICs) could be attributed to inadequate drinking-water (34%), sanitation (19%) and hygiene (20%) (Prüss-Üstun et al., 2014).

In Senegal, diarrhoeal diseases continue to cause significant mortality and morbidity. The highest burdens in terms of Disability-Adjusted Life Years (DALYs) among children under the age of five years were and still caused by diarrhoeal diseases. Even the burden of diarrhoeal diseases decreased by 6% between 1990 and 2016 in the country, it is still responsible for 7% of all child deaths and 325,335 DALYs (13,776 DALYs per 100,000 children under 5 years) (GBD 2015 DALYs and HALE collaborators, 2016; Institute for Health Metrics Evalutation., 2016). This high burden of diarrhoea occurs despite improvement in access to drinking water and sanitation. Previous studies in Senegal have mainly focused either on the clinical features of diarrhoea in single geographic units (Sire et al., 2013; Sambe-Ba et al., 2013). Hence, a knowledge gap with respect to the spatial patterns of diarrhoea still remains, because these studies are unable to identify the existing areas of priority for intervention. No previous investigation of the spatial patterns of diarrhoea has been carried out in Senegal, and particularly in Mbour. Diarrhoea morbidity varies across geographical areas; some areas are likely to sustain high morbidity over time due to unplanned rapid urbanization; and no improvement on the existing amenities (i.e. safe water source and good sanitation) which do not meet the demands of the rising population (Osei and Stein, 2017a).

It is therefore crucial to identify areas with high risk of diarrhoea, as it is important to assist decision makers to prioritize interventions and monitor progress. And also due to the fact that children are the most vulnerable group to suffer from diarrhoea, information on diarrhoea and age specific patterns will be a crucial step towards achieving the Sustainable Development Goal 3 ensuring healthy lives and promotes wellbeing for all at all age. This paper aims to map the spatial pattern of diarrhoeal prevalence at neighbourhood level, and assess the effect of sociodemographic/economic and climatic factors on diarrhoea morbidity in children under the age of 5 years in Mbour, Senegal

1.2 Methods

Ethical approval

An interview was conducted only if the respondent provided their consent in response to being read and the informed consent statement by the reviewer. A verbal informed consent was collected by the interviewer after reading a prescribed statement to the respondent and recording in the questionnaire whether or not the respondent consented or assent was provided. The interviewer signed his or her name attesting to the fact that he/she read the consent statement to the respondent.

Study areas and survey data

The study was conducted in the secondary city of Mbour located in the south-western part of Senegal. The city consists of 25 neighbourhoods. A cross-sectional survey was carried out in the entire 25 neighbourhoods between September and October 2016. The outcome of interest was diarrhoeal disease case report among children under the age of five years in the sampled household. As diarrhoea transmission is known to be influenced by several factors, including water, sanitation and hygiene (WASH), climatic, and socio-economic and demographic factor, we obtained socio-demographic and economic and socio-environmental covariate variables from the survey questionnaire. We constructed for socio-demographic variables as risk factors of diarrhoea, namely, unsafe drinking water source (*udws*), untreated stored drinking water (*usdw*), unsafe liquid waste disposal (*ulwd*), and unsafe solid waste disposal (*usw*). We estimated the socio-environmental variables as follows: (i) *udws* as the proportion of the neighbourhood's surveyed household who do not have access to pipe-borne water (either in dwellings, outside dwellings, or public standpipes); (ii) *utsdw* as the proportion of the neighbourhood's surveyed household who do not treat their stored drinking water; (iii) *ulwd* as the proportion of the neighbourhood's surveyed households who dispose liquid waste in the street and (iv)- *uswd* as the proportion of the neighbourhood's surveyed household who do not have waste bin. Socio-economic status variable was also derived from Principal Component Analysis (PCA) as a weighted sum of household assets. Socio-economic status values were included in the analysis as continuous covariates.

Climatic data

Climatic covariates were obtained from remote sensing sources. The acquired climatic factors used in the analysis namely, day and night temperature and altitude covering the survey period i.e. September and October 2016 were extracted at neighbourhood level from the Moderate Resolution Imaging Spectroradiometer (MODIS) database, and rainfall data for the same period was download from the Africa Data Dissemination Service database. Climatic covariates were included in the analysis as continuous covariates. The data are aggregated per neighbourhood units and the geographical scale of the analyses considered the entire 25 neighbourhoods of the city

Bayesian conditional autoregressive (CAR) modelling

First, a preliminary binomial logistic regression of diarrhoea cases was performed to select covariates. Four climatic variables were included as covariates namely day and night temperature, rainfall and altitude. Four sociodemographic and socioeconomic variables were also included as covariates. Second, we fitted three separate logistic regression models to estimate the effect of sociodemographic/economic and climatic factors on diarrhoea morbidity in children under the age of 5 years in Mbour using a Bayesian framework. The first model included only climatic covariates; the second model included socio-demographic/economic covariates, whereas the third model contained all the components of the two preceding model and a spatially structured random effect. The third model assessed the effects of climatic and socio-demographic/economic factors at neighbourhood level using spatially varying effect. The spatially structured random effect was formulated assuming a CAR model prior distribution (Cressie, 2015; Ssempiira et al., 2017), which introduces a neighbours-based spatial structure random effect for the regression coefficients (Bivand et al., 2013).
To adjust for spatial correlation present in diarrhoea data due to similar exposure effect in neighbouring areas, cluster-specific random effects were added to each model to account for unknown or unmeasured risk factors by introducing an extra source of variability into the model. This was used to generate spatial weights matrix, which assigned value one to areas that shares border and zero if they do not share.

The third model assumed that Y_{ij} is a binary outcome taking value 1 or 0 if a child *i* at neighbourhood s_j had diarrhoea in the 2 weeks prior to the survey. Y_{ij} is assumed to follow a Bernoulli distribution $Y_{ij} \sim Bn$ (N_{ij}, P_{ij}) and is related to its predictors using a logistic regression model as follows:

$$logit(p_{ij}) = \beta_0 + \sum_{k=1}^{k} \beta_k X_{ij}^k + \emptyset_j + \omega_i$$

Where p_{ij} is the diarrhoea case *at* neighbourhood i, s_j of having diarrhoea (is an offset to control for population size), and $\beta = (\beta_0, \beta_1, \ldots, \beta_k)$ is the vector of k regression coefficients. Spatial dependence is introduced by adding location-specific random effects $\emptyset_j$ at every surveyed s_j location. Non-spatial variation is estimated by the random effects $\omega_i \sim N\ (0,\ \sigma_w^2\ )$ for the unstructured spatial effect assumed independent and normally distributed with mean 0 and variance σ_w^2 for the spatially structured random effect.

A conditional autoregressive (CAR) prior distribution was employed to model the spatially structured random effect. Spatial correlations between neighbourhoods were determined considering an adjacency weights matrix of neighbourhood structure. For two neighbourhoods sharing a border, a weight of 1 was assigned, if not a weight of 0 was assigned. A flat prior distribution was specified for the intercept, while a non-informative normal prior distribution was used for the coefficients. The prior for the precision of the spatially structured random effects was specified using non-informative gamma distribution with shape and scale parameters equal to 0.5. An initial burn-in of 1000 iterations was run, and these iterations were discarded. Subsequent blocks of 250,000 iterations were run and checked for convergence. Convergence was assessed by visual inspection of posterior density and history plots. Each model parameters were stored and summarised for the analysis. In all analyses, a level of 0.05 was adopted to indicate statistical significance as indicated by 95% BCI for the relative risk that excluded 1.

Models fit, parameter estimation were performed using a Bayesian framework and Markov Chain Monte Carlo (MCMC) estimation. Model specification was completed by assigning gamma prior distributions to model parameters.

Data analysis was carried out in STATA software (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP). OpenBUGS version 3.2.3 (Imperial College and Medical Research Council, London, UK) was used to perform model fit. The maps were produced using ArcGIS software version 10.5.

Continuous covariates were standardized for addressing correlation between covariates. Parameters estimates were summarized using posterior medians and the corresponding 95%

Bayesian Credible Intervals (BCI). For epidemiological interpretation, model estimates were exponentiated to produce Odds ratios (OR).

1.3 Results

Summary of socio-demographic and WASH conditions of the surveyed household

A total of 1,083 children under the age of five years from 761 households participated in the survey conducted in Mbour, between September and October 2016. Socio-demographic and economic characteristics of the surveyed households and WASH conditions in the four stratified zones of Mbour are provided as supplementary files (Table S1 and Table S2).

Distribution of the observed diarrhoeal prevalence and the socio-demographic covariates

Table1 summarize the observed diarrhoea prevalence among children under the age of five years stratified by age group, zone and neighbourhoods. The number of children who reportedly had diarrhoea during the 2 weeks preceding the survey per number of children surveyed was mapped by neighbourhood areas to illustrate the distribution patterns of the observed prevalence.

Table 1 shows the overall observed diarrhoea prevalence of 33.9% (n=367), which varied from 20.0% in the neighbourhood Grand Mbour to 57.9% the neighbourhood Baye Deuk. The overall diarrhoea observed prevalence (31.6%) for children aged 0-11 months varied from 8.6% in the neighbourhood Zone Résidentielle to 42.9% in Mbour Sérère Souf. For children aged 12-24 months the overall prevalence of 40.0% varied from 14.3% in Mbour Sérère Souf to 57.9% in Baye Deuk; and for children aged 36-59 months, the observed prevalence varied from 21.0% in Baye Deuk to 53.1% in Medine. Maps of the distribution of the observed prevalence stratified by age group are presented in Figure 1.

Figure 2 shows the spatial distribution of the model-based estimation of diarrhoea risk from the posterior estimate adjusted for spatially random effect, spatial correlation and varying coefficient effects. We interpreted the model as model-based estimate of the smoothed prevalence. The distribution of the estimated diarrhoea risk varies in Mbour between 26.0% and 52.5%. Most of the neighbourhoods in the city exhibit similar patterns except four neighbourhoods with diarrhoea risk of more than 40%.

Table 9.1 Summary of the observed diarrhoeal prevalence among children under the age of five years stratified by age group, zone and neighbourhood in Mbour in 2016

Zone	Neighbourhood	Observed diarrhoeal prev. 0-59 months (%)	Observed diarrhoeal prev. 0-11 months (%)	Observed diarrhoeal prev. 12-24 months (%)	Observed diarrhoeal prev. 36-59 months (%)
UCA		38.3	21.1	38.3	40.5
	Château d'eau Nord	30.6	19.4	38.7	41.9
	Château d'eau Sud	27.6	31.0	27.6	41.4
	Onze Novembre	33.3	20.5	43.6	35.9
	Tefess	57.1	32.1	39.3	28.6
	Golf	38.5	15.4	38.5	46.2
	Zone Residentielle	54.3	8.6	42.9	48.6
	Mbour serère souf	28.6	42.9	14.3	42.9
PCA		34.8	22.5	39.5	37.9
	Darou Salam	30.6	16.1	40.3	43.5
	Diamaguene 1	35.6	19.2	47.9	32.9
	Diamaguene 2	34.7	27.7	35.6	36.6
	Baye Deuk	57.9	21.1	57.9	21.1
	Santessou	31.8	18.2	40.9	40.9
	Thiocé Est	32.4	18.9	36.5	44.6
	Thiocé Ouest	36.4	33.3	33.3	33.3
	Mbour Toucouleur	32.3	22.6	41.9	35.5
	Mbour serère kaw	36.4	27.3	30.3	42.4
NPA		26.9	15.5	36.2	48.3
	Grand Mbour	20.0	12.5	38.8	48.8
	Liberté	31.6	10.5	36.8	52.6
	Médine	26.6	15.6	31.3	53.1
	Santhie	31.4	27.5	37.3	35.3
SPA		37.2	13.1	42.3	44.5
	Gouye Mouride	32.4	10.8	37.8	51.4
	Oncad	34.6	15.4	46.2	38.5
	Mbour Maure	33.3	22.2	44.4	33.3
	Zone Sonatel	46.2	10.3	41.0	48.7
Overall		**33.9**	**31.6**	**40.0**	**29.3**

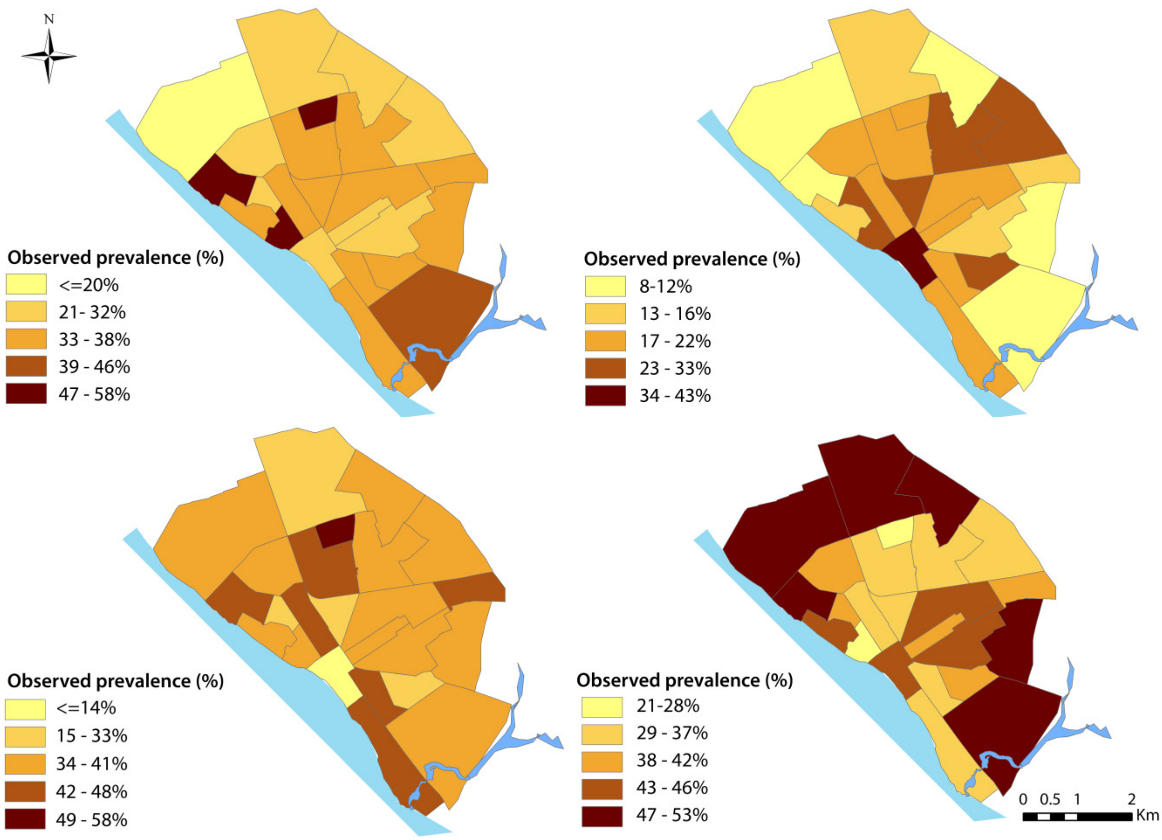


Figure 9.1 Spatial distribution of the observed diarrhoea prevalence in children under the age of 5 years in Mbour in 2016; Overall observed prevalence (Top left); observed diarrhoea prevalence among children aged 0-11 months (Top right), observed prevalence among children aged 12-24 months (bottom left) and observed prevalence among children aged 25-59 months (bottom right).

Table 2 presents the summary of the socio-demographic covariates. The proportion of the surveyed household without safe drinking water was higher 41.7%, varying from 0% in Mbour Sérère Souf to 100% in Baye Deuk and Gouye Mouride. About sixty-nine percent of the surveyed household do not treated their stored drinking water; this proportion varied from 28.9% in Médine to 85.0% in Tefess. The proportion of the surveyed household without access to safe liquid waste disposal ranged from 4.2% in Thiocé Ouest to 91.7% in Zone Residentielle and Mbour Sérère Kaw. The proportion of the surveyed households without access to proper solid waste disposal ranged from 0% to 100%.

Table 9.2 Summary of the socio-demographic covariates by stratified zones and neighbourhoods in Mbour in 2016

Zone	Neighbourhood	Proportion udws[a] (%)	Proportion utsdw[b] (%)	Proportion ulwd[c] (%)	Proportion uswd[d] (%)
UCA		16.3	77.1	60.1	85.6
	Château d'eau Nord	4.8	76.2	81.0	95.2
	Château d'eau Sud	26.3	79.0	63.2	100.0
	Onze Novembre	7.1	78.6	39.3	78.6
	Tefess	20.0	85.0	10.0	80.0
	Golf	57.1	78.6	57.1	100.0
	Zone Residentielle	16.7	70.8	91.7	83.3
	Mbour serère souf	0.0	60.0	60.0	0.0
PCA		28.9	75.8	76.7	93.2
	Darou Salam	41.9	81.4	88.4	90.7
	Diamaguene 1	22.2	83.3	72.2	90.7
	Diamaguene 2	27.9	76.5	88.2	97.1
	Baye Deuk	100.0	60.0	86.7	93.3
	Santessou	5.6	66.7	83.3	100.0
	Thiocé Est	17.9	71.4	76.8	94.6
	Thiocé Ouest	8.3	79.2	4.2	91.7
	Mbour Toucouleur	20.0	65.0	80.0	90.0
	Mbour serère kaw	50.0	79.2	91.7	87.5
NPA		59.5	56.2	71.9	88.1
	Grand Mbour	40.7	66.1	72.9	76.3
	Liberté	78.3	56.5	76.1	95.7
	Médine	82.2	28.9	53.3	93.3
	Santhie	37.1	74.3	88.6	91.4
SPA		88.1	57.4	75.2	92.1
	Gouye Mouride	100.0	60.0	80.0	100.0
	Oncad	92.5	62.5	80.0	97.5
	Mbour Maure	37.5	50.0	75.0	37.5
	Zone Sonatel	85.7	50.0	64.3	92.9
Overall		**41.7**	**68.9**	**72.0**	**90.3**

[a]Proportion of the surveyed household who do not have access to pipe-borne water (either in dwellings, outside dwellings, or public standpipes)

[b]Proportion of the neighbourhood's surveyed household who do not treated their stored drinking water

[c]Proportion of the neighbourhood's surveyed household who dispose wastewater in the street

[d]Proportion of the neighbourhood's surveyed household who do not have proper waste bin

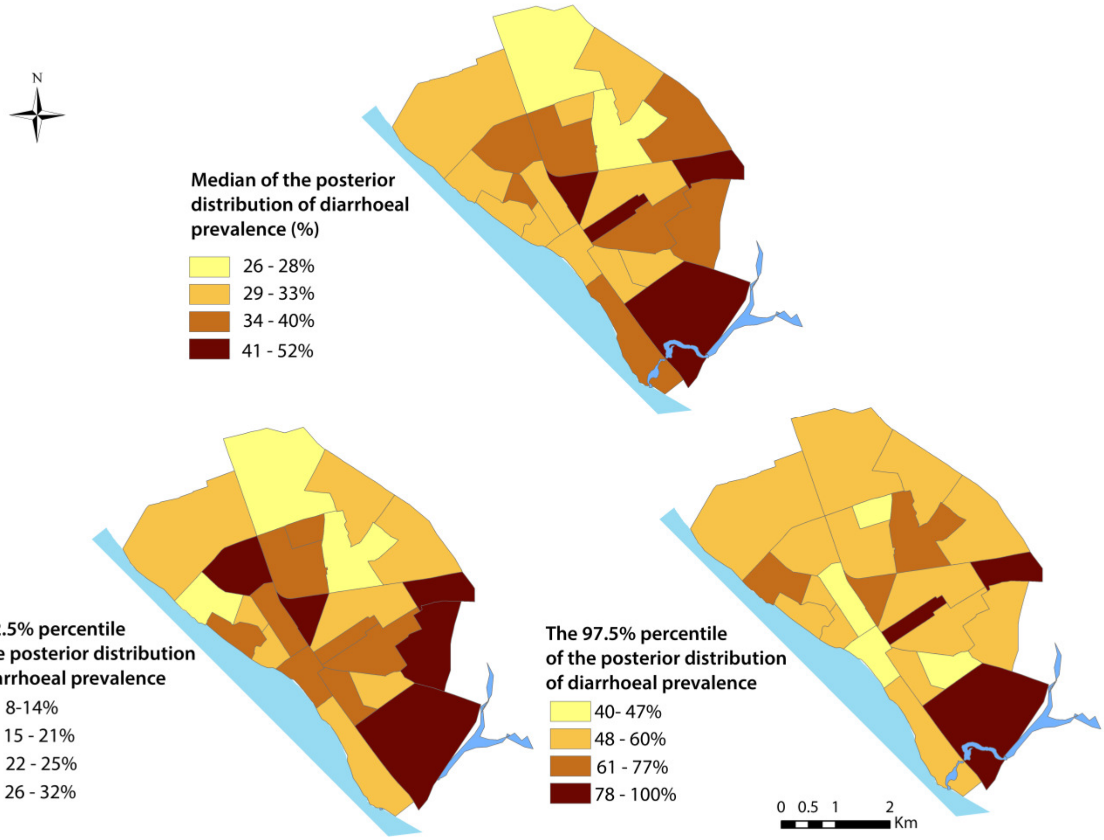


Figure 9.2 Spatial distribution of the smoothed diarrhoeal prevalence from the posterior median, 2.5% and 97.5%. (Top) median posterior distribution, (bottom left) the 2.5% and 97.5% (bottom right) and 97.5 of the posterior distribution of diarrhoeal prevalence. Estimations are based on model 3.

