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# Development of Municipal Decision-Making Strategies as Management Tools to Combat Waterborne Diseases

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## Abstract

Waterborne diseases pose a significant global public health threat, particularly in sub-Saharan Africa, where frequent outbreaks occur. These diseases stemming from contaminated drinking water, poor waste management, and insufficient hygiene contribute to high morbidity and mortality in children under 5 years old. A study addressed waterborne diseases in N'Djamena, Chad's 3rd and 9th districts, through decision-making strategies. The research employed various methods, including a household survey using questionnaires, workshops, semi-structured interviews, and focus group discussions. Additionally, documentary research provided essential data for analysing the situation of diseases in the community. Epidemiological data from 2019- 2022 indicated a substantial prevalence of diseases such as diarrhoea, dysentery, skin infections, typhoid, abdominal pain, and malaria, with notable mortality, especially among children. Amongsurveyed households, 50% believed the consumed water was contaminated, attributing it to faecal matter, while 28% and 22% linked the diseases to inadequate hygiene and unsanitary conditions, respectively. The study advocates for comprehensive strategies, including improving water treatment efficiency, implementing safe waste management, promoting hygiene, and vaccination. Active involvement of all stakeholders, with municipal authorities leading, is crucial for effective implementation and combating waterborne diseases.

## Introduction

Water is a precious resource vital to all life forms on our planet. Unfortunately,

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the ever- increasing use of freshwater worldwide has brought significant challenges. One of the most pressing issues is the deterioration of water quality due to rampant urbanisation and various human activities [126]. Approximately 2.1 billion people, which is 30% of the world's population, lack access to safe drinking water at home—additionally, nearly 60% lack secure sanitation [14]. By 2025, an estimated 3 billion people will live in water-stressed environments without adequate access to safe drinking water [10]. The global situation in 2020 presented significant challenges for around 2 billion people who had to contend with issues such as using contaminated drinking water, inadequate handwashing facilities, and insufficient sanitation. These challenges had far-reaching consequences that could not be ignored [142].

Waterborne diseases caused by consuming contaminated water continue to pose a significant challenge worldwide, impacting both developed and developing countries. While it is true that less developed countries tend to report more cases, developed countries have also faced outbreaks of waterborne diseases [78]. Each year, over 2.2 million people die from these diseases worldwide, with approximately 5.3% of the fatalities occurring among children under five years old [115]. It has been estimated that there is an annual economic burden of around $1 billion in the United States alone, which can be attributed to these diseases [58]. Ensuring access to safe drinking water is a significant challenge many African countries face today [90].

In Africa, only 22% of the population believes that they have access to adequate sanitation facilities [16]. Additionally, a significant portion of the sub-Saharan African population, approximately 28%, practice open defecation, while 23% rely on "non-improved" sanitation facilities that may not meet optimal hygienic separation of faecal matter [78]. Even where safe drinking water and secure toilets are available in Africa, a lack of awareness and mobilisation of proper hygiene practices continue to lead to waterborne disease outbreaks [6].

In Chad, the Ministry of Health and Prevention reports that diarrhoea is a significant concern for children under the age of 5, with an estimated nationwide prevalence of 17%. The incidence of diarrhoea is even higher in rural areas, where it affects 22% of children, compared to 10% in urban areas. It is important to note that each episode of diarrhoea can contribute to child malnutrition and impede growth. Diarrhoea has been linked to different pathogens and is often associated with water insecurity [59]. The issues mentioned have tragic consequences, especially for disadvantaged populations, particularly women of childbearing age and children [17]. Dr. Ahmat Moustapha, head of the Centre for the Prevention of Major Endemics in Chad, revealed that waterborne diseases claim the lives of roughly 19,000 children every year. Furthermore, these diseases are three times more prevalent in remote provinces than in urban areas. As a result, the Chadian government is burdened with an annual cost of approximately $25 million to manage and treat these illnesses in children.

According to Dr. Jean Bosco NDIHOKUBWAYO, the World Health Organization representative in Chad, healthcare accessibility in Chad is still quite limited, with only 28% of the population having access to it. Malaria continues to be the most pressing public health issue, leading to over 3000 deaths in Chadian hospitals in 2021 and accounting for 25.1% of morbidity in the general population. Tragically, it is also the leading cause of death in children