Posterior estimates of the effect of sociodemographic/economic and climatic factors

Table 3, presents the results from the Bayesian CAR models. To facilitate interpretation of the effect of socio-demographic and climatic factors on diarrhoea risk, all parameter estimates were exponentiated. In model 1, association of diarrhoea prevalence with altitude, rainfall and day land surface temperature (LST) were positive, while we did not find any evidence of an association. Untreated stored drinking water was significantly associated with diarrhoea prevalence in children (Model 2). A unit increase in the proportion of people who do not treated their stored drinking water increases diarrhoea risk by 22%, suggesting that diarrhoea risk for people used untreated stored drinking water is 22% higher than those who used treated stored drinking water. Also the results from model 2 indicate a significant association with diarrhoea risk and socio-economic status. No multiplicative effect were observed for udws and uwwd, meaning that differences in sources of drinking water and wastewater disposal could not account for variation in diarrhoea risk across neighbourhoods.

Table 9.3: Posterior median and 95% Bayesian Credible Intervals (BCI) of model 1[a], Model 2[b] and Model 3[c]

Model/variables	Model 1[a] RR (95% BCI)	Model 2[b] RR (95% BCI)	Model 3[c] RR (95% BCI)
Climatic Variable			
Altitude	1.03 (0.83 - 1.25)		0.79 (0.63 - 0.96)*
Rainfall	1.18 (0.89 - 1.44)		1.40 (1.10 - 1.74)*
Temperature day	1.07 (0.89 - 1.16)		1.07 (0.93 - 1.27)
Temperature Night	0.91 (0.81 - 1. 03)		0.82 (0.69 - 1. 03)
socio-economic and environmental factors			
Udws[d]		0.96 (0.55 - 1.45)	0.83 (0.69 - 1.05)
Utsdw[e]		1.22 (1.01 - 1.53)*	1.29 (1.06 - 1.60)*
Uwwd[f]		0.89 (0.78 - 1.05)	0.96 (0.86 - 1.12)
Uswd[g]		1.03 (0.78 - 1.30)	1.06 (0.78 - 1.43)
Socio-economic status		1.32 (0.77 - 2.24)	1.95 (1.43 - 2.54)*

[a]Model of diarrhoea risk based on climatic covariates.
[b]Model of diarrhoeal risk based on sociodemographic/economic covariates.
[c]Model of diarrhoeal risk comprised climatic+ sociodemographic/economic covariates
[d]Unsafe drinking water source; [e]Untreat stored drinking water; [f]Unsafe wastewater disposal; [g]Unsafe solid waste disposal
*Statistically significant

1.4 Discussion

This study aimed to explore and map the spatial pattern of neighbourhood-wise diarrhoeal prevalence and assess the effect of climatic and sociodemographic factors on the distribution of diarrhoeal prevalence in children under five years old in Mbour, Senegal. The study is the first effort that explored the spatial patterns of diarrhoea in Senegal and in Mbour in particular. The assumptions in the modelling approach are that effect of sociodemographic and climatic factors in neighbouring areas should be similar and dissimilar effect when area is located away from each other. The effects of these factors in space were assessed using the neighbourhood in the city as our unit of analysis.

The findings from the Bayesian smoothed maps show substantial variation in the spatial distribution of diarrhoea with neighbourhoods of higher and lower than expected risk clustered. This might be explained by wider sociodemographic and economic inequalities between neighbourhoods (Osei and Stein, 2017b). Unsafe treated stored water and the high prevalence of diarrheal disease observed in the city of Mbour near coastal area could be explained by the presence of many pathogens, which lives in the environment in brackish rivers and coastal water and also the presence of higher levels of enteric microorganisms in coastal area. Moreover, similar to our findings higher incidence of acute diarrhoea and cholera were observed in India near the coastal areas (Alam et al., 2006; Kumar et al., 2016) . In several epidemiological studies, it was observed that the people living near to coastal area are at higher risk of contracting diseases. This could be due to the fact that polluted coastal water may run into inland during rainy season and lead to higher incidence of diarrhoea and its transmission (Lipp et al., 2002; Rajendran et al., 2011; Jayakumar and Malarvannan, 2013).

The limitations of this study need to be mentioned. First, the study is based on morbidity data aggregated at a neighbourhood level. That is why we focus on modelling the spatially varying coefficient as realizations of CAR process producing from the weighting of the burden in the neighbouring areas. As we work on small areas and due to the small distance between the neighbourhood centroids, we were not able to fit a geostatistical model. Therefore, this study could not account for local variations in neighbourhood covariates effects through spatially varying coefficient; thus did not estimate neighbourhood specific relative risk, which relies on point referenced data (Gelfand et al., 2003). Disease indices, such as relative risk, of common morbidities, are an important measure of estimate in disease mapping used for comparing neighbourhood health status and health planning etc. (Osei and Stein, 2017b). However, further studies using rigorous statistical estimation should map neighbourhood specific relative risk estimates and estimate the spatially varying association between the relative and potential risk factors. Second, due to unavailability of temporal data, this study did not not consider a possible temporal variation of the prevalence and possible temporal change in the sociodemographic and climatic factors. The identification and understanding of clusters in space and time at neighbourhood level should be considered for future research. Nonetheless, the finding of this study has valuable policy implications for health programs design and interventions. Diarrhoea risk areas can be identified at neighbourhood level to tackle area specific interventions, ad may also be important for control and prevention of suspected diarrhoea outbreaks. These findings are also important for the Ministry of Health and other ministries responsible for water, sanitation and hygiene aspects.

1.5 Conclusion

The findings of this study shows that childhood diarrhoea is a public health problem and had a varying spatial pattern across the city. Our findings provide a better understanding of the geographical variation of neighbourhood health status and suggest that attention should be paid in children above two years in the north and south peripheral neighbourhoods such as Médine, Liberté, Grand Mbour, Zone Sonatel and Gouye Mouride, which are characterized by a lack of amenities such as availability of safe water source and good sanitation. In such areas, priority attention should be given to water, sanitation, and hygiene-related interventions in order to prevent and control diarrhoea in children.

1.6 Appendix

Table S1 Socio-demographic characteristics of study population in the four stratified zones of Mbour

Variable	Overall N= 761 n (%)	UCA N= 153 n (%)	PCA N= 322 n (%)	NPA N= 185 n (%)	SPA N= 101 n (%)	P-value
Gender of the respondents						0.005
Female	711 (93.4)	144 (94.1)	301 (93.5)	165 (89.2)	101 (100)	
Male	50 (6.6)	9 (5.9)	21 (6.5)	20 (10.8)		
Age of the respondents in years						0.130
15-24	190 (25.0)	41 (26.8)	82 (25.5)	42 (22.79	25 (24.7)	
25-30	232 (30.5)	54 (35.3)	104 (32.3)	43 (23.2)	31 (30.7)	
31-35	135 (17.7)	25 (16.3)	56 (17.49	37 (20.0)	17 (16.8)	
36- 44	129 (16.9)	25 (16.3)	54 (16.8)	34 (18.4)	16 (15.8)	
More than 45	75 (9.9)	8 (5.2)	26 (8.1)	29 (15.7)	12 (11.9)	
Educational level						0.046
Never go to school	219 (28.8)	45 (29.4)	96 (29.8)	42 (22.7)	36 (35.6)	
Primary school	225 (29.6)	47 (30.7)	99 (30.7)	53 (28.6)	26 (25.7)	
Secondary education	177 (23.3)	38 (24.8)	80 (24.8)	41 (22.2)	18 (17.8)	
Koranic school	140 (18.4)	23 (15.0)	47 (14.6)	49 (26.5)	21 (20.8)	
Occupation of head of household						**< 0.001**
Public service	17 (2.2)	4 (2.6)	5 (1.5)	7 (3.8)	1 (0.9)	
Private service	46 (6.0)	8 (5.2)	30 (9.3)	4 (2.2)	4 (3.9)	
Merchant	150 (19.7)	21 (13.7)	72 (22.4)	37 (20.0)	20 (19.8)	
Housewife	358 (47.0)	94 (61.4)	152 (47.2)	59 (31.9)	53 (52.5)	
Others (no employment, etc.)	190 (24.9)	26 (16.9)	63 (19.6)	78 (42.2)	23 (22.8)	
Wealth Index						**< 0.001**
Poorer	213 (27.9)	28 (18.3)	85 (26.4)	67 (36.2)	33 (32.7)	
Middle	284 (37.3)	58 (37.9)	146 (45.3)	47 (25.4)	33 (32.7)	
Richer	264 (34.7)	67 (43.8)	91 (28.3)	71 (38.4)	35 (34.6)	
Child characteristic (n=1,083)						
Gender of the child						0.533
Female	507 (46.8)	109 (48.0)	198 (44.2)	132 (48.7)	60 (49.6)	
Male	576 (53.2)	118 (52.0)	250 (55.8)	139 (51.3)	69 (50.4)	
Age of the child						< 0.039
0-11 months	209 (19.3)	48 (21.1)	101(22.5)	42 (15.5)	18 (13.1)	
12-24 months	420 (38.8)	87 (38.3)	177 (39.5)	98 (36.2)	58 (42.3)	
36-59 months	454 (41.9)	92 (40.5)	170 (37.9)	131 (48.3)	61 (44.5)	

Table S2 Characteristics of study population and WASH conditions in the four stratified zones of Mbour

Variable	Overall N= 761 n (%)	UCA N= 153 n (%)	PCA N= 322 n (%)	NPA N= 185 n (%)	SPA N= 101 n (%)	P-value
Drinking water source						**< 0.001**
Private tap at home	444 (58.39	128 (83.7)	229 (71.1)	75 (40.5)	12 (11.9)	
Public tap	187 (24.6)	18 (11.8)	76 (23.6)	29 (15.7)	64 (63.4)	
well water	79 (10.4)	5 (3.3)	12 (3.7)	49 (26.5)	13 (12.8)	
Others	51 (6.7)	2 (1.3)	5 (1.5)	32 (17.3)	12 (11.9)	
Water storage						**< 0.001**
Yes	621 (81.6)	141 (92.2)	284 (88.2)	112 (60.59	84 (83.2)	
No	140 (18.4)	12 (7.8)	38 (11.8)	73 (39.5)	17 (16.8)	
Container to store water at home						**< 0.001**
Clay	43 (6.9)	4 (2.8)	30 (10.5)	5 (4.5)	4 (4.8)	
Plastic	420 (67.6)	96 (68.1)	198 (69.7)	67 (59.8)	59 (70.2)	
Metal	24 (3.9)	5 (3.5)	8 (2.8)	8 (7.1)	3 (3.6)	
At least one of the three	115 (18.5)	29 (20.6)	37 (13.0)	32 (28.6)	17 (20.2)	
Others	19 (3.0)	7 (4.9)	11 (3.9)	0	1 (1.2)	
Status of container during storage						**0.009**
Not available	6 (1.0)		1 (0.3)	5 (4.3)		
Covered	580 (92.8)	132 (93.6)	265 (93.3)	104 (89.7)	79 (94.0)	
Uncovered	39 (6.2)	9 (6.4)	18 (6.3)	7 (6.0)	5 (5.9)	
Water storage duration						**< 0.001**
One day	509 (81.4)	119 (84.4)	240 (84.5)	84 (72.4)	66 (78.6)	
Two days	88 (14.1)	19 (13.5)	30 (10.5)	29 (25.0)	10 (11.9)	
Three days and more	28 (4.5)	3 (2.1)	14 (4.9)	3 (2.6)	8 (9.5)	
Container washing frequency						
Never	2 (0.3)			1 (0.9)	1 (1.2)	0.036
Daily	494 (79.0)	117 (82.9)	233 (82.0)	85 (73.3)	59 (70.2)	
Weekly	92 (14.7)	20 (14.2)	37 (13.0)	17 (14.7)	18 (21.4)	
Others	37 (5.9)	4 (2.8)	14 (4.9)	13 (11.2)	6 (7.1)	
Stored water treatment						**< 0.001**
Treated	193 (31.1)	33 (23.4)	74 (26.1)	49 (43.7)	37 (44.0)	
No treated	425 (68.4)	108 (76.6)	210 (73.9)	60 (53.6)	47 (55.9)	
Not indicated	3 (0.5)			3 (2.7)		
Type of stored water treatment						**< 0.001**
Javellisation	132 (68.4)	27 (81.8)	62 (83.8)	22 (44.9)	21 (56.8)	
Filtration	20 (10.4)	3 (9.1)	5 (6.8)	8 (16.3)	4 (10.8)	
Others	41 (21.2)	3 (9.1)	7 (9.5)	19 (38.8)	12 (32.4)	
Toilet availability						**< 0.001**
Yes	745 (97.9)	151 (98.7)	321 (99.7)	181 (97.8)	92 (91.1)	
No	16 (2.1)	2 (1.3)	1 (0.3)	4 (2.2)	9 (8.9)	
Type of toilet facilities						**< 0.001**
Flush latrine	517 (69.4)	123 (81.5)	219 (68.29	137 (75.7)	38 (41.3)	
Open pit latrine with slab	183 (24.6)	27 (18.9)	79 (24.6)	36 (19.9)	41 (44.6)	
Traditional latrine	45 (6.0)	1 (0.7)	23 (7.2)	8 (4.4)	13 (14.1)	
Toilet shared with others households						**< 0.001**
Yes	106 (14.2)	25 (16.6)	31 (9.7)	40 (22.1)	10 (10.9)	
No	639 (85.8)	126 (83.4)	290 (90.3)	141 (77.9)	82 (89.1)	
Domestic wastewater disposal						**< 0.001**
Pit	27 (3.5)	16 (10.5)	10 (3.1)	1 (0.59		
Street	548 (72.0)	92 (60.1)	247 (76.7)	133 (71.9)	76 (75.2)	
Others	186 (24.4)	45 (29.4)	65 (20.29	51 (27.6)	25 (24.7)	
Storage of household solid waste						**< 0.001**
Waste bins	74 (9.79	22 (14.49	22 (6.8)	22 (11.9)	8 (7.9)	
Open pail/basin	122 (16.0)	5 (3.39	35 (10.99	61 (32.9)	21 (20.8)	
Open bag	487 (63.9)	110 (71.9)	257 (79.8)	76 (41.1)	44 (43.5)	
Others	78 (10.29	16 (10.5)	8 (2.5)	26 (14.0)	28 (27.7)	
Handwashing						0.019
only water	90 (11.8)	8 (5.29	49 (15.2)	16 (8.6)	17 (16.8)	
water with soap	653 (85.8)	141 (92.2)	267 (82.9)	165 (89.2)	80 (79.2)	
others	8 (1.09	2 (1.3)	1 (0.3)	2 (1.1)	3 (2.9)	
Not indicated	10 (1.3)	2 (1.3)	5 (1.5)	2 (1.1)	1 (0.9)	

10. ARTICLE 5: Knowledge and practice of mothers and caregivers on diarrhoeal management among under 5-year-old children in a medium-sized town of Senegal

Photo: Field survey about Knowledge and practice of mothers and caregivers on diarrhoeal management in Mbour, Senegal (©S. Thiam, 2016)

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Knowledge and practices of mothers and caregivers on diarrhoeal management among under 5-year-old children in a medium-size town of Senegal

Sokhna Thiam[a,b,*], Ibrahima Sy[c,d], Christian Schindler[a,b], Aminata Niang-Diène[d], Ousmane Faye[e], Jürg Utzinger[a,b], Guéladio Cissé[a,b]

[a] Swiss Tropical and Public Health Institute, Basel, Switzerland
[b] University of Basel, Basel, Switzerland
[c] Department of Geography, University Cheikh Anta Diop de Dakar, Dakar, Senegal
[d] Centre de Suivi Ecologique, Dakar-Fann, Senegal
[e] Department of Biology Animal, University Cheikh Anta Diop de Dakar, Dakar, Senegal

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ABSTRACT

In 2016, about one out of 10 children in sub-Saharan Africa died due to diarrhoea, causing an estimated burden of 25 million disability-adjusted life years. A prominent cause of death is dehydration linked to lack of knowledge and adequate management of diarrhoeal episodes. This study assessed knowledge and practices of mothers and caregivers on diarrhoeal management among under 5-year-old children in a medium-size town of Senegal. A cross-sectional survey was carried out between September and October 2016 in four zones of Mbour, located in the south-western part of Senegal. Mothers and caregivers of children under the age of 5 years were interviewed to determine their levels of knowledge and management practice of diarrhoea. The association between diarrhoea and source of care was determined using logistic regression analyses. In total, 367 mothers and caregivers who reported a diarrhoeal episode in at least one of their children under 5 years of age were included. Slightly less than a quarter (23.2%, 95% confidence interval (CI) 18.9–27.8%) of respondents had good management practice of diarrhoea, while 40.0% (95% CI: 34.5–45.6%) had high level of knowledge about diarrhoea. Mothers and caregivers having sought care from public health facilities had two and four times higher odds of good knowledge and good management practices of diarrhoea, respectively, compared to those seeking no care outside the home or from traditional healers. The weakness regarding knowledge and quality management practice, particularly the poor use of internationally recommended treatment of childhood diarrhoea among mothers and caregivers, confirms the low coverage of oral rehydration salt and zinc and lack of sensitization about diarrhoea. We conclude that diarrhoea management practices in this part of Senegal do not correspond with international recommendations, even when mothers and caregivers visit government health facilities. There is a need to develop and implement communication strategies for health care providers' and the mothers and caregivers in order to facilitate sustainable positive change in the management of childhood diarrhoea at the community level. Moreover, mothers, caregivers and health care providers need specific training on the current guidelines for diarrhoea management.

1. Introduction

Over the past 15 years, considerable progress has been made in reducing the burden of childhood diarrhoea (WHO/UNICEF, 2005; GBD 2017 DALYs and HALE Collaborators, 2018). Preventive measures and public health interventions, such as the use of low osmolarity oral rehydration salt (ORS) formula and zinc supplementation, are jointly recommended by the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) to reduce the burden of diarrhoea in children under the age of 5 years (WHO/UNICEF, 2004). These

Abbreviations: CI, Confidence Interval; DHS, Demographic and Health Survey; GBD, Global Burden of Disease (study); MICS, Multiple Indicator Cluster Surveys; NPA, north peripheral area; ODK, open data kit; OR, odds ratio; ORS, oral rehydration salt; PCA, peri-central area; SPA, south peripheral area; UCA, urban central area; UNICEF, United Nations Children's Fund; WHO, World Health Organization

* Corresponding author at: Swiss Tropical and Public Health Institute, P.O. Box, CH-4002 Basel, Switzerland.
E-mail address: sokhna.thiam@swisstph.ch (S. Thiam).

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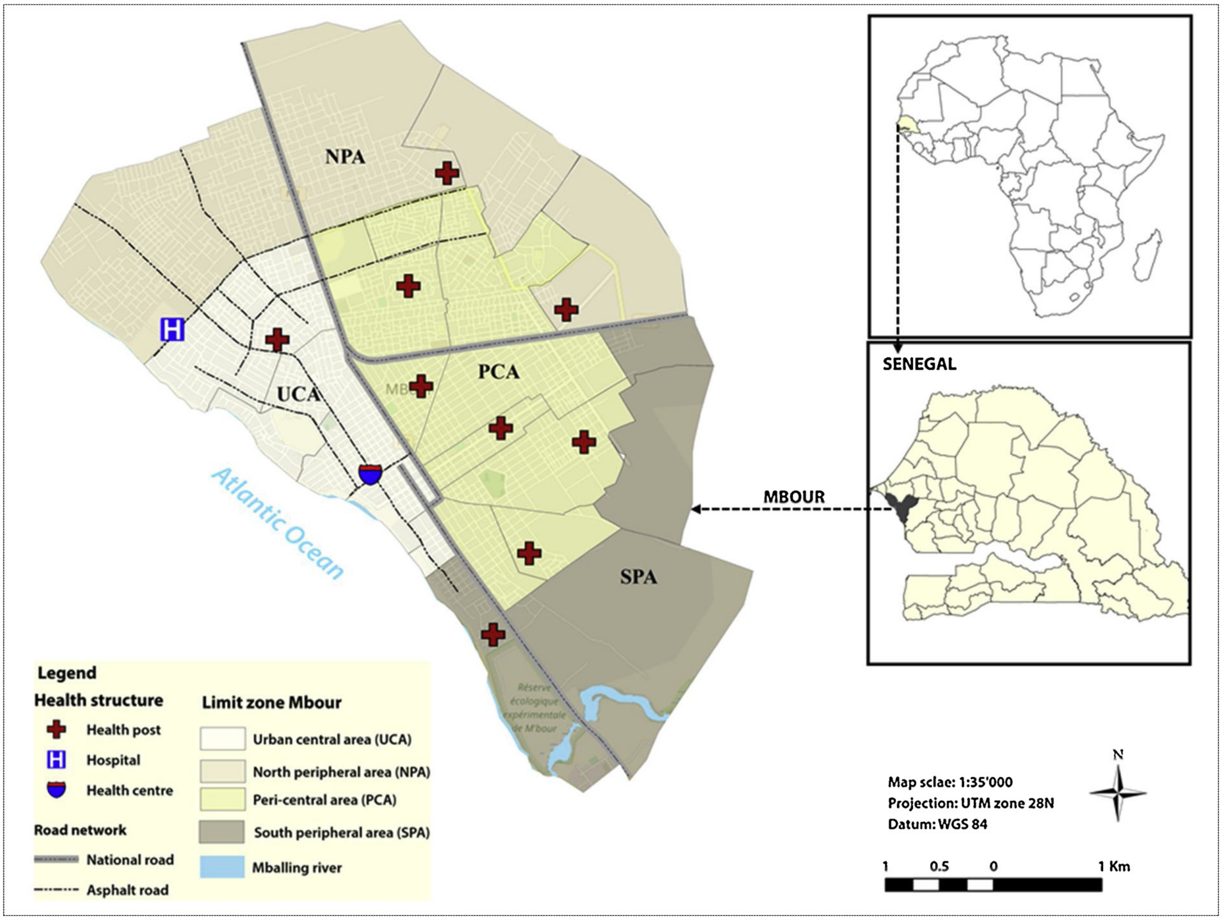

Fig. 1. Location of the mid-sized town of Mbour in Senegal and the four different zones of the city (modified from Thiam et al., 2017a,b).

interventions, along with exclusive breastfeeding in the first months of life, increased amounts of appropriate fluids and micronutrients during diarrhoeal episodes, and significantly contributed to the worldwide reduction of diarrhoea-related mortality in children, from 1.2 million in 2000 to 526,000 in 2015 (WHO, 2015). Yet, diarrhoeal diseases are still responsible for 9% of child deaths worldwide (Liu et al., 2015; WHO, 2015). Nearly all of these deaths are caused by dehydration, which is preventable with the timely use of ORS (Munos et al., 2010).

Despite the evidence that ORS may prevent 93% of diarrhoeal mortality (Brewster and Greenwood, 1993; Munos et al., 2010), population coverage for this life-saving intervention remains low, particularly in sub-Saharan Africa, including Senegal (Bhattacharya, 2003; Forsberg et al., 2007; Osonwa et al., 2016; El-Khoury et al., 2016; Carvajal-Velez et al., 2016). Indeed, in sub-Saharan Africa, only about one out of three children suffering from diarrhoea received ORS in 2015, and the percentage of children receiving zinc was below 5% (UNICEF, 2016). In Senegal, in 2016, the Institute for Health Metrics and Evaluation (IHME; Global Burden of Disease (GBD) study) country profile data reported that diarrhoea was the leading causes of child mortality and morbidity combined, accounting for 14% of total child deaths and 14% of the disability-adjusted life years (DALYs) (IHME, 2018).

In 2008, the Ministry of Health in Senegal put forward new guidelines for diarrhoeal management, emphasizing the use of low osmolarity ORS, combined with zinc supplementation, increased fluid intake and continued feeding based on joint recommendations by WHO and UNICEF (WHO/UNICEF, 2004, 2005; WHO, 2006). In spite of substantial progress made in reducing infant and child mortality from 139 to 72 per 1000 children between 1997 and 2010, diarrhoea remains a major public health problem in Senegal (ANSD, 2012). Hence, more needs to be done to further reduce childhood diarrhoea in order to achieve the Sustainable Development Goals (SDGs), particularly SDG 3, target 3.2 related to ending preventable child deaths and reducing mortality by 2030 (ICS, 2017). Improvements in diarrhoeal case management, both at the unit of health facilities and households, are necessary to make progress towards SDG 3.

According to a Senegalese study done in 2015, the proportion of children with diarrhoea for whom advice or treatment was sought from a health facility or health care provider was only 41%. This situation is linked to the knowledge, attitudes, and management practices of mothers and caregivers. Indeed, early and accurate recognition of illness and timely administration of appropriate treatment by caregivers, including increased fluids supplementation and continued feeding, are crucial elements to prevent child deaths, but this knowledge is often missing (Diaby et al., 2016).

While diarrhoea remains a pressing public health issue in Senegal, it is important to note that there is a paucity of data at small scale pertaining to knowledge and practice of the mothers and caregivers on the management of childhood diarrhoea. New research is needed to strengthen the local evidence and put forth guidance documents for optimal planning of interventions to reduce the burden of diarrhoea in Senegal. The present study intends to fill some of the scientific gaps by generating better knowledge and evidence on the knowledge and practice about the management of childhood diarrhoea among children under the age of 5 years in a medium-size town of Senegal.

2. Materials and methods

2.1. Ethics statement

The national research ethics committee (*Comité National d'Ethique de la Recherche*-CER) of Senegal approved the study (reference number: 0l06/2015/CER/UCAD). Prior to administering a questionnaire, a disclosure statement, indicating that participation in the survey was voluntary, was presented to all participants and read aloud to each of the non-literate participants. Written informed consent was requested from mothers and caregivers of under 5-year-old children. Participants were free not to answer to a specific question or to cease the interview anytime without further obligations. All information gathered was handled confidentially. No biological specimens (stool, urine or blood samples) were collected.

2.2. Study design, setting and population

We conducted a cross-sectional survey between September and October 2016 in four zones of Mbour, a medium-size town located in the south-western part of Senegal. As shown in Fig. 1, the zones included: (i) urban central area (UCA); (ii) peri-central area (PCA); (iii) north peripheral area (NPA); and (iv) south peripheral area (SPA) (Thiam et al., 2017b). The eligibility criteria for the study population were: (i) being a mother or caregiver of at least one child under the age of 5 years; and (ii) providing written informed consent to participate in the study. If an eligible household contained more than one mother or caregiver of an appropriately aged child, the field enumerators randomly selected one child for the survey, using a Kish grid, which is a method that involves constructing a list of eligible individuals at a particular address and then selecting based on the number of the address itself (Kish, 1949). This method gives all eligible individuals in a household an equal chance to be selected. The same approach was applied to randomly select one child if the selected mother or caregiver had more than one child under the age of 5 years.

2.3. Sample size, power calculation and household selection

For the sample size calculation, as the power calculation related to the primary objective of the study and not to the present secondary analysis, we refer the reader to the details of the power calculation presented elsewhere (Thiam et al., 2017a). In short, the power calculation was done using the statistics software Stata version 13 (Stata Corporation; College Station, TX, USA) and applying a design effect of 2.

Households were randomly selected within the four study zones. A two-stage procedure was employed to identify households with children under the age of 5 years. We first determined the numbers of households to be allocated in each zone based on population size, and then further subdivided these numbers by neighbourhood, again in proportion to size. Households were randomly selected within zones using a detailed map of household locations in the city on which the randomly selected households were shown. Then, the field enumerators were charged to identify the selected households and invite those with at least one mother or caregiver of a child under the age of 5 years, using a hand-held global positioning system (GPS; eTrex® 30; Garmin Ltd. Olathe, KS, USA). Field enumerators could orient themselves by prominent infrastructures, such as a mosque, a school or other major administrative infrastructures. In case the mother or caregiver was absent, the field enumerator took a new appointment. After two unsuccessful appointments, the preselected household was replaced by another household in the same zone.

2.4. Survey instrument design and administration

The survey questionnaire was developed in French, based on standardized questions from international guidelines (WHO and UNICEF Joint Statement on Diarrhoea Management 2004, DHS, MICS). Five experienced field enumerators collected survey data under direct supervision of the first author and other members of the research team in Senegal. The field enumerators were trained on how to administer the survey questionnaire using tablets equipped with open data kit (ODK) software (Open data kit, 2008). Interviews were conducted face-to-face and mothers and caregivers were asked whether one of their children under the age of 5 years had experienced diarrhoea, defined as three or more loose or watery bowel movements within 24 h, in the 2 weeks preceding the survey. Mothers and caregivers who responded positively to this question were asked about care seeking behaviour, knowledge of causes, prevention and case management of childhood diarrhoea, including the four recommended management interventions by WHO/UNICEF. Mothers and caregivers were also asked whether the child was exclusively breastfed. The interview further included questions pertaining to socio-demographic and economic characteristics of the households and on general characteristics of the children.

To ensure high data quality, the questionnaire was pretested on about 40 households before survey implementation with mothers and caregivers who were not otherwise involved in the survey presented here. The survey data collection tools were pre-tested to ensure that the questions was comprehensible and locally appropriate. Furthermore, pre-testing was provided some crucial information on the validity and usefulness of the data collected. Based on issues identified during the pre-test, the questionnaire was adapted prior to the start of the survey. The questionnaire was translated from local languages other than French and from French into English. Data collectors contacted the supervisors for any problem they faced during data collection and would keep records of progress and problems/challenges faced during data collection. The supervisors controlled the quality of the data by regularly checking the data collected. Additionally, the supervisors randomly sampled 10% of the collected data (in each zone) to conduct a complete check of data entry. If data quality of this sample was found unsatisfactory, all data were verified.

2.5. Outcome measures

Quality of diarrhoea management practice among mothers and caregivers was divided into three categories; good, fair or poor, based on readily available guidelines put forth by WHO/UNICEF Joint Statement on Clinical Management of Acute Diarrhoea (Table 1) (Carvajal-Velez et al., 2016). A scoring system was employed to assess mothers' and caregivers' knowledge about causes, preventive measures and recommended management of diarrhoea. The following five knowledge questions were considered: (i) Do you know what can cause diarrhoea?; (ii) Do you know how to prevent diarrhoea?; (iii) Have you heard about ORS?; (iv) Have you ever used ORS or zinc?; and (v) Do you know how to prepare ORS and can you demonstrate the preparation steps? An "overall knowledge" variable was created by taking into

Table 1
Quality of diarrhoea management among children under 5 years of age, stratified into good, fair and poor based on WHO/UNICEF recommendations.

Categorization	Children given ORS or zinc or both ORS and zinc	Children given increased fluids	Children continued feeding
Good	Yes	Yes	Yes
Good	Yes	Yes	No
Good	Yes	No	Yes
Fair	Yes	No	No
Fair[a]	No	Yes	Yes
Fair[a]	No	Yes	No
Poor	No	No	Yes
Poor	No	No	No

[a] Defined as "good" practice for children of 6 months old and younger.

account the total score for each mother or caregiver in the five aforementioned questions. This variable was divided into three categories: (i) good (all questions correctly answered); (ii) fair (either knows causes and preventive measures or knows causes or preventive measures and has at least three correct answers); and (iii) poor (others). The reported sources of care were divided into five categories; namely: (i) public facility; (ii) private facility; (iii) community health worker (CHW); (iv) traditional healer; and (v) no care sought outside the household. Public facilities included hospitals, health centres and health posts. Private facilities refer to care sought at clinics, pharmacies and private dispensaries. CHW refers to care sought at health workers such as "Badiane gokh" and "relais communautaire" in local language. "No care outside the household" refers to children under the age of 5 years suffering from diarrhoea for which no care outside the household was sought.

2.6. Statistical analysis

Data collected from the questionnaire were transferred and stored on a secure server at the Swiss Tropical and Public Health Institute (Swiss TPH; Basel, Switzerland). Data were exported electronically to a CSV data spreadsheet format, and imported into Stata version 13 (Stata Corp; College Station, TX, USA). The distribution of categorical variables was described in terms of absolute and relative frequencies. Continuous variables were described by their mean and standard deviation (SD) if they were normally distributed and by their median and interquartile range otherwise. Results were presented by zone of residence.

Socio-economic status was characterized using a list of recorded household asset variables collected in the survey (e.g. car, radio and television) and housing characteristics (e.g. materials used to construct floors, roofs and walls and drinking water and sanitary facilities for the household). These variables were subject to factor analysis and the first factor was categorized into three groups, indicating households with high, medium or low socio-economic status.

In the present analysis, "good practices of diarrhoea management" and "good knowledge" were used as the two main outcomes of interest, while "source of care" served as the main independent variable. Prevalence of diarrhoea management practice and knowledge were described across zones. For each outcome variable, a logistic regression analysis was performed to examine its relationship with sources of care overall, and for each of the four zones separately. To control for potential confounding, the following variables were additionally included in the model: age of mother or caregiver, child's age, educational attainment of the mother or caregiver, socio-economic status and zone. All analyses were done using Stata version 13 (Stata Corp; College Station, TX, USA).

3. Results

3.1. Socio-demographic characteristics of the respondents

A total of 800 households with at least one child under the age of 5 years were visited. Among these households, 761 completed the questionnaire owing to a response rate of 95.1%. Overall, 1083 children under the age of 5 years were included in the final analyses. There were 367 children who experienced a diarrhoeal episode in the 2 weeks preceding the interview, as reported by their mothers or caregivers. Hence, these children were included in the further analyses.

The demographic and socio-economic characteristics of the respondents and their children who suffered at least one episode of diarrhoea are presented as a supplementary file (Table S1). The mean ($\pm$ SD) age of the respondents was 30.1 years ($\pm$ 9.4) with significant differences between zones ($p < 0.001$). The majority of respondents were mothers (n = 311, 84.7%). Slightly less than a third had no education (n = 108, 29.4%), a third attended primary school (n = 121, 33.0%), while koranic education (n = 59, 16.1%) and secondary education or university was less frequent (n = 79, 21.5%). Two-third of the respondents (n = 253, 68.9%) were in a monogamous marriage. More than half (n = 205, 55.9%) of the respondents had one child, while 33 (9.0%) had three children or more. Slightly less than half of the respondents (n = 168, 45.8%) were housewives, while 32 (8.7%) were public or private sector employees. The numbers of households surveyed, stratified by children under the age of 5 years with or without diarrhoea and the response rates by zone are presented as a supplementary file (Table S2).

3.2. Diarrhoeal prevalence and care seeking behaviour

One third of the children enrolled (n = 367, 33.9%) experienced a diarrhoeal episode in the 2 weeks prior to the survey according to a widely used definition of diarrhoea. There were 203 (55.3%) boys and 164 (44.7%) girls affected by diarrhoea, but this difference lacked statistical significance. Diarrhoeal prevalence differed significantly with the child's age; the highest prevalence was noted in children aged 12–24 months. Acute diarrhoea (duration < 14 days) was predominant (n = 349, 95.1%), while only 18 (4.9%) of the children reported persistent diarrhoea (duration ≥14 days).

As summarized in Table 2, slightly more than half of the mothers and caregivers with children having suffered from diarrhoea sought care outside the home (n = 188, 51.2%) with about two thirds visiting care providers in a public health facility, such as hospitals, health centres or health posts (n = 125, 66.5%). The remaining mothers and caregivers sought care at a traditional healer or friend (n = 38, 20.2%), a private health sector facility, such as clinics, pharmacies or private dispensaries (n = 22, 11.7%), while only 3 (1.6%) visited CHWs. The majority of mothers and caregivers obtained specific information regarding ORS and zinc or learned about ORS and zinc from health personnel at public health facilities, such as hospitals, health centres or health posts.

3.3. Diarrhoea management practices

Among the 367 children who suffered from diarrhoea, 98.3% received some kind of treatment (note that respondents could provide up to three responses). Of those, 301 (82.0%) received a single type of treatment, 47 (12.8%) received two different kinds of treatment, while 13 (3.5%) received three types of treatment. Table 2 indicates that medications (e.g. antibiotics, paracetamol and a syrup) and unidentified drugs made up one third of common treatments (n = 129, 35.1%). We found that 102 (27.8%) of the children did not receive any treatment. ORS was given to 68 (18.5%) of the children, while only 20 (5.4%) of the children received a combination of ORS and zinc and five (1.4%) received zinc alone. Traditional medicines from plants (e.g. extracts of leaves, stems and roots), including mostly monkey bread juice extracted from the fruit of "*Adansonia digitata*" and rice juice were given to 37 (10.1%) of the children.

Table 3 presents the reported numbers of children who experienced diarrhoea and were managed with any of the four recommended interventions, including ORS and zinc. The results did not differ significantly between zones. Of note, the coverage of ORS and zinc was low all over the study town of Mbour. Fig. 2 presents the distribution of good, fair and poor diarrhoea management practice, stratified by zone. Of the 367 mothers and caregivers, who reported a diarrhoeal episode among their children, 85 (23.2%), showed good diarrhoeal management practice. The prevalence of good practice of diarrhoeal management, stratified by zone, ranged from 17.8% to 26.4%. Even among children with diarrhoea for whom care was sought in public health facilities, the prevalence of good quality management practice and good knowledge was quite low (39.2% and 9.3%, respectively), as shown in Tables 4 and 5. The results for the unadjusted and adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for good diarrhoeal

Table 2
Self-reported number of children with diarrhoea in the last 2 weeks prior to the survey according to different treatment strategies, stratified by zones in Mbour, Senegal, October 2016.

Variable	All N = 367 n (%)	UCA* N = 87 n (%)	PCA** N = 156 n (%)	NPA*** N = 73 n (%)	SPA**** N = 51 n (%)	P-value+
When your child had diarrhoea, did you seek advice or treatment from someone?						***0.019***
Yes	188 (51.2)	50 (57.5)	87 (55.8)	29 (39.7)	22 (43.1)	
No	179 (48.8)	37 (42.5)	69 (44.2)	44 (60.3)	29 (56.9)	
Where did you go for advice or treatment?						0.097
Public health facility[a]	125 (66.5)	34 (68.0)	61 (70.1)	21 (72.4)	9 (40.9)	
Community health worker	3 (1.6)	–	2 (2.3)	–	1 (4.5)	
Private health facility[b]	22 (11.7)	7 (14.0)	6 (6.9)	3 (10.3)	6 (27.3)	
Traditional healer, parents or friends	38 (20.2)	9 (18.0)	18 (20.7)	5 (17.2)	6 (27.3)	
Have you ever used ORS or zinc?						0.015
Yes	188 (80.0)	45 (78.9)	97 (85.1)	22 (61.1)	24 (85.7)	
No	47 (20.0)	12 (21.1)	17 (14.9)	14 (38.9)	4 (14.3)	
Where did you get information regarding ORS or zinc?						0.519
From public health facility	155 (82.4)	41 (91.1)	80 (82.5)	17 (77.3)	17 (70.8)	
From community health worker	11 (5.8)	1 (2.2)	6 (6.2)	1 (4.5)	3 (12.5)	
From private health facility	13 (6.9)	1 (2.2)	7 (7.2)	3 (13.6)	2 (8.3)	
From more than one provider[c]	5 (2.7)	–	3 (3.1)	1 (4.5)	1 (4.2)	
Not indicated	4 (2.1)	2 (4.4)	1 (1.0)	–	1 (4.2)	
What was given to your child to treat diarrhoea?						***0.043***
Nothing	102 (27.8)	30 (34.5)	32 (20.5)	25 (34.2)	15 (29.4)	
ORS	68 (18.5)	20 (23.0)	29 (18.6)	10 (13.7)	9 (17.6)	
Zinc	5 (1.4)	3 (3.4)	2 (1.3)	–	–	
ORS/zinc in combination	20 (5.4)	2 (2.3)	12 (7.7)	4 (5.5)	2 (3.9)	
Drugs	129 (35.1)	23 (26.4)	64 (41.0)	25 (34.2)	17 (33.3)	
Traditional medicines[d]	37 (10.1)	8 (9.2)	17 (10.9)	5 (6.8)	7 (13.7)	
Not indicated	6 (1.6)	1 (1.1)	–	4 (5.5)	1 (1.9)	

* UCA = Urban central area.
** PCA = Peri-central area.
*** NPA = North peripheral area.
**** SPA = South peripheral area.
[a] Including hospitals, health centres and health posts.
[b] Including clinics and pharmacies.
[c] From public health facility, private facility or community health workers.
[d] Including plants leaves, stems, roots mostly (monkey bread juice extracted from the fruit of "*Adansonia digitata*").
+ p-value refer to the respective differences between zones and they derive from a X^2 test.

management practice and good knowledge by source of care are presented in Table 6. The logistic regression analysis showed that mothers and caregivers who sought care in public health facilities had a 4.2-fold higher odds (adjusted OR = 4.17; 95% CI: 2.35–7.39) to report good quality diarrhoeal management practices, compared to those who did not seek care outside their household, after adjusting for potential confounders. There were no statistically significant differences in the management of diarrhoea between mothers and caregivers who did not seek care outside their household, and respondents who sought care in private facilities or with traditional healers.

3.4. Knowledge regarding causes, preventive measures and recommended management interventions for childhood diarrhoea

Table 7 presents mothers' and caregivers' knowledge on causes, preventive measures and recommended treatment of diarrhoea. While 325 (88.6%) of the mothers and caregivers had knowledge on the causes of diarrhoea overall, we observed significant differences between zones (p = 0.008). Table 7 also indicates that half of the respondents (n = 185, 50.4%) mentioned two pathways through which people can contract diarrhoea; poor hygiene practices and contaminated water were given by 92 (25.1%) and poor hygiene practices and contaminated food by another 80 (21.8%) of the respondents. Among those who identified one single cause (n = 102, 27.8%), poor

Table 3
Proportion of children with diarrhoea who have been given any of the four recommended interventions, stratified by zones in Mbour, Senegal, October 2016.

Zone (N = 367)	Proportion of children with diarrhoea in the 2 weeks prior to the survey who were given:				
	ORS n (%)	Zinc n (%)	ORS/zinc n (%)	Continued feeding n (%)	Increased fluids n (%)
UCA	20 (22.9)	3 (3.4)	2 (2.3)	76 (87.4)	10 (11.5)
PCA	29 (18.6)	2 (1.3)	12 (7.7)	133 (85.3)	10 (6.4)
NPA	10 (13.7)	–	4 (5.5)	64 (87.7)	10 (13.7)
SPA	9 (17.6)	–	2 (3.9)	46 (90.2)	8 (15.7)
Overall	68 (18.5)	5 (1.4)	20 (5.4)	319 (86.9)	38 (10.3)

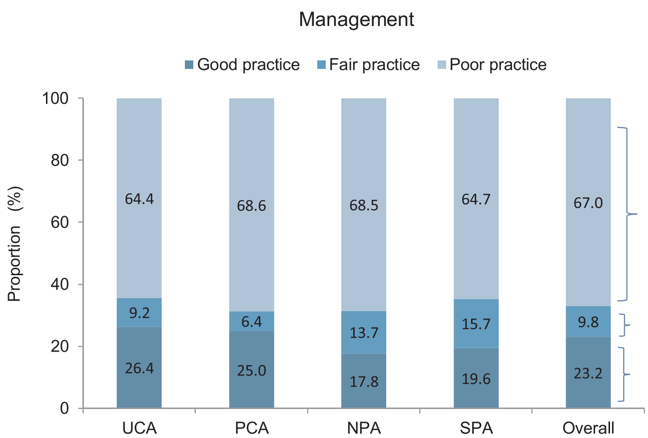

Fig. 2. Management practices on diarrhoea among mothers and caregivers with children aged 5 years and below having had diarrhoea in the 2 weeks preceding the survey, stratified by zone in Mbour, Senegal, October 2016.

hygiene practices was the predominant cause of diarrhoea mentioned (n = 32, 31.4%), while 42 (11.4%) of the respondents did not mention any cause of diarrhoea. Moreover, almost half of the interviewed mothers and caregivers knew how diarrhoea can be prevented.

Of the 188 mothers and caregivers of children with diarrhoea who sought advice or treatment during a diarrhoeal episode, 147 (78.2%) reported knowing how to prepare ORS at home, but less than half of them (n = 66, 44.9%) were able to adequately prepare the solution. Fig. 3 presents the distribution of good, fair and poor knowledge on the causes of diarrhoea, preventive measures and recommended treatment, stratified by zone. Overall, 128 (40.0%) of the mothers and caregivers had good knowledge with significant differences between zones ($p < 0.001$). The prevalence of good knowledge ranged from 10% in NPA to 68% in PCA. Table 6 presents the unadjusted and adjusted ORs and 95% CIs for good knowledge by source of care. Compared to mothers who did not seek care for their child, those who sought care at public or private health facilities were significantly more likely to have a good knowledge regarding causes (adjusted OR 2.71, 95% CI: 1.47–4.99) and preventive measures and recommended treatment (adjusted OR 2.96, 95% CI: 0.98–8.92). The level of management practices, knowledge and socio-demographic and economic characteristics of the mothers and caregivers of children with diarrhoea are presented in a supplementary file (Table S3).

4. Discussion

In the present study, we assessed the knowledge and practice of mothers and caregivers on management of childhood diarrhoea among children under the age of 5 years in four zones of Mbour, a medium-sized town located in south-western Senegal. We determined knowledge and practices of mothers and caregivers on management of childhood diarrhoea at the unit of the household, as these factors are considered important for reducing mortality and morbidity related to diarrhoea. We found that, despite the availability of affordable, effective and simple-to-use treatments, diarrhoeal disease burden is still high among under 5-year-old children in this urban part of Senegal. Indeed, our findings showed that 40.0% of mothers and caregivers had high level of knowledge on causes and prevention measures of childhood diarrhoea, while only 23.2% had good practice on management of diarrhoea. We also found significant differences in knowledge and practice of mothers and caregivers on management of diarrhoea according to the source of care used. For example, mothers and caregivers having sought care from public health facilities had two and four times higher odds of a good level of knowledge and practices on management of childhood diarrhoea, respectively, compared to those seeking no care outside the home or from traditional healers.

The majority of mothers and caregivers interviewed reported to have some level of knowledge regarding causes of childhood diarrhoea.

Table 4
Percentage of children with diarrhoea in the 2 weeks preceding the survey, according to quality of diarrhoea management practice, stratified by source of care and zone in Mbour, October 2016.

Zone	Care-seeking for diarrhoea[a]														
	Public health facility[b]			Private health facility[c]			Community health worker			Traditional healer			No care outside household		
	Good n (%)	Fair n (%)	Poor n (%)	Good n (%)	Fair n (%)	Poor n (%)	Good n (%)	Fair n (%)	Poor n (%)	Good n (%)	Fair n (%)	Poor n (%)	Good n (%)	Fair n (%)	Poor n (%)
UCA	18 (52.9)	2 (5.9)	14 (41.2)	2 (25.0)	–	6 (75.0)	–	–	–	–	–	8 (100.0)	3 (8.1)	6 (16.2)	28 (75.7)
PCA	19 (31.1)	5 (8.2)	37 (60.7)	1 (14.3)	–	6 (85.7)	2 (100.0)	–	–	4 (23.59)	1 (5.9)	12 (70.6)	13 (18.8)	4 (5.8)	52 (75.4)
NPA	6 (28.6)	3 (14.3)	12 (57.1)	1 (33.3)	–	2 (66.7)	–	–	–	–	2 (40.0)	3 (60.0)	6 (13.6)	5 (11.4)	33 (75.0)
SPA	6 (66.7)	–	3 (33.3)	–	1 (16.7)	5 (83.3)	1 (100.0)	–	–	1 (16.7)	4 (66.7)	1 (16.7)	2 (6.9)	3 (10.3)	24 (82.8)
Overall	49 (39.2)	10 (8.0)	66 (52.8)	4 (16.7)	1 (4.2)	19 (79.2)	3 (100.0)	–	–	5 (13.9)	7 (19.4)	24 (66.7)	24 (13.4)	18 (10.1)	137 (76.5)

[a] There are no statistically significant differences in the quality of diarrhoea management practice between zones, indicated by X^2 test.
[b] Public facility including hospital, health centre and health post.
[c] Private facility, including clinics, pharmacies, and dispensaries.

Table 5
Percentage of children with diarrhoea in the 2 weeks preceding the survey according to knowledge of diarrhoea, stratified by source of care and zone in Mbour, Senegal, October 2016.

Zone	Care-seeking for diarrhoea[a]														
	Public health facility			Private health facility			Community health worker			Traditional healer			No care outside household		
	Good n (%)	Fair n (%)	Poor n (%)	Good n (%)	Fair n (%)	Poor n (%)	Good n (%)	Fair n (%)	Poor n (%)	Good n (%)	Fair n (%)	Poor n (%)	Good n (%)	Fair n (%)	Poor n (%)
UCA	2 (6.7)	9 (30.0)	19 (63.3)	–	5 (50.0)	5 (50.0)	–	–	–	–	5 (62.5)	3 (37.5)	5 (16.1)	20 (64.5)	6 (19.3)
PCA	5 (8.9)	21 (37.5)	30 (53.6)	–	3 (42.9)	4 (57.1)	1 (50.0)	–	1 (50.0)	3 (18.7)	4 (25.0)	9 (56.2)	16 (27.6)	18 (31.0)	24 (41.4)
NPA	3 (23.1)	6 (46.1)	4 (30.8)	2 (66.7)	1 (33.3)	–	–	–	–	2 (40.0)	3 (60.0)	–	18 (47.4)	14 (36.8)	6 (15.8)
SPA	–	4 (44.4)	5 (55.6)	–	1 (20.0)	4 (80.0)	–	–	1 (100)	5 (83.3)	–	1 (16.7)	11 (42.3)	7 (26.9)	8 (30.8)
Overall	10 (9.3)	40 (37.0)	58 (53.7)	2 (9.5)	8 (38.1)	11 (52.4)	1 (33.3)	–	2 (66.7)	10 (28.6)	12 (34.3)	13 (37.1)	50 (32.7)	59 (38.5)	44 (28.8)

[a] The X^2 test showed significant differences in knowledge regarding causes and preventive measures of diarrhoea and ORS use and its preparation between zones in Mbour.

Table 6
Unadjusted and adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for good diarrhoea management practice and good knowledge of mothers, stratified by source of care sought in Mbour, October 2016.

Good management practices	Unadjusted OR and 95 % CI		Adjusted OR and 95 % CI*		(%)
	OR (95 % CI)	P-value	OR (95 % CI)	P-value	
No care outside home	Ref		Ref		28.2
Public health facility care	4.42 (2.53–7.70)	< 0.001	4.17 (2.35–7.39)	< 0.001	61.2
Private health facility care	1.29 (0.41–4.10)	0.664	1.24 (0.37–4.09)	0.728	4.7
Tradipratician and parents	1.04 (0.37–2.94)	0.939	1.01 (0.35–2.92)	0.979	5.9
Good knowledge	**Unadjusted OR and 95 % CI**		**Adjusted OR and 95 % CI**		**(%)**
	OR (95 % CI)	P-value	OR (95 % CI)	P-value	
No care outside home	Ref		Ref		34.4
Public health facility care	2.91 (1.74–4.86)	< 0.001	2.71 (1.47–4.99)	< 0.001	46.8
Private health facility care	2.72 (1.08–6.87)	0.034	2.96 (0.98–8.92)	0.053	8.6
Tradipratician and parents	1.46 (0.68–3.16)	0.332	1.75 (0.72–4.25)	0.213	10.2

*The model estimating for the probability of "good" management practice, and for "good" knowledge on source of care were adjusted by mothers/caregiver's age, socioeconomic status, occupational status, educational level, child age, child sex and zone.

Poor hygiene practices, consumption of contaminated water and food were often mentioned by the mothers and caregivers as causes of diarrhoea. Yet, 11% of the mothers and caregivers interviewed had no knowledge of the causes of diarrhoea. Similar findings on knowledge pertaining to the causes of diarrhoea were reported in previous studies conducted in Kenya and Nigeria, where caregivers stated unclean water and contaminated food as the main causes of diarrhoea in young children (Othero et al., 2008; Okoh and Alex-Hart, 2014). A recent study carried out in Odukpani, Nigeria, reported that about 60% of the caregivers identified at least one cause of childhood diarrhoea (Osonwa et al., 2016). Our findings are in line with prior observations elsewhere in sub-Saharan Africa; most of the mothers knew how to prevent diarrhoea. The high level knowledge about causes of diarrhoea may be explained by the relatively high rate of seeking care at health facilities and diffusion of information related to diarrhoea.

More than 60% of the mothers and caregivers of children with diarrhoea in the present study had heard about ORS. Yet, 35% had never heard about this recommended treatment for prevention of dehydration, although rehydration is a major cause of death during diarrhoeal episodes. Two previous studies conducted in Nigeria reported that 62% and 85% of mothers interviewed were aware of ORS (Olakunle et al., 2012; Osonwa et al., 2016). In addition, more than 80% of them obtained specific information regarding ORS and zinc or learned about ORS and zinc from health workers. Similar to a previous study conducted in The Gambia in 2013, 80% of the mothers learned about ORS from a health worker (Sillah et al., 2013). In our study, among those mothers and caregivers who had reportedly heard of ORS, 20% never used it, while only 44.9% knew how to prepare the solution and described the correct method of ORS preparation. Our findings are consistent with a study carried out in Fenote Selam town, Ethiopia, which reported that 45% of the mothers knew how to prepare ORS (Amare et al., 2014). Other studies reported considerably lower proportions of mothers (17.5% and 29.8%) who knew the correct method for preparing ORS (Shah et al., 2012; Osonwa et al., 2016). Our findings also suggest that there is a gap in knowledge about the correct preparation of ORS in Senegal, corroborating findings from elsewhere (Sillah et al., 2013). Hence, ORS preparation should be one of the essential components of practical mother and child educational

Table 7
Knowledge regarding causes of diarrhoea, preventive measures and recommended treatments among mothers and caregivers of children with diarrhoea in the last 2 weeks prior to the survey, stratified by zones in Mbour, Senegal, October 2016.

Variable	All N = 367 n (%)	UCA* N = 87 n (%)	PCA** N = 156 n (%)	NPA*** N = 73 n (%)	SPA**** N = 51 n (%)	P-value[+]
Did you know, what can cause diarrhoea in children?*						***0.008***
No single cause	42 (11.4)	3 (3.4)	13 (8.3)	18 (24.7)	8 (15.7)	
One cause	102 (27.8)	30 (34.5)	41 (26.3)	15 (20.5)	16 (31.4)	
Two causes	185 (50.4)	44 (50.6)	85 (54.5)	36 (49.3)	20 (39.2)	
Three causes	37 (10.1)	10 (11.5)	16 (10.3)	4 (5.5)	7 (13.7)	
Four causes	1 (0.27)		1 (0.64)			
Have you heard about ORS?						***0.008***
Yes	235 (64.0)	57 (65.5)	114 (73.1)	36 (49.3)	28 (54.9)	
No	129 (35.1)	29 (33.3)	40 (25.6)	37 (50.7)	23 (45.1)	
Not indicated	3 (0.8)	1 (1.1)	2 (1.3)			
Did you know how to prepare ORS?						0.514
Yes	147 (78.2)	34 (75.6)	79 (81.4)	14 (63.6)	20 (83.3)	
No	40 (21.3)	11 (24.4)	17 (17.5)	8 (36.4)	4 (16.7)	
Not indicated	1 (0.5)		1 (1.0)			
Can you demonstrate the preparation steps?						0.239
Correct	66 (44.9)	14 (41.2)	32 (40.5)	7 (50.0)	13 (65.0)	
Incorrect	81 (55.1)	20 (58.8)	47 (59.5)	7 (50.0)	7 (35.0)	
Have you ever combined ORS with zinc?						0.011
Yes	53 (28.2)	5 (8.8)	36 (31.6)	5 (12.2)	7 (25.0)	
No	129 (68.6)	52 (91.2)	73 (64.0)	36 (87.8)	19 (67.9)	
Not indicated	6 (3.2)	5 (4.39)	5 (4.39)		2 (7.1)	
Did you know how to prevent diarrhoea?**						***0.007***
No single preventive measure	62 (16.9)	5 (5.7)	23 (14.7)	18 (24.7)	16 (31.4)	
One preventive measure	188 (51.2)	46 (52.9)	86 (55.1)	35 (47.9)	21 (41.2)	
Two preventive measures	100 (27.2)	34 (39.1)	39 (25.0)	16 (21.9)	11 (21.6)	
Three preventive measures	2 (0.5)		1 (0.6)		1 (1.9)	
Four preventive measures	15 (4.1)	2 (2.3)	7 (4.5)	4 (5.5)	2 (3.9)	
Overall knowledge						< ***0.001***
Poor	73 (22.8)	7 (9.3)	25 (18.0)	25 (42.4)	16 (34.0)	
Fair	119 (37.2)	37 (49.3)	46 (33.1)	24 (40.7)	12 (25.5)	
Good	128 (40.0)	31 (41.3)	68 (48.9)	10 (16.9)	19 (10.4)	

*Number of causes identified.
**Number of preventive measures identified.
Categories regarding diarrhoea causes (1 = lack of hygiene, 2 = consumption of unsafe drinking water; 3 = consumption of contaminated food; 4 = infection or germs; 5 = don't know the causes; 6 = not indicated).
Categories regarding diarrhoea prevention measures (1 = have a good hygiene behaviour; 2 = hand washing before eating with soap, 3 = hand washing before feeding, 4 = hand washing with soap after defecation, 5 = protecting food from microbes; 6 = immunization, 7 = avoiding wastewater contact and place at risk of contamination, 8 = drug distribution for diarrhoea treatment).
+ p-value refer to the respective differences between zones and they derive from a X^2 test.

programmes in low- and middle-income countries in order to improve their knowledge for a better diarrhoeal management.

A low level of ORS coverage is a major driver of poor practice on management of childhood diarrhoea. Of the 367 children with diarrhoea in the 2 weeks prior to our survey, only 68 (18.5%) received ORS. This percentage is lower than that reported in other African countries; 24% in Burkina Faso, 28.4% in Ghana, 43.5% in Nigeria and 45.9% in Ethiopia (Wilson et al., 2012; Saltzman et al., 2013; Amare et al., 2014; Osonwa et al., 2016). Differences in the proportion of ORS use might be related to idiosyncrasies of the study settings and level of knowledge of the mothers and caregivers regarding the management of childhood diarrhoea. The low coverage of receiving ORS and poor quality

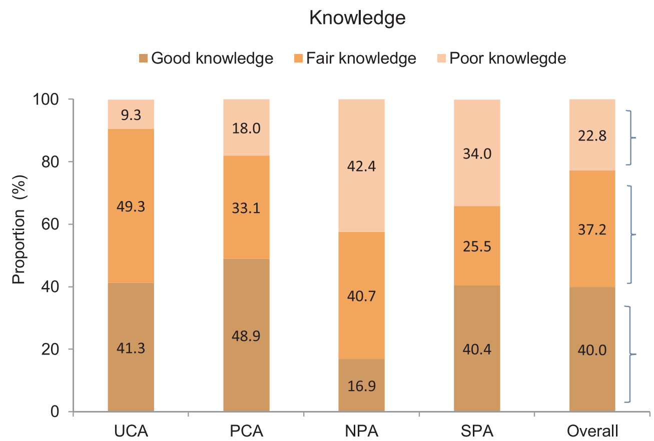

Fig. 3. Level of knowledge on diarrhoea among mothers and caregivers with children under 5 years of age having had diarrhoea in the 2 weeks preceding the survey, stratified by zone in Mbour, Senegal, October 2016.

management might also be explained by a limited availability ORS at the health facilities (Diaby et al., 2016). However, even when children have access to health care, many of them still fail to be treated with ORS. There are several barriers that may lead health workers to underprovide ORS. First, due to supply and distribution issues, ORS and zinc are frequently out of stock at all levels of the health system in Senegal, and hence, might be inaccessible for parents (Gitanjali and Weerasuriya, 2011; Gill et al., 2013; Diaby et al., 2016). Second, due to a lack of adequate knowledge of importance rules for the use of ORS and zinc to be given at home, many health care providers just prescribe antibiotics to treat children suffering of diarrhoea (Mittal and Mathew, 2001). Health care providers should be able to educate mothers and caregivers on the importance of the utilization of ORS in diarrhoeal management of children at home. Third, private providers may have limited ability to generate benefit from ORS in comparison to other treatments, as ORS is relatively inexpensive and often subsidized by the government.

The results of our regression analyses showed that good knowledge and practice on management of childhood diarrhoea were significantly more frequent among mothers and caregivers seeking care from a public health facility than among those who did not seek care outside the household or turned to a traditional healer. Diarrhoea care-seeking from the private health facility was also associated with higher odds of good knowledge. A previous study also observed a significant association between diarrhoea care-seeking from health facilities and good management practices (Carvajal-Velez et al., 2016). Even if the mothers and caregivers who sought care in a public health facility had good knowledge and practice on management of diarrhoea, only 61.2% of children were given high-quality management during a diarrhoeal episode. The high level of poor diarrhoeal management observed was similar in the four zones, ranging between 64.4% and 68.6%.

Our study has several limitations that are offered for consideration. First, the main focus of our study was on mothers and caregivers of children under 5 years of age who experienced diarrhoea in the 2 weeks prior to a cross-sectional survey. This limits the power of our analysis and excludes those who did not have children with diarrhoea. As the study was primarily designed to identify risk factors of childhood diarrhoea, the results of the present paper may be weakened by a lack of statistical power. Nevertheless, we found some strongly significant differences in knowledge of caregivers according to type of health facility used. Although associations between knowledge of mothers and caregivers and type of source of care used were adjusted for educational attainment of the caregiver, we cannot completely rule out some remaining bias due to residual reverse causality. Hence, generalization of our findings to the whole population of Mbour and other urban settings in Senegal is not possible. The study might be replicated on a larger sample to validate and generalize the findings. Second, it is conceivable that the clinically defined cases of diarrhoea were misclassified because the information on the number of loose bowel movement and stool consistency depended on mothers' and caregivers' reports. It was not possible to validate the accuracy of these reports and no laboratory confirmation of the aetiology of the reported diarrhoea was made (Becker et al., 2013). Third, our cross-sectional design and a 2-week recall period for diarrhoea tend to over-represent longer duration episodes because mothers and caregivers are more likely to remember on illnesses episodes that are ongoing at the time of the interview than those that had been resolved (Koepsell and Weiss, 2014). Under-reporting of previously resolved episodes of shorter duration by mothers and caregivers could also affect the conclusion regarding diarrhoeal case management practices if children with shorter episodes were less likely to have been treated. Despite these limitations, our findings are of direct public health relevance and call for setting-specific promotion of health education messages related to diarrhoea in the city of Mbour.

In conclusion, the findings presented here showed that mothers and caregivers had reasonable knowledge on causes of, and preventive measures against, diarrhoea on one hand, but lacked knowledge on ORS preparation on the other hand. There is a need to intensify the promotion and implementation of relevant policies for diarrhoea control and treatment in Mbour and elsewhere in Senegal. This requires strengthening of the capacity of mothers and caregivers and health governance actors who are involved in the implementation of a diarrhoeal control strategy, and to ensure a regular supply of the health facilities with ORS and zinc. It will be important that mass media and health education programmes are tailored to mothers and caregivers, including those not currently utilizing public health facilities. In addition, the role of health care providers is crucial to increase awareness of appropriate and optimal use of ORS among mothers and caregivers. The combined role of health workers and mass media will provide the needed knowledge to the mothers and caregivers about the benefits of using ORS and zinc and the simple needs of preparation at household level in the sense of a good diarrhoea management. Hence, only an enhanced knowledge of mothers and caregivers regarding diarrhoeal practices would have a positive effect on management of diarrhoea in young children. Efforts to increase care-seeking and improve quality of care for childhood diarrhoea are a public health priority in Mbour and perhaps in other similar settings of Senegal and elsewhere in sub-Saharan Africa.

Author's contribution

ST, IS, AN-D, OF, JU and GC designed the study. ST, IS and AN-D coordinated the field data collection. ST and CS did the statistical analysis. ST wrote the first draft of the manuscript. IS, CS, AND, OF, JU and GC reviewed the manuscript. All authors read and approved the final version of the manuscript prior to submission.

Author details

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Conflict of interests

The authors declare that they have no conflicts of interest to disclose.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.actatropica.2019.03.013.

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11. Discussion

Diarrhoeal diseases are among the most important infectious diseases in West Africa (Table 11.1), especially for children under the age of 5 years, despite improvements in health, improved management and increased use of oral rehydration salts (ORS). Senegal bears some of the highest burdens (in terms of DALYs) of diarrhoeal diseases among young children (Figure 11.1). Even though the burden of diarrhoeal diseases decreased by 6% between 1990 and 2016, it is still responsible for 325,335 DALYs (13,776 DALYs per 100,000 children below the age of 5 years) (IHME 2015). While diarrhoea remains a pressing public health issue, previous studies were mainly conducted in rural areas or in capital cities rather than in "small and medium-sized cities", the so-called "secondary cities". It is important to note that there is a paucity of epidemiological data pertaining to diarrhoea in secondary cities in Senegal, and elsewhere in Africa face a lack of epidemiological data at small scale. Yet, high-resolution data are needed for effective guidance and optimal planning of interventions in contexts with limited resources.

The current PhD thesis was conducted in Mbour, a secondary city of Senegal, characterized by rapid urbanization and where the control of infectious diseases, including diarrhoea, is still problematic. The overarching goal of this PhD thesis was to provide further disaggregated evidence on diarrhoeal disease prevalence and incidence among children under the age of 5 years and on associated risk factors in order to improve disease control through the implementation of targeted preventive measures. To achieve this goal, the PhD work pursued the following five specific objectives: (i) to provide an overview of the urbanization trends of the secondary city of Mbour and its effects on water supply, sanitation and hygiene (WASH), including wastewater and solid waste management systems (Chapter 6); (ii) to determine the prevalence of diarrhoea among children under the age of 5 years and its associated risk factors in four different zones of the city (Chapter 7); (iii) to investigate the association between childhood diarrhoeal incidence and climatic factors, such as temperature and rainfall (Chapter 8); (iv) to map the spatial pattern of diarrhoea and estimate the effect of sociodemographic and climatic factors on diarrhoea morbidity using a Bayesian conditional autoregressive (CAR) model (Chapter 9); and (v) to assess mothers'/caregivers' knowledge and management of diarrhoea (Chapter 10).

The current discussion chapter addresses the five aforementioned objectives by highlighting the key findings and lessons learned. In the first sections, the key findings from the case studies are discussed in a broader context of diarrhoea epidemiology, WASH and climatic factors in Mbour.

The third section discusses the contribution of the spatial sampling and analysis methods applied in a broader public health context. The fourth section explains how the results support the research mission of the Swiss Tropical and Public Health Institute (Swiss TPH) through innovation, validation and application. The fifth section considers the limitations of the study and highlights future research needs. Finally, Chapter 12 provides some general conclusions and recommendations, including policy implications for public health in the context of global environmental change, Sustainable Development Goals (SDGs) and cities, in term of prevention, treatment and focused interventions for improving children's health in the secondary city of Mbour and in other similar cities in West Africa.

Table 11.1 Three main causes of disease for children under the age of five years old (assessed by attribution of DALYs) in 19 countries of Western Africa in 2016 (from the GBD estimates database)

	Cause of disease #1	Cause of disease #2	Cause of disease #3
Western sub-Saharan Africa			
Benin	Malaria	Diarrhoeal diseases	Lower respiratory infections
Burkina Faso	Malaria	Lower respiratory infections	Neonatal preterm birth
Cameroun	Malaria	Lower respiratory infections	Neonatal preterm birth
Cape Verde	Neonatal preterm birth	Neonatal encephalopathy	Lower respiratory infections
Chad	Diarrhoeal diseases	Lower respiratory infections	Neonatal encephalopathy
Cote d'Ivoire	Malaria	Diarrhoeal diseases	Lower respiratory infections
Gambia	Neonatal preterm birth	Lower respiratory infections	Neonatal encephalopathy
Ghana	Malaria	Neonatal encephalopathy	Neonatal sepsis
Guinea	Malaria	Lower respiratory infections	Neonatal encephalopathy
Guinea-Bissau	Neonatal encephalopathy	Neonatal preterm birth	Diarrhoeal diseases
Liberia	Diarrhoeal diseases	Malaria	Neonatal encephalopathy
Mali	Malaria	Diarrhoeal diseases	Neonatal encephalopathy
Mauritania	Neonatal preterm birth	Lower respiratory infections	Neonatal encephalopathy
Niger	Malaria	Diarrhoeal diseases	Lower respiratory infections
Nigeria	Malaria	Diarrhoeal diseases	Neonatal encephalopathy
Sao Tome Principe	Lower respiratory infections	Neonatal encephalopathy	Neonatal preterm birth
Senegal	**Diarrhoeal diseases**	**Lower respiratory infections**	**Neonatal preterm birth**
Sierra Leone	Malaria	Diarrhoeal diseases	Lower respiratory infections
Togo	Malaria	Neonatal encephalopathy	Neonatal preterm birth

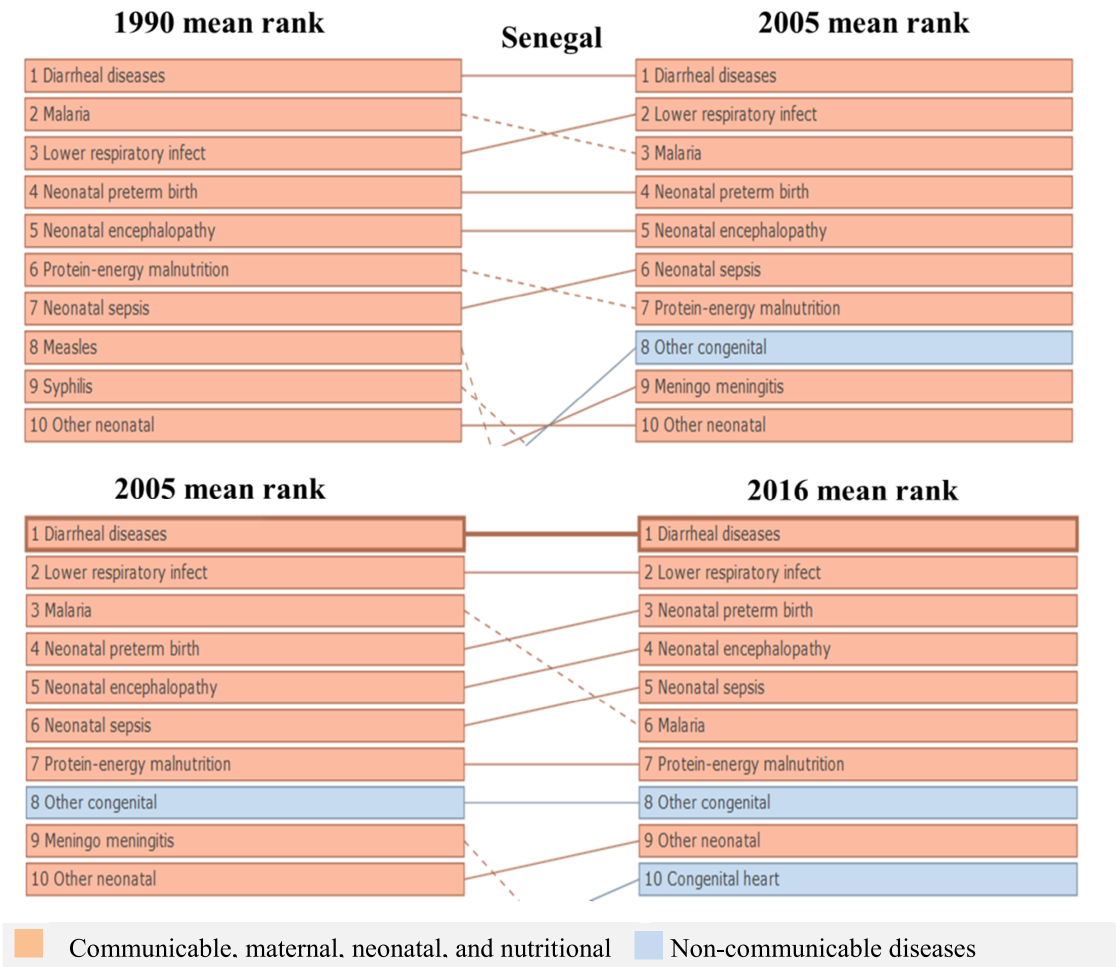

Figure 11.1 Arrow diagram of the GBD study 2010 showing the 10 main cause of disease in children for Senegal in Disability-adjusted life years between 1990 and 2005, 2005 and 2016.

11.1. Epidemiology of diarrhoea and WASH conditions in Mbour

Our findings from the cross-sectional epidemiological surveys (Chapters 7 & 9) showed that diarrhoeal diseases constitute an important public health problem among children under the age of 5 years in the secondary city of Mbour. This study compared diarrhoea prevalence (recall period: 2 weeks) and risk factors among children under the age of 5 years in four zones of Mbour. We found that the 2-week caregiver-reported prevalence of diarrhoea among this age group was 26.0% and 33.9%, in 2014 and 2016, respectively, which are slightly above the rates reported for the same age group in the 2014 Senegalese Demographic and Health Survey (DHS) (19%) and the 2016 Senegalese DHS (15%) (ANSD and ICF International, 2015; ANSD and ICF International, 2017). However, the rate we found in the 2014 survey is below that reported in the ENSAN 2013 survey report (32%) for the Thiès region, where Mbour is located; while the rate found in the 2016 survey is slightly similar to this finding (ENSAN, 2013). The differences might be explained by the different survey periods.

Our 2016 survey was conducted during the rainy season, as was the ENSAN survey (conducted in the beginning of the rainy season in June). The high prevalence of diarrhoea in urban Senegal found in the present study was observed during our two survey periods, between February and March (cold dry season) and between September and October (rainy season).
Moreover, our analytic and spatial analyses indicate that higher diarrhoeal prevalence prevailed among children living in the Urban Central Areas (UCA) (36.3% in 2014 and 38.3% in 2016) and in the Peri-Central Areas (PCA) (44.8% in 2014 and 34.8% in 2016). In UCA, the prevalence was higher in the neighbourhood nearer the coastal area, namely Tefess (57.1%), Zone Résidentielle (54.3%) and Golf (31.4%). In PCA, the prevalence was higher in the slum Baye Deuk (57.1%), located at the heart of the city. Hence, our study highlights that there is considerable spatial heterogeneity of diarrhoeal prevalence in Mbour, which can partially be explained by differences in the distribution of risk factors across zones, such as living conditions, population density, socioeconomic status and WASH conditions.

Our study did not find significant associations between diarrhoeal prevalence and drinking water sources, compared to results from previous studies, which found that water sources are an important environmental predictor of diarrhoea morbidity (Shikur et al., 2013; Wanzahun and Bezatu, 2013). On the other hand, our findings are in line with those from a study conducted in southwest Ethiopia (Gebru et al., 2014). These findings indicate an inconclusive association between diarrhoea and water source, which might be explained by the fact that in urban Africa, there are multiple sources of drinking water (e.g. tap water at home, standpipes, wells, etc.). Even if a household has a water connection at home, an inhabitant might need to go to the public tap or use well water due to recurrent cuts in the network (Dos Santos, 2012; Dos Santos et al., 2015). Hence, we found that the lack of treatment of stored drinking water was positively associated with the prevalence of diarrhoea in Mbour. Significant association was also seen between diarrhoeal prevalence and stored water contaminated by *E. coli*.

Of the households participating in our study, 76% and 72% in 2014 and in 2016, respectively, reported disposing their wastewater in the street; 54% and 64% reported using open plastic bags to store their solid waste (Thiam et al., 2017a). These findings indicate that there is a lack of proper wastewater and solid waste disposal and inadequate sanitary conditions in the city, another factor that may increase the risk of diarrhoea transmission among children through water or food during flooding events. Data from a recent survey conducted in Senegal shows that, respectively, 30% and 61% of the urban population in Dakar and in other urban cities dispose of wastewater in the street, which confirm our findings and the fact that wastewater and solid waste disposal constitute an important public health concern in urban areas in Senegal (ANSD and World Bank., 2015). In addition, our results revealed that the diarrhoeal disease risk was significantly associated with unemployment of mothers (adjusted odds ratio (aOR)=1.62, 95% confidence interval (CI) 1.18–2.23), use of open bags for storing household waste (aOR=1.75, 95% CI 1.00–3.02), evacuation of household waste in public streets (aOR=2.07, 95% CI 1.20–3.55), no treatment of stored drinking water (aOR=1.69, 95% CI 1.11–2.56) and use of shared toilets (aOR=1.69, 95% CI 1.11–2.56). Previous studies conducted in other African cities show that open disposal of waste around the house increases diarrhoea (Bezatu et al., 2013; Wanzahun and Bezatu, 2013; Oloruntoba et al., 2014). Our findings support the 'urban health penalty' hypothesis, which posits that the poor in urban settings are pushed to marginal areas, where environmental health conditions are not suitable for health. Our findings and those from others call for urgent actions to implement WASH intervention programmes, including increasing the priority of solid waste and wastewater management with the aim of improving children's health.

11.2. Effect of climatic factors on childhood diarrhoea in Mbour

Results from our time-series analysis (Chapter 8) using health surveillance data for the period 2011-2014 showed that in Mbour, diarrhoea was one of the most important causes for seeking health care (23,543 visits, 21.1%), ranking just after lower respiratory infections (35,385 visits, 32.0%). These time-series analyses and those of satellite remote sensing (e.g. temperature and rainfall) for the same period, allowed an examination of the seasonal patterns of diarrhoea in Mbour. We noted a seasonal pattern of diarrhoeal cases in Mbour with two annual peaks in the number of diarrhoeal cases: one in the cold dry season, with 42.7% of the reported cases, and corresponding to the lowest mean temperature and lowest amount of rainfall; and one in the rainy season, marked by high temperature, with 37.8% of the reported cases. We found that in the cold dry season, diarrhoea was more likely to occur in January (17.6% of the reported cases). The high number of diarrhoeal cases in the cold dry season and rainy season is consistent with previous studies in Senegal, which revealed that most diarrhoea cases are due to rotavirus and bacterial infection (Sambe-Ba et al., 2013; Sire et al., 2013). Our findings are also in line with observations made in neighbouring countries, Guinea Bissau (Molbak et al., 1994) and Burkina Faso (Nitiema et al., 2011).

Diarrhoeal cases were more clustered around densely clustered urban settings, compared to less densely populated areas of Mbour, which indicates that high population density, coupled with inadequate sanitary conditions in urban settings leads to water contamination in face of flooding events (Thiam et al., 2017b). Consistent seasonality of diarrhoeal episodes among children was found in Mbour. The finding calls for interventions and mitigation strategies at specific times of the year.

The study also revealed that, apart from seasonality, independent effects of temperature and rainfall are associated with diarrhoeal incidence in Mbour. We found an association between diarrhoeal incidence in children and high average temperatures of 36°C and above and cumulative monthly rainfalls of 57 mm and above, from 2011 to 2014. Children living in rural settings (IRR=1.15; 95% CI: 0.91 - 1.46) appeared to be more vulnerable to the effects of temperature than those living in urban settings (IRR=1.05; 95% CI: 0.93 - 1.19); while rainfall had a significant effect on childhood diarrhoea in urban settings (IRR=1.31; 95% CI: 1.12–1.54). In urban settings, the effects of overcrowding on diarrhoea may be exacerbated by high temperatures, associated with lower water availability for hygiene and sanitation. Hence, the positive association we found between diarrhoea and rainfall in urban settings of Mbour may be due to higher levels of faecal contamination with higher exposure during the rainy season because of non-existent or unimproved sanitation systems. A further explanation is that high rainfall can directly affect the transport of pathogens, and the existing water and sanitation infrastructure, altering human exposure patterns (Levy et al., 2016; Cissé et al., 2016). For instance, if pathogens from animal or human excreta are present in soils and on environmental surfaces, rainfall can mobilize theses pathogens and transport them to surface water or well water, thereby exposing people to pathogens (Dorner et al., 2006).

Findings from previous studies on the association between diarrhoea and rainfall have shown contradictory results. In some cases, studies indicated that rainfall increases the risk of diarrhoea, which is in line with our observations (Singh et al., 2001; Bandyopadhyay et al., 2012; Seidu et al., 2013; Carlton et al., 2014); other studies observed no association between rainfall and diarrhoeal risk (Hashizume et al., 2007; Bhavnani et al., 2014; Mukabutera et al., 2016).

The findings from the current research are largely consistent with the original hypotheses, underscoring the importance of environmental and climatic factors as risk factors for diarrhoeal diseases; these are not uniform across or within zones and neighbourhoods.

Our findings provide evidence that the influence of temperature on diarrhoeal risk is more pronounced in rural areas compared to urban settings, while rainfall is more likely to increase diarrhoeal risk in the urban settings of Mbour. This may be explained by the interaction between climatic factors and differences in hygiene behaviour and sanitation status in urban and rural settings. The identification of climatic factors associated with diarrhoea in this study sheds new light on the possible role of climatic variability in the occurrence of diarrhoea. Furthermore, the potential factors of diarrhoeal seasonality we identified will facilitate future studies assessing the impact of social and economic development on diarrhoeal diseases in Senegal and other similar settings in sub-Saharan Africa.

11.3. Contribution of the spatial sampling and analysis applied in the PhD thesis

This PhD work used an interdisciplinary approach, combining geographical and epidemiological methods. A spatial multi-stage cluster sampling method was adopted using geographical information system (GIS) to select target households, with the aim of identifying particular area(s) in the city of Mbour where diarrhoeal diseases are more prevalent. The choice of method was based on the hypothesis that diarrhoeal risk factors might differ for children living in different areas.

In recent years, significant progress has been made in the development of GIS and its application in public health and spatial epidemiology (Simoonga et al., 2009; Fletcher-Lartey and Caprarelli, 2016). Spatial sampling design of households for survey-based research has begun to draw attention recently due to the greater use of GIS, hand-held global positioning system (GPS) receivers and remote sensing (RS) technologies (Lee et al., 2006). While spatial sampling has been recognized for collecting physical environmental data, such as air pollution, soil minerals and plant species (Gan et al., 2006; Zhu and Stein, 2006), its use for collecting social data has been limited (Kumar, 2007; Jie et al., 2009; Kumar et al., 2011). The change is likely due to the increasing importance of place, space and time in social sciences, especially in public health research. Recent studies have demonstrated the value of spatial sampling methods for population health surveys in low- and middle-income countries (LMICs), where little spatial information is available (Lowther et al., 2009; Escamilla et al., 2014; Kassie et al., 2017).

This PhD research applied spatial analyses methods to generate maps and to visualize, in the form of a succinct video presentation, the urbanization process of Mbour over the past 60 years and the spatial distribution of environmental risk factors associated with diarrhoeal transmission, with an emphasis on WASH factors including solid and wastewater management at neighbourhood level (Chapter 6). An important feature of the maps generated at neighbourhood level is the ability to show the heterogeneity of diarrhoea-associated risk factors within the city. This will facilitate communication with municipal authorities and policymakers for attention to and focused action in priority areas. It also offers a clearer understanding of the spatial distribution of diarrhoea prevalence/incidence and its risk factors and may help decision-makers (e.g. public health authorities) in their efforts to control and prevent diarrhoea among children in these areas.

Of note, this sampling method requires some basic knowledge on the use of GPS and the reading of maps. Nowadays, instead of using expensive spatial data sources (e.g. satellite imagery) or expensive software like ArcGIS, several free-of-charge software packages, like QGIS, data provided by Open Street Map and readily accessible and available RS data, allow this method to be applied in epidemiological household surveys.

Spatial sampling, which builds on the use of geospatial technologies and spatial analytical methods, offers several advantages over the classical methods of field-based social surveys. As the desire and need to work at small scale increases, this method ensures spatial coverage and population representation at multiple geographic scales (parcel, neighbourhood and zone). In such approaches, surveyors have only to find randomly generated points in the field and select the households for surveying (Grais et al., 2007). The random points may be generated through different methods.

In this study, plot centres were used to generate the centroid coordinates of each plot and then produce a random sample from the list of households for the epidemiological household surveys (Figure 11.2). This method provides an alternative sampling technique that reduces selection bias in the surveyed households.

The method offers the possibility of getting spatial disease data and associated risk factors at small scale (e.g. plot, neighbourhood and zone). Kassie et al. (2017) and Lowther et al. (2009) recently applied a similar method for a health survey of urban areas in Burkina Faso and Zambia, while Escamilla et al. (2014) used Google Earth imagery and Digipoint 2 to digitalize household structures in Malawi and produce a random sample from the list of generated households. These studies have shown the applicability of spatial sampling both in regularized areas and in non-regularized areas, and highlight the accuracy of these methods.

This sampling technique is likely to have important implications for survey methodologies for collecting social, demographic and health data (Kumar et al., 2011). The use of spatial sampling methods produces spatial data for small geographic units (e.g. plot, neighbourhood, zone, etc.), and plays a decisive role in the field of public health by supporting decision-making tools.

11.4. Contribution of the thesis to innovation, validation and application

The key findings of the present PhD, conducted at the Swiss Tropical and Public Health Institute (Swiss TPH) within the Ecosystem Health Sciences Unit, contributes to the value chain of the institute that covers the entire spectrum from innovation to validation and application, which, together are important to advance science. Our research provides new evidence and ideas that are significant from a public health perspective for Senegal and other countries in sub-Saharan Africa. The main contributions of the PhD thesis research are presented in Table 11.2.

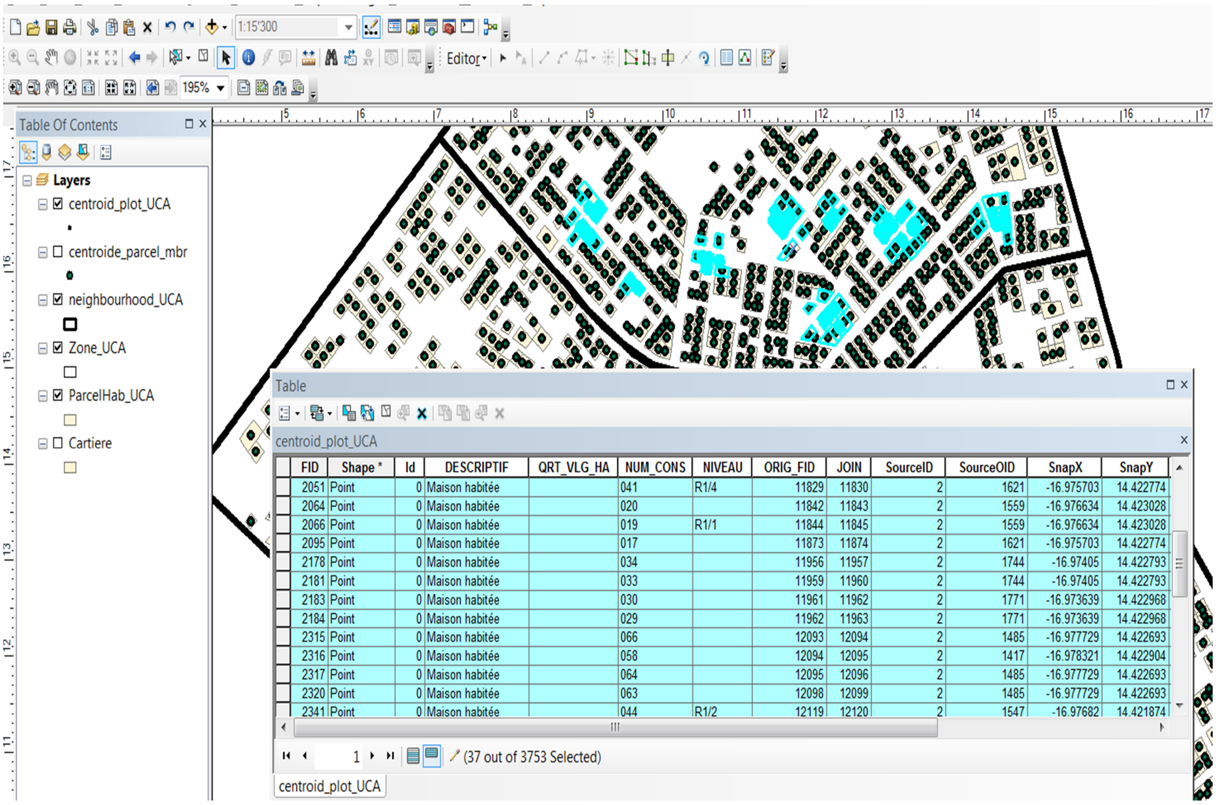

Figure 11.2 Example of the spatial distribution of generating centroid coordinates of the plots for the random selected households for the epidemiological household surveys in Mbour

Table 11.2 Summary of the PhD thesis contribution to the Swiss TPH research mission of innovation, validation and application

	Innovation	Validation	Application
Chapter 6	Visualization of urbanization trends and its effect on childhood diarrhoea risk factors in form of a novel video contribution		Communication with policymakers and municipal officials to advocate for attention and action to improve water access, sanitation system coverage and hygiene including waste and solid waste management
Chapters 7 & 9		Identification of spatial pattern of diarrhoea risk and comparison of prevalence and risk factors with findings from previous epidemiological surveys in LMICs	Identification of risk factors, high risk group and areas for preventive measures and interventions to reduce the burden of diarrhoea in the secondary city of Mbour
Chapter 8	Few studies used remote sensing data to assess the effect of climatic factors such as temperature and rainfall on childhood diarrhoea	Identification of seasonal pattern and climate parameters associated with diarrhoeal incidence and comparing incidence with previous findings	Identification of period of the year where control and preventive measures should be more suitable in Mbour
Chapter 10		Assessing knowledge and management practices of mothers/caregiver's of children based on the WHO/UNICEF recommendations for diarrhoea cases management in children	Identification of poor level of knowledge and management practices for diarrhoea, which show a need to intensify the promotion and implementation of relevant policies for diarrhoea control and treatment

11.5. Limitations and recommendations for research needs

Our study has several limitations that are presented for consideration. Future research should be conducted to expand upon the findings of the research presented in this PhD thesis.

- Diarrhoea prevalence was assessed based on parents/caregivers' reports, which may have introduced some recall bias, despite the relatively short recall period of 2 weeks. As this is the standard reference from WHO and the DHS, we presented and analysed our results according to this period.
- Due to budget limitations, microbiological analysis of stool samples for intestinal parasitic infections among children was not undertaken; future research might include assessment of intestinal parasitic infections and the main pathogens that are responsible for diarrhoea among children under the age of 5 years in Mbour, Senegal.

Such aetiological studies will provide essential information on the extent of specific pathogens in different neighbourhoods for spatial targeting of interventions.

- Epidemiological and molecular studies, including a case-control design and using sensitive diagnostic methods (e.g. PCR), are also warranted to deepen the understanding of virulence of the main pathogens causing diarrhoea and many more risk factors; such knowledge will guide preventive measures and might be necessary for future vaccine programmes.
- Microbiological analysis of drinking water at community (public tap and wells) and household levels was conducted with a small sample in our study. This may explain the weakness of association between various risk factors and diarrhoea. Our laboratory bacteriological analyses were limited to *E. coli* and faecal coliform. Further studies assessing water quality should increase the sample sizes both at community and household levels, and sample water categories multiple times in order to get a stronger conclusive result; upcoming studies should also consider more pathogens and parameters (such as physical and chemical) when analysing water quality.
- Using a cross-sectional approach, our study could not highlight changes in pathogens causing childhood diarrhoea at different seasonal variations; as it is known that the incubation period varies between seasons for viral and bacterial infections, future studies could collect and use lab-confirmed pathogen data over time to more accurately assess the effects of climatic factors, namely temperature and rainfall, and the seasonality of water quality.
- Furthermore, future study designs could account for spatio-temporal variability in climatic factors and environmental risk factors.
- Future studies should also undertake further integrated analyses on behavioural, climatic and socioeconomic factors with more detailed surveillance data, including individual child data, on diarrhoeal causation agents. These analyses will better explain the seasonal peaks and trends in diarrhoeal occurrence as observed in Mbour.

12. Conclusions and recommendations

12.1. Conclusions

The epidemiological questions that motivated the current study and its contribution to the scientific knowledge were to provide further disaggregated evidence on diarrhoeal prevalence and incidence among children under the age of 5 years as well as the associated risk factors in order to improve the control of the disease through the implementation of targeted preventive measures. The current study is one of the few using a multidisciplinary approach to assess the spatial patterns of diarrhoeal diseases and its associated risk factors in a context of a secondary city in Senegal.

Our study identified an important spatial heterogeneity in patterns of diarrhoeal diseases as well as meaningful neighbourhood-level variation in sensitivity to climatic and environmental risk factors in the city of Mbour. Our findings indicated that the reported prevalence of diarrhoea among children under the age of five were high in Mbour; with the highest prevalence observed in the neighbourhoods near coastal area. Moreover, we noted a seasonal fluctuation of diarrhoeal cases in Mbour; and found that diarrhoeal incidence was associated with temperature and rainfall in Mbour. The findings presented in this PhD thesis showed also that mothers/caregivers had good knowledge on causes and preventive measures of diarrhoea, but lack knowledge on ORS preparation. Of note, a low prevalence of good diarrhoeal management practice in children and poor utilisation of ORS was a major concern among the mothers/caregivers of children in the city of Mbour.

We focused in this PhD thesis research on this citywide and localized patterns and risk factors of diarrhoeal diseases among children under the age of 5 years with the aim of informing and guiding future public health intervention on diarrhoea in similar cities. The disaggregated findings provide a useful baseline for more targeted interventions and future studies in more vulnerable urban settings in Mbour. The produced maps aggregated at neighbourhood level are essential for the implementation of diarrhoea control and prevention programmes because they offer valuable information on the areas which are at high risk of diarrhoea. Furthermore, the diarrhoea maps provide a baseline against which the effectiveness of diarrhoea intervention programmes can be assessed. The maps of the city produced in this thesis with an emphasis on drinking water supply, sanitation system and hygiene behaviour can have an important role in planning intervention programmes in these domains as long as they reach the key people in diarrhoea control programmes.

The findings also provide useful information to the existing national programme for the fight against diarrhoea and to all other actors developing targeted interventions for preventing childhood diarrhoea in the country. Our findings support on-going targets of the SDGs which aim to improve modifiable factors, particularly SDG 3 on "good health and well-being"; SDG 6.1 "universal and equitable access to safe and affordable drinking water for all", SDG 6.2 "access to adequate and equitable sanitation and hygiene behaviour"; SDG 11.1 "ensure access to good housing conditions to all". The new SDG era provides a timely opportunity to increase attention to childhood diarrhoea control and prevention through multi-sectorial approach, particularly in the face of predicted effects of climate change on diarrhoea. Understanding the contribution of each cause of diarrhoea burden and how this varies geographically will enable intervention to be targeted. Vaccine use and a continued focus on improving access to WASH indicators, providing appropriate treatment and case management will accelerate reduction in diarrhoeal disease burden in the city and in other similar cities in Senegal.

12.2. Recommendations and policy implications (considering the SDGs targets and climate change impact on diarrhoea)

The findings from the current PhD thesis underscore that strong effort to reduce the burden of diarrhoea, which is the leading cause of child mortality and morbidity among children under the age of 5 years in Senegal, is still needed at policy and effective public health intervention programme (providers, community and household levels). Based on these findings, the following recommendations for public health interventions to policymakers, local authorities and the broader international research and development community are offered for considerations on childhood diarrhoea prevention, treatment and targeted interventions.

Recommendations for focused interventions at the city level

- In light of the fact that children in Mbour are exposed to enormous environmental risk factors (pollution, water contamination, etc.) due to rapid urbanization rate, public health programmes should be taken to protect children from diarrhoea in this secondary city.
- Local authorities must have specific interventions for urban population with difficulties to get drinking water source and adequate sanitation. Urban planning should take in account the water supply, sanitation and hygiene, including wastewater,

solid waste and faecal disposal. Access to WASH is essential; and must be imperatively improved and scaling up if we want to move towards a significant reduction of diarrhoea transmission and achieving the SGDs targets 3 and 6. WASH interventions have shown to be an effective means of reducing diarrhoeal diseases burden elsewhere. However, WASH intervention programmes should be implemented in the city at both household and community level with strong community participation. For instance, national programme for community empowerment can be used by local authorities for encouraging the populations to have their own sanitation facility and promote the use of safe drinking water source. Such interventions tailored to access to safe water and sanitation, including promotion of solid waste disposal and management and reduction of wastewater exposure, should be implemented without delay, particularly in the PCA and the UCA, where diarrhoeal diseases are most common in the city.

- Targeted educational campaign on drinking water storage practices and treatment and handwashing, particularly during the cold dry and the rainy season might be implemented.
- Health education programme should be implemented for the mothers of children and family members about the benefits and use of ORS and zinc and its preparation at household level in the sense of a good diarrhoea management importance.

Climate-diarrhoea related recommendations

- In the cold dry season and in the rainy season interventions focusing on morbidity control and prevention should be launched, particularly in urban settings where diarrhoea is more likely to occur, in order to reduce the incidence in the health district of Mbour in this context of climatic variability, which is expected to increase in urban areas in the face of global warming.
- As it is predicted that climate change will impact children's health, particularly diarrhoea incidence, future public health prevention strategies and disease response tactics may need to include the environmental sector.

Recommendations for prevention and treatment of diarrhoea

- Scaling up diarrhoeal control and prevention in the country by repositioning diarrhoeal control programme in the Ministry of Health (MoH) priority programmes, like malaria, tuberculosis (TB) and HIV, is crucial for achieving the SDGs targets, particularly target 3 on ending preventable child deaths and reducing mortality.

- Allow the actors who are active in the fight against diarrhoea to have financial resources as those made available for the aforementioned programmes by the Global Fund to Fight AIDS, Tuberculosis and Malaria for scaling up diarrhoea control and treatment.
- Invest in first-line health facilities (health post), including community management to reach vulnerable population and ensure rapid assessment and treatment.
- Promote access to commodities such as ORS and zinc for diarrhoea in health facilities by registering diarrhoea in the priority programme of the National Supply Pharmacy (PNA: Pharmacy National d'Approvisionnement) to better monitor and ensure these commodities like malaria, TB and HIV programmes.
- Train the actors who are involved in the implementation of child monitoring programmes both in the administration and use of ORS and zinc, and on the scientific evidence in the fight against diarrhoea.
- Strengthen and revitalize the diarrhoea management steering committee by involving other departments of the MoH and other ministries responsible for WASH.
- Develop a communication plan adapted to the local context to make people aware of hygiene measures.
- Establish a diarrhoea surveillance system to collect and record childhood morbidity and mortality data due to diarrhoea and their causes using new information technologies (e.g. mobile phone or ODK and rapid diagnostic test) in order to address the lack of data on many of these challenges, especially disaggregated data (i.e. data on small area within urban centres), and better estimate the burden and monitor treatment.

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14. Appendix

14.1. Chapter 6

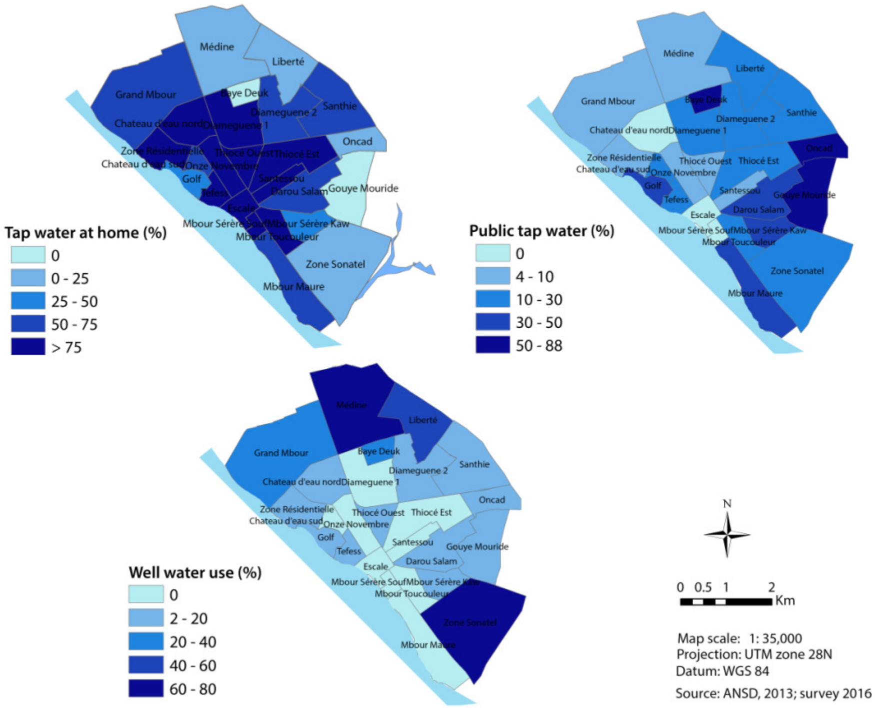

Figure S1: Spatial distribution of the drinking water source stratified by neighbourhood in Mbour. Proportion of visited household with tap water at home (top right); proportion of visited household using public tap water (top left); proportion of visited household using well water (bottom).

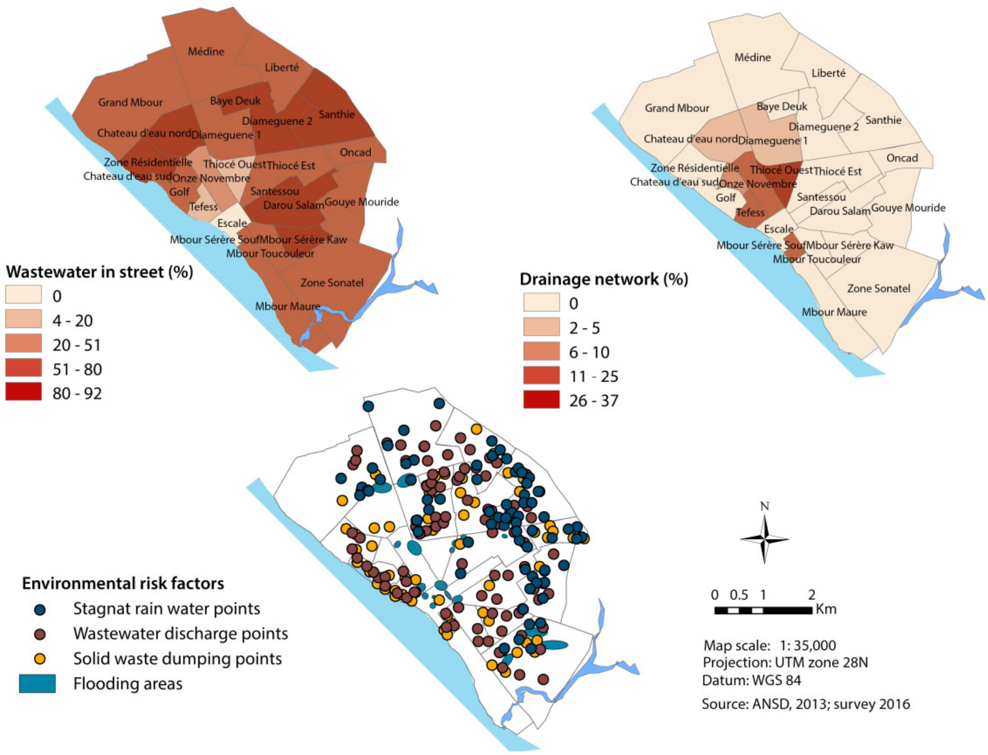

Figure S2: Spatial distribution of wastewater disposal methods stratified by neighbourhood and environmental risk factors in Mbour. Proportion of visited household disposed their liquid waste in the street (right); proportion of visited household disposed their liquid waste through the drainage network (left); environmental risk factors located (bottom)

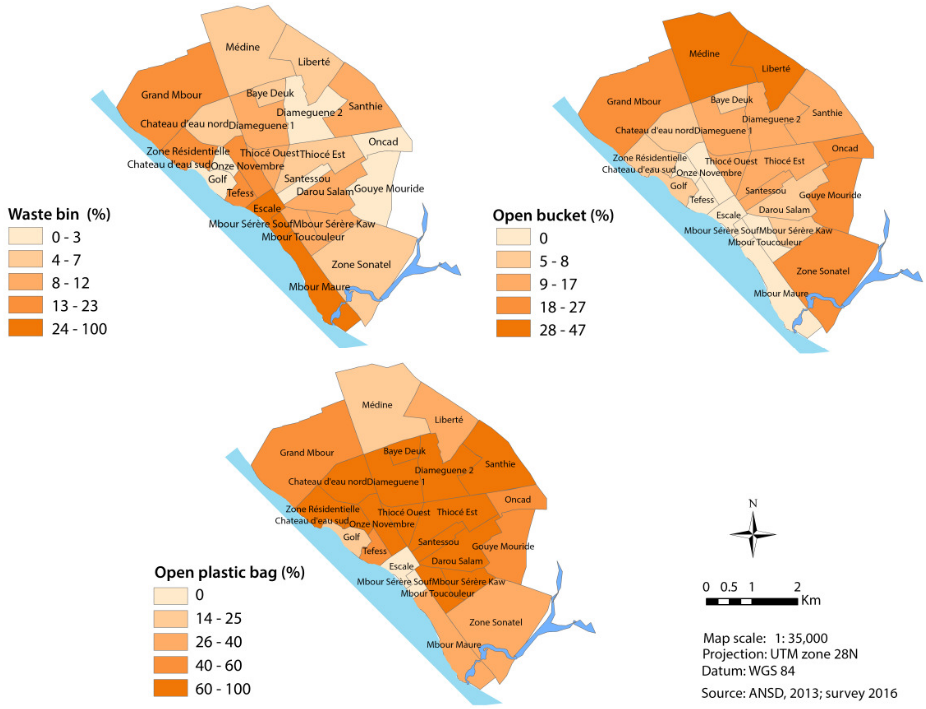

Figure S3: Spatial distribution of solid waste storage methods stratified by neighbourhood in Mbour. Proportion of visited household using waste bin (top right); proportion of visited household using open bucket (top left); proportion of visited household using open plastic bag (bottom).

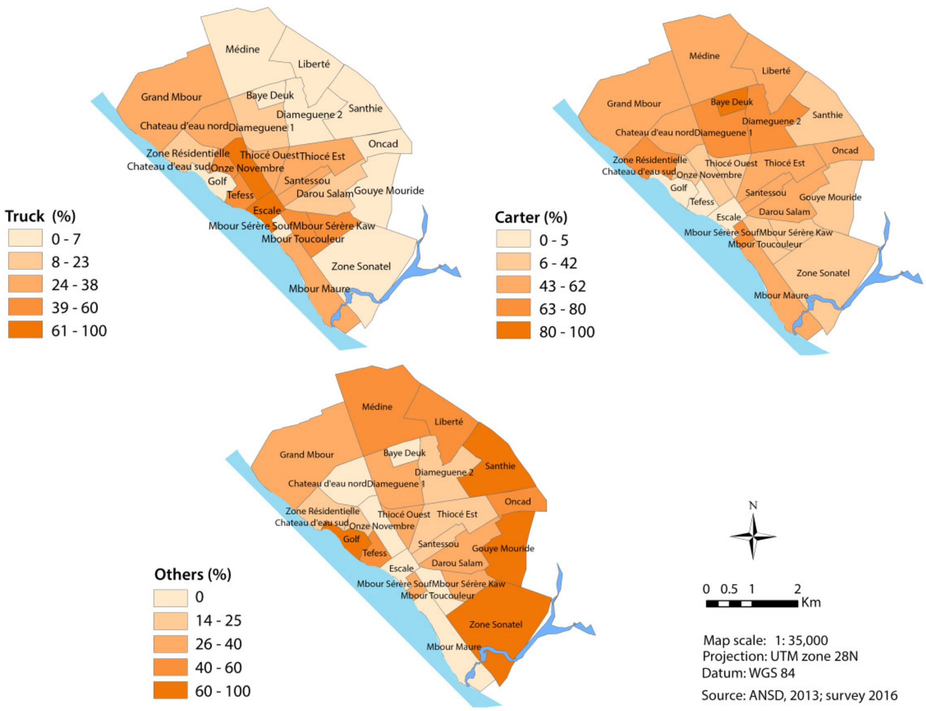

Figure S4: Spatial distribution of solid waste evacuation methods stratified by neighbourhood in Mbour. Proportion of visited household using municipal collection truck (top right); proportion of visited household using private carter collector (top left); proportion of visited household using other methods such as incineration, burial, seaside, wild deposit etc. (bottom).

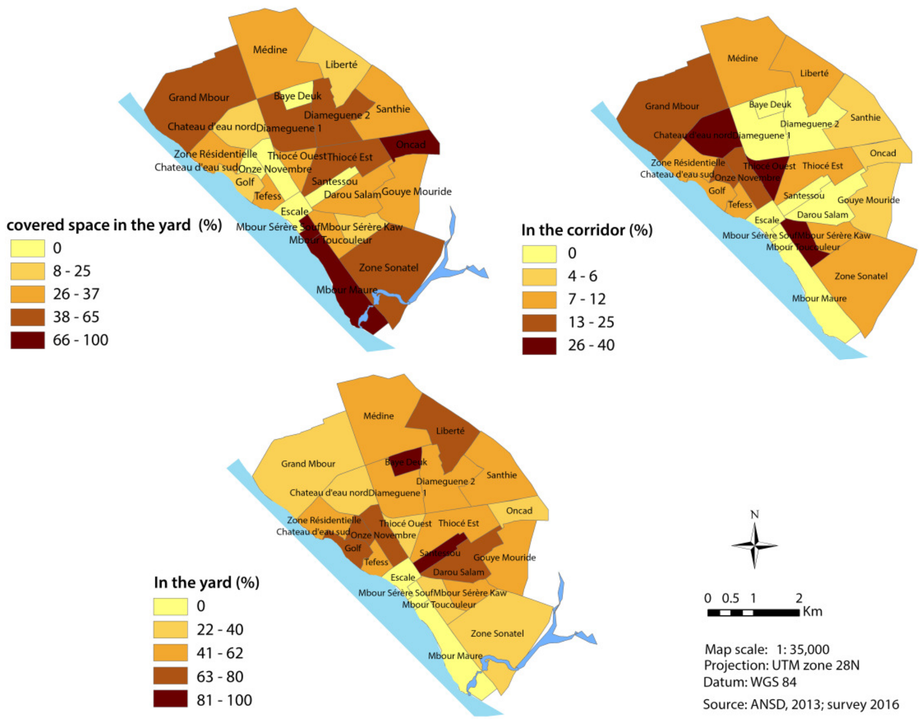

Figure S5: Spatial distribution of the cooking place for household without kitchen stratified by neighbourhood in Mbour. Proportion of visited household cooking in a covered space in the yard (top right); proportion of visited household cooking in the corridor (top left); proportion of visited household cooking in an open space in the yard (bottom).

14.2. Chapter 8: Table S1. Results from the unadjusted negative binomial regression models with climatic variables of the same and the preceding month, in the health district of Mbour (January 2011-December 2014)

Parameter		Unadjusted model	
		Continuous	
		IRR (95%CI)	**P-value**
Average lst[a)]			
Lag 0	Low	Ref	
	Moderate	1.25 (1.04 – 1.72)	0.017
	High	1.02 (0.83 – 1.24)	0.860
	Very high	1.25 (1.00 – 1.55)	0.048
Lag 1	Low	Ref	
	Moderate	1.01 (0.84 – 1.22)	0.895
	High	0.70 (0.58 – 0.86)	< 0.001
	Very high	0.62 (0.49 – 0.77)	< 0.001
Mean LST_{Day} (°C)			
Lag 0	Low	Ref	
	Moderate	1.27 (1.06 – 1.52)	0.010
	High	1.54 (1.25 – 1.90)	< 0.001
	Very high	1.62 (1.29 – 2.03)	< 0.001
Lag 1	Low	Ref	
	Moderate	1.00 (0.83 – 1.21)	0.968
	High	1.11 (0.90 – 1.38)	0.323
	Very high	0.93 (0.74 – 1.18)	0.565
Mean LST_{Night} (°C)			
Lag 0	Low	Ref	
	Moderate	1.03 (0.88 – 1.21)	0.695
	High	0.73 (0.62 – 0.85)	< 0.001
	Very high	0.67 (0.57 – 0.79)	< 0.001
Lag 1	Low	Ref	
	Moderate	0.77 (0.66 – 0.90)	< 0.001
	High	0.76 (0.65 – 0.89)	< 0.001
	Very high	0.53 (0.45 – 0.62)	< 0.001
LST variability[b)]			
Lag 0	Low	Ref	
	Moderate	1.48 (1.25 – 1.75)	< 0.001
	High	1.95 (1.62 – 2.34)	< 0.001
	Very high	1.95 (1.59 – 2.40)	< 0.001
Lag 1	Low	Ref	
	Moderate	1.37 (1.16 – 1.62)	< 0.001
	High	1.57 (1.30 – 1.89)	< 0.001
	Very high	1.42 (1.16 – 1.75)	< 0.001
Mean cumulative rainfall (mm)			
Lag 0	Low	Ref	
	Moderate	1.18 (1.01 – 1.38)	0.035
	High	1.02 (0.85 – 1.23)	0.830
Lag 1	Low	Ref	
	Moderate	1.12 (0.96 – 1.31)	0.130
	High	1.21 (1.01 – 1.45)	0.037

IRR: Incidence-rate ratio; LST: Land surface temperature; a) Average of LST_{Day} and LST_{Night}; b) Difference LST_{Day} and $LST_{Night.}$ Categories: LST_{Day} - low (<27), moderate (27-32), high (32-36), very high (>=36). LST_{Nigh}t - low (<18), moderate (18-19), high (19-21), very high (>=21). LST-low (<24), moderate (24-26), high (26-28), very high (>=28). LST variability -low (<8), moderate (8-12), high (12-18), very high (>=18). Rainfall - low (<=12), moderate (13-56), high (>=57). The model also included health facility as fixed factors.

Table S2. Results from the adjusted negative binomial regression model with climatic variables of the same and preceding month, in the health district of Mbour (January 2011- December 2014).

		Adjusted model	
Parameter		**IRR (95%CI)**	***P-value***
Residual lag 1		1.04 (1.03 – 1.06)	< 0.001
Areas			
	Rural	Ref	
	Urban	1.53 (1.17 - 1.99)	0.002
Season			
	Hot dry season	Ref	
	Cold dry season	1.76 (1.61 - 1.92)	< 0.001
	Rainy season	1.04 (0.90 - 1.21)	0.551
Mean LST (°C)			
Lag 0	Low	Ref	
	Moderate	1.08 (0.96 - 1.21)	0.198
	High	1.08 (0.96 - 1.22)	0.206
	Very high	1.05 (0.91 - 1.21)	0.529
Lag 1	Low	Ref	
	Moderate	1.01 (0.91 - 1.13)	0.870
	High	0.82 (0.73 - 0.92)	< 0.001
	Very high	0.76 (0.66 - 0.87)	< 0.001
Mean cumulative rainfall (mm)			
Lag 0	Low	Ref	
	Moderate	1.20 (1.05 - 1.38)	0.009
	High	1.25 (1.08 - 1.44)	0.003
lag 1	Low	Ref	
	Moderate	1.07 (0.93 - 1.22)	0.368
	High	0.92 (0.80 - 1.06)	0.273
Annual trend			
	2011	Ref	
	2012	1.21 (1.10 – 1.34)	< 0.001
	2013	1.24 (1.12 – 1.37)	< 0.001
	2014	1.39 (1.26 – 1.53)	< 0.001

IRR: Incidence-rate ratio; LST: Land surface temperature. Rainfall - low (<=12), moderate (13-56), high (>=57)
LST-low (<24), moderate (24-26), high (26-28), very high (>=28).
In this table, results for average mean temperature and mean monthly cumulative rainfall in the same month (lag 0) and the previous month (lag 1) are presented. The model also included health facility and type of setting as fixed factors and the lag1 Pearson residual as further covariate

Table S3. Results from the adjusted negative binomial regression model with climatic variables of the same and preceding month, in urban areas of district of Mbour (January 2011- December 2014).

		Multivariate analysis	
Parameter		**IRR (95%CI)**	***P-value***
Season			
	Hot dry season	Ref	
	Cold dry season	1.81 (1.64 - 2.00)	< 0.001
	Rainy season	1.04 (0.88 - 1.24)	0.615
Mean LST (°C)			
Lag 0	Low	Ref	
	Moderate	1.05 (0.93 - 1.19)	0.437
	High	1.08 (0.95 - 1.23)	0.237
	Very high	1.03 (0.87 - 1.21)	0.714
Lag 1	Low	Ref	
	Moderate	0.98 (0.87 - 1.11)	0.777
	High	0.79 (0.70 - 0.89)	< 0.001
	Very high	0.73 (0.63 - 0.85)	< 0.001
Mean cumulative rainfall (mm)			
Lag 0	Low	Ref	
	Moderate	1.12 (0.96 - 1.32)	0.154
	High	1.31 (1.12 - 1.54)	< 0.001
lag 1	Low	Ref	
	Moderate	1.03 (0.87 - 1.21)	0.725
	High	0.98 (0.83 - 1.15)	0.789
Annual trend		1.00 (1.00 – 1.01)	0.073
	2011		
	2012	1.17 (1.04 – 1.30)	0.006
	2013	1.15 (1.03 – 1.29)	0.011
	2014	1.24 (1.11 – 1.38)	< 0.001

IRR: Incidence-rate ratio; LST: Land surface temperature. Rainfall - low (<=12), moderate (13-56), high (>=57)
LST-low (<24), moderate (24-26), high (26-28), very high (>=28).
In this table, results for average mean temperature and mean monthly cumulative rainfall in the same month (lag 0) and the previous month (lag 1) in urban areas are presented. The model also included health facility as fixed factor

Table S4. Results from the adjusted negative binomial regression model with climatic variables of the same and preceding month, in rural areas of the health district of Mbour (January 2011-December 2014).

Multivariate analysis			
Parameter		**IRR (95%CI)**	***P-value***
Season			
	Hot dry season	Ref	
	Cold dry season	1.69 (1.41 - 2.02)	< 0.001
	Rainy season	1.12 (0.84 - 1.49)	0.439
Mean LST (°C)			
Lag 0	Low	Ref	
	Moderate	1.15 (0.91 - 1.46)	0.248
	High	1.08 (0.81 - 1.43)	0.610
	Very high	1.11 (0.82 - 1.51)	0.490
Lag 1	Low	Ref	
	Moderate	1.04 (0.81 - 1.34)	0.743
	High	0.93 (0.70 - 1.25)	0.660
	Very high	0.80 (0.58 - 1.10)	0.172
Mean cumulative rainfall (mm)			
Lag 0	Low	Ref	
	Moderate	1.30 (0.99 - 1.71)	0.056
	High	1.01 (0.74 - 1.37)	0.945
lag 1	Low	Ref	
	Moderate	1.08 (0.83 - 1.40)	0.549
	High	0.80 (0.60 - 1.07)	0.134
Annual trend			
	2011	Ref	
	2012	1.24 (0.98 – 1.55)	0.068
	2013	1.48 (1.19 – 1.85)	< 0.001
	2014	1.83 (1.48 – 2.26)	< 0.001

IRR: Incidence-rate ratio; LST: Land surface temperature. Rainfall - low (<=12), moderate (13-56), high (>=57)
LST-low (<24), moderate (24-26), high (26-28), very high (>=28).
In this table, results for average mean temperature and mean monthly cumulative rainfall in the same month (lag 0) and the previous months (lag 1) in rural areas are presented. The model also included health facility as fixed factors.

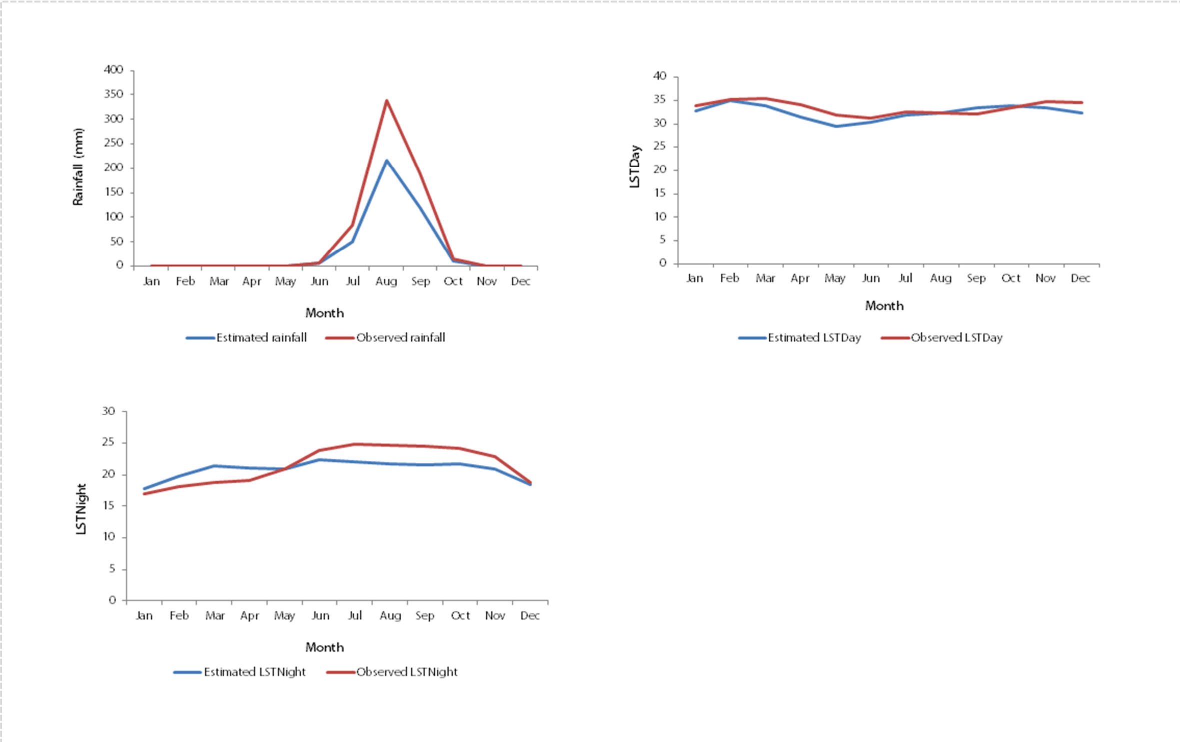

Figure S1. Comparison of satellite remote sensing data of monthly temperatures and rainfall extracted at the health facility location closest to the meteorological station with measured data from this station

14.3. Chapter 9: Table S1. Socio-demographic characteristics of study population in the four stratified zones of Mbour

Variable	Overall N= 761 n (%)	UCA N= 153 n (%)	PCA N= 322 n (%)	NPA N= 185 n (%)	SPA N= 101 n (%)	P-value
Gender of the respondents						0.005
Female	711 (93.4)	144 (94.1)	301 (93.5)	165 (89.2)	101 (100)	
Male	50 (6.6)	9 (5.9)	21 (6.5)	20 (10.8)		
Age of the respondents in years						0.130
15-24	190 (25.0)	41 (26.8)	82 (25.5)	42 (22.79	25 (24.7)	
25-30	232 (30.5)	54 (35.3)	104 (32.3)	43 (23.2)	31 (30.7)	
31-35	135 (17.7)	25 (16.3)	56 (17.49	37 (20.0)	17 (16.8)	
36- 44	129 (16.9)	25 (16.3)	54 (16.8)	34 (18.4)	16 (15.8)	
More than 45	75 (9.9)	8 (5.2)	26 (8.1)	29 (15.7)	12 (11.9)	
Educational level						0.046
Never go to school	219 (28.8)	45 (29.4)	96 (29.8)	42 (22.7)	36 (35.6)	
Primary school	225 (29.6)	47 (30.7)	99 (30.7)	53 (28.6)	26 (25.7)	
Secondary education	177 (23.3)	38 (24.8)	80 (24.8)	41 (22.2)	18 (17.8)	
Koranic school	140 (18.4)	23 (15.0)	47 (14.6)	49 (26.5)	21 (20.8)	
Occupation of head of household						**< 0.001**
Public service	17 (2.2)	4 (2.6)	5 (1.5)	7 (3.8)	1 (0.9)	
Private service	46 (6.0)	8 (5.2)	30 (9.3)	4 (2.2)	4 (3.9)	
Merchant	150 (19.7)	21 (13.7)	72 (22.4)	37 (20.0)	20 (19.8)	
Housewife	358 (47.0)	94 (61.4)	152 (47.2)	59 (31.9)	53 (52.5)	
Others (no employment, etc.)	190 (24.9)	26 (16.9)	63 (19.6)	78 (42.2)	23 (22.8)	
Wealth Index						**< 0.001**
Poorer	213 (27.9)	28 (18.3)	85 (26.4)	67 (36.2)	33 (32.7)	
Middle	284 (37.3)	58 (37.9)	146 (45.3)	47 (25.4)	33 (32.7)	
Richer	264 (34.7)	67 (43.8)	91 (28.3)	71 (38.4)	35 (34.6)	
Child characteristic (n=1,083)						
Gender of the child						0.533
Female	507 (46.8)	109 (48.0)	198 (44.2)	132 (48.7)	60 (49.6)	
Male	576 (53.2)	118 (52.0)	250 (55.8)	139 (51.3)	69 (50.4)	
Age of the child						< 0.039
0-11 months	209 (19.3)	48 (21.1)	101(22.5)	42 (15.5)	18 (13.1)	
12-24 months	420 (38.8)	87 (38.3)	177 (39.5)	98 (36.2)	58 (42.3)	
36-59 months	454 (41.9)	92 (40.5)	170 (37.9)	131 (48.3)	61 (44.5)	

Table S2 Characteristics of study population and WASH conditions in the four stratified zones of Mbour

Variable	Overall N= 761 n (%)	UCA N= 153 n (%)	PCA N= 322 n (%)	NPA N= 185 n (%)	SPA N= 101 n (%)	P-value
Drinking water source						**< 0.001**
Private tap at home	444 (58.39	128 (83.7)	229 (71.1)	75 (40.5)	12 (11.9)	
Public tap	187 (24.6)	18 (11.8)	76 (23.6)	29 (15.7)	64 (63.4)	
well water	79 (10.4)	5 (3.3)	12 (3.7)	49 (26.5)	13 (12.8)	
Others	51 (6.7)	2 (1.3)	5 (1.5)	32 (17.3)	12 (11.9)	
Water storage						**< 0.001**
Yes	621 (81.6)	141 (92.2)	284 (88.2)	112 (60.59	84 (83.2)	
No	140 (18.4)	12 (7.8)	38 (11.8)	73 (39.5)	17 (16.8)	
Container to store water at home						**< 0.001**
Clay	43 (6.9)	4 (2.8)	30 (10.5)	5 (4.5)	4 (4.8)	
Plastic	420 (67.6)	96 (68.1)	198 (69.7)	67 (59.8)	59 (70.2)	
Metal	24 (3.9)	5 (3.5)	8 (2.8)	8 (7.1)	3 (3.6)	
At least one of the three	115 (18.5)	29 (20.6)	37 (13.0)	32 (28.6)	17 (20.2)	
Others	19 (3.0)	7 (4.9)	11 (3.9)	0	1 (1.2)	
Status of container during storage						**0.009**
Not available	6 (1.0)		1 (0.3)	5 (4.3)		
Covered	580 (92.8)	132 (93.6)	265 (93.3)	104 (89.7)	79 (94.0)	
Uncovered	39 (6.2)	9 (6.4)	18 (6.3)	7 (6.0)	5 (5.9)	
Water storage duration						**< 0.001**
One day	509 (81.4)	119 (84.4)	240 (84.5)	84 (72.4)	66 (78.6)	
Two days	88 (14.1)	19 (13.5)	30 (10.5)	29 (25.0)	10 (11.9)	
Three days and more	28 (4.5)	3 (2.1)	14 (4.9)	3 (2.6)	8 (9.5)	
Container washing frequency						
Never	2 (0.3)			1 (0.9)	1 (1.2)	0.036
Daily	494 (79.0)	117 (82.9)	233 (82.0)	85 (73.3)	59 (70.2)	
Weekly	92 (14.7)	20 (14.2)	37 (13.0)	17 (14.7)	18 (21.4)	
Others	37 (5.9)	4 (2.8)	14 (4.9)	13 (11.2)	6 (7.1)	
Stored water treatment						**< 0.001**
Treated	193 (31.1)	33 (23.4)	74 (26.1)	49 (43.7)	37 (44.0)	
No treated	425 (68.4)	108 (76.6)	210 (73.9)	60 (53.6)	47 (55.9)	
Not indicated	3 (0.5)			3 (2.7)		
Type of stored water treatment						**< 0.001**
Javellisation	132 (68.4)	27 (81.8)	62 (83.8)	22 (44.9)	21 (56.8)	
Filtration	20 (10.4)	3 (9.1)	5 (6.8)	8 (16.3)	4 (10.8)	
Others	41 (21.2)	3 (9.1)	7 (9.5)	19 (38.8)	12 (32.4)	
Toilet availability						**< 0.001**
Yes	745 (97.9)	151 (98.7)	321 (99.7)	181 (97.8)	92 (91.1)	
No	16 (2.1)	2 (1.3)	1 (0.3)	4 (2.2)	9 (8.9)	
Type of toilet facilities						**< 0.001**
Flush latrine	517 (69.4)	123 (81.5)	219 (68.29	137 (75.7)	38 (41.3)	
Open pit latrine with slab	183 (24.6)	27 (18.9)	79 (24.6)	36 (19.9)	41 (44.6)	
Traditional latrine	45 (6.0)	1 (0.7)	23 (7.2)	8 (4.4)	13 (14.1)	
Toilet shared with others households						**< 0.001**
Yes	106 (14.2)	25 (16.6)	31 (9.7)	40 (22.1)	10 (10.9)	
No	639 (85.8)	126 (83.4)	290 (90.3)	141 (77.9)	82 (89.1)	
Domestic wastewater disposal						**< 0.001**
Pit	27 (3.5)	16 (10.5)	10 (3.1)	1 (0.59		
Street	548 (72.0)	92 (60.1)	247 (76.7)	133 (71.9)	76 (75.2)	
Others	186 (24.4)	45 (29.4)	65 (20.29	51 (27.6)	25 (24.7)	
Storage of household solid waste						**< 0.001**
Waste bins	74 (9.79	22 (14.49	22 (6.8)	22 (11.9)	8 (7.9)	
Open pail/basin	122 (16.0)	5 (3.39	35 (10.99	61 (32.9)	21 (20.8)	
Open bag	487 (63.9)	110 (71.9)	257 (79.8)	76 (41.1)	44 (43.5)	
Others	78 (10.29	16 (10.5)	8 (2.5)	26 (14.0)	28 (27.7)	
Handwashing						0.019
only water	90 (11.8)	8 (5.29	49 (15.2)	16 (8.6)	17 (16.8)	
water with soap	653 (85.8)	141 (92.2)	267 (82.9)	165 (89.2)	80 (79.2)	
others	8 (1.09	2 (1.3)	1 (0.3)	2 (1.1)	3 (2.9)	
Not indicated	10 (1.3)	2 (1.3)	5 (1.5)	2 (1.1)	1 (0.9)	

14.4. Chapter 10: Table S1. Socio-demographic and economic characteristics of respondents enrolled in a cross-sectional survey carried out in October 2016 in Mbour, stratified by zones

Sociodemographic and socioeconomic characteristics (N=367)	All n (%)	UCA* N= 87 n (%)	PCA** N= 156 n (%)	NPA*** N= 73 n (%)	SPA**** N= 51 n (%)	P-value
Children						
Gender						0.302
Male	203 (55.3)	51 (58.6)	92 (59.0)	35 (47.9)	25 (51.0)	
Female	164 (44.7)	36 (41.4)	64 (41.0)	38 (52.1)	25 (49.0)	
Age in month						0.065
< 6 months	30 (8.2)	10 (11.5)	10 (6.4)	5 (6.8)	5 (9.8)	
6 - 11 months	41 (11.2)	12 (13.8)	23 (14.7)	5 (6.8)	1 (1.9)	
12 < 36 months	165 (44.9)	42 (48.3)	70 (44.9)	28 (38.4)	25 (49.0)	
> 36 months	131 (35.7)	23 (26.4)	53 (34.0)	35 (47.9)	20 (39.2)	
Diarrhoea duration						0.207
< 3 days	79 (21.5)	20 (23.0)	32 (20.5)	12 (16.4)	15 (29.4)	
3 - 6 days	174 (47.4)	38 (43.7)	69 (44.2)	45 (61.6)	22 (43.1)	
7 - 13 days	96 (26.2)	22 (25.3)	47 (30.1)	15 (20.5)	12 (23.5)	
>= 14 days	18 (4.9)	7 (8.0)	8 (5.1)	1 (1.4)	2 (3.9)	
Breast-feeding						***0.002***
Yes	356 (97.0)	86 (98.9)	155 (99.4)	65 (89.0)	50 (98.0)	
No	11 (3.0)	1 (1.1)	1 (0.6)	8 (11.0)	1 (2.0)	
Breast-feeding method						0.085
Exclusive breast-feeding	303 (85.1)	75 (87.2)	132 (85.2)	55 (84.6)	41 (82.09	
Breast-feeding and bottle	48 (13.5)	11 (12.8)	23 (14.8)	8 (12.3)	6 (12.0)	
Only bottle	1 (0.3)	-	-	-	1 (2.0)	
Not indicated	4 (1.1)	-	-	2 (3.1)	2 (4.0)	
Breast-feeding duration						***< 0.001***
< 6 months	2 (0.6)	-	1 (0.6)	1 (1.5)	-	
6- 12 months	12 (3.4)	1 (1.2)	4 (2.6)	5 (7.79	2 (4.0)	
More than 12 months	210 (59.0)	45 (52.3)	87 (56.1)	52 (80.0)	26 (52.0)	
Breast-feeding in progress	121 (34.0)	39 (45.3)	55 (35.5)	7 (10.8)	20 (40.0)	
Not indicated	11 (3.1)	1 (1.2)	8 (5.2)	-	2 (4.0)	
Mothers/caregivers						
Gender						***0.002***
Male	25 (6.8)	5 (5.7)	8 (5.1)	12 (16.4)	-	
Female	342 (93.2)	82 (94.2)	148 (94.9)	61 (83.62)	51 (100)	
Age in years[a]						***< 0.003***
15-25	127 (37.3)	29 (39.2)	61 (40.4)	25 (36.8)	12 (25.5)	
26-30	89 (26.2)	27 (36.5)	44 (29.1)	8 (11.8)	10 (21.3)	
31-35	37 (10.9)	6 (8.1)	14 (9.3)	11 (16.2)	6 (12.8)	
More than 35	87 (25.6)	12 (16.2)	32 (21.2)	24(35.3)	19 (40.4)	
Educational level						0.077
Never went to school	108 (29.4)	21 (24.14)	52 (33.3)	19 (26.0)	16 (31.4)	
Incomplete primary	61 (16.6)	19 (21.8)	26 (16.7)	7 (9.6)	9 (17.6)	
Complete primary	60 (16.3)	11 (12.6)	25 (16.0)	12 (16.4)	12 (23.5)	
Secondary education	79 (21.5)	22 (25.3)	35 (22.4)	14 (19.2)	8 (15.7)	
Koranic school	59 (16.1)	14 (16.1)	18 (11.5)	21 (28.8)	6 (11.8)	
Relationship with the child						***0.002***
Mother	303 (82.6)	78 (89.7)	133 (85.3)	47 (64.4)	45 (88.2)	
Father	17 (4.6)	4 (4.6)	6 (3.8)	8 (11.0)	-	
Grand-mother	14 (3.8)	-	4 (2.6)	6 (8.2)	4 (7.8)	
Aunt	24 (6.5)	4 (4.6)	11 (7.0)	7 (9.6)	2 (3.9)	
Others[b]	8 (2.2)	1 (1.1)	2 (1.3)	5 (6.8)	-	
Marital status[c]						***< 0.001***
Single	14 (3.8)	8 (9.2)	2 (1.3)	-	4 (7.8)	
Married monogamous	253 (68.9)	62 (71.3)	132 (86.6)	28 (38.4)	31 (60.8)	
Married polygamous	81 (22.1)	17 (19.5)	12 (7.7)	37 (50.7)	15 (29.4)	
Divorced/Separated	9 (2.4)	-	6 (3.8)	3 (4.1)	-	
Widower/widow	10 (2.7)	-	4 (2.6)	5 (6.8)	1 (2.0)	
Marital position[d]						0.722
First wife	38 (46.9)	10 (58.8)	4 (33.3)	19 (51.3)	5 (33.3)	
Second wife	41 (50.6)	7 (41.2)	8 (66.7)	16 (43.2)	10 (66.7)	

Third wife	1 (1.2)	-		1 (2.7)	-	
Fourth with	1 (1.2)	-		1 (2.7)	-	
Number of children below five years[e]						***0.002***
One child	205 (55.9)	45 (51.7)	92 (59.0)	42 (57.5)	26 (51.0)	
Two children	129 (35.1)	28 (32.2)	60 (38.4)	19 (26.0)	22 (43.1)	
More than two children	33 (9.0)	14 (16.1)	4 (2.6)	12 (16.4)	3 (5.9)	
Occupation of head of household						***< 0.001***
Public service	5 (1.4)	2 (2.3)	2 (1.3)	-	1 (2.0)	
Private service	27 (7.4)	2 (2.3)	21 (13.5)	1 (1.4)	3 (6.1)	
Merchant	66 (18.0)	12 (13.8)	32 (20.5)	10 (13.7)	12 (23.5)	
Housewife	168 (45.8)	54 (62.1)	68 (43.6)	26 (35.6)	20 (39.2)	
Others (no employment, etc.)	101 (27.5)	17 (19.5)	33 (21.1)	36 (49.3)	15 (29.4)	

a=mean age of 30.1(±9.8) years; 27.4 (±5.8) in UCA; 29.2 (±9.6) in PCA; 32.7 (±12.5) in NPA; 33.2 (±9.8) in SPA
b=others including sister and brother, grand-father;
c=marital status of the mother
d= marital position of the mother
e=number of child below five years of the mother; *Urban central area; **Peri-central area; ***North peripheral area; ****South peripheral area
Significant P-values based on Chi-square test for differences between zones are indicated in bold

Table S2 Number of households surveyed, children under 5 years with and without diarrhoea and response rates in a cross-sectional survey carried out in October 2016 in Mbour, overall and stratified by zones

Zone	Households (N)	[a]No cases (N)	[b]Cases (N)	Response rate (%)	[c]Refused (N)
UCA	153	140	87	95.0	8
PCA	322	292	156	98.5	5
NPA	185	198	73	91.1	18
SPA	101	86	51	92.7	8
Overall	761	716	367	95.1	39

[a]Number of children under 5 years without diarrhoea in the surveyed household
[b]Number of children under 5 years old with diarrhoea in the 2 weeks prior to the survey
[c]Number of households in the sample having refused to sign the consent form

Table S3 Level of management practices and knowledge of diarrhoea according to socio-demographic and economic characteristics of the mothers and caregivers of children with diarrhoea enrolled in the survey in October 2016

Variables	Level of management practices			P-value	Level of knowledge*			P-value
	Good	Fair	Poor		Good	Fair	Poor	
Age of mothers/caregivers				0.807				0.265
15-25	33 (40.7)	10 (29.4)	84 (37.3)		25 (35.7)	47 (42.7)	39 (33.0)	
26-30	20 (24.7)	10 (29.4)	59 (26.2)		19 (27.19	18.2)	39 (33.0)	
31-35	9 (11.1)	6 (17.6)	22 (9.8)		7 (10.0)	13 (11.8)	15 (12.7)	
>35	19 (23.59	8 (23.5)	60 (26.7)		19 (27.1)	30 (27.3)	25 (21.2)	
Educational level				0.677				**<0.001**
Never went to school	35 (41.8)	19 (52.8)	113 (45.9)		46 (63.0)	54 (45.4)	51 (39.8)	
Primary school	33 (38.8)	10 (27.8)	78 (31.7)		18 (24.7)	34 (28.6)	52 (40.6)	
Higher school**	17 (20.0)	7 (19.4)	55 (22.4)		9 (12.3)	31 (26.0)	25 (19.5)	
Marital status				0.225				0.081
Single	1 (1.2)		13 (5.3)		1 (1.4)	7 (5.9)	2 (1.6)	
Married monogamous	63 (74.1)	24 (66.7)	166 (67.5)		46 (63.0)	84 (70.6)	95 (74.2)	
Married polygamous	18 (21.2)	12 (33.3)	51 (20.7)		24 (32.9)	20 (16.8)	25 (19.5)	
Divorced/Separated	2 (2.3)	-	7 (2.8)		1 (1.4)	5 (4.2)	2 (1.6)	
Widower/widow	1 (1.2)	-	9 (3.7)		1 (1.4/	3 (2.5)	4 (3.1)	
Occupation				0.846				**0.004**
Public services employee	2 (2.3)	-	3 (1.2)		-	3 (2.5)	-	
Private employee	5 (5.9)	2 (5.6)	20 (8.1)		2 (2.7)	11 (9.2)	12 (9.4)	
Merchant	15 (17.6)	6 (16.7)	45 (18.39		17 (23.3)	15 (12.6)	25 (19.5)	
Housewife	40 (47.1)	14 (38.9)	114 (46.3)		26 (35.6)	53 (44.5)	68 (53.1)	
Others	23 (27.1)	14 (38.99	64 (26.09		28 (38.4)	37 (31.1)	23 (17.9)	
Socioeconomic status				0.535				**0.001**
Poor	23 (27.1)	14 (38.9)	85 (34.5)		40 (54.8)	36 (30.2)	32 (25.0)	
Medium	26 (30.6)	10 (27.8)	59 (24.0)		12 (16.4)	31 (26.0)	36 (28.1)	
rich	36 (42.3)	12 (33.3)	102 (41.5)		21 (28.8)	52 (43.7)	60 (46.9)	
Relationship with the child				0.298				0.673
Mother	72 (84.7)	32 (88.9)	207 (84.1)		59 (80.8)	100 (84.0)	112 (87.5)	
Father	2 (2.35)	-	8 (3.25)		4 (5.5)	3 (2.5)	3 (2.3)	
Grand-parents	1 (1.2)	-	13 (5.3)		4 (5.5)	6 (5.0)	2 (1.6)	
Aunt	9 (10.6)	3 (8.3)	12 (4.9)		5 (6.8)	8 (6.7)	7 (5.5)	
Others	1 (1.2)	1 (2.8)	6 (2.4)		1 (1.4)	2 (1.7)	4 (3.1)	
Number of children under 5 years				0.826				0.778
One child	52 (61.2)	19 (52.8)	134 (54.5)		39 (53.4)	63 (52.9)	77 (60.2)	
Two child	27 (31.8)	13 (36.1)	89 (36.2)		28 (38.4)	47 (39.5)	41 (32.0)	
More than three	6 (7.1)	4 (11.1)	23 (9.3)		6 (8.2)	9 (7.6)	10 (7.8)	

*Level of knowledge on causes, preventives measures and recommended treatment of diarrhoea
**Higher school including secondary and University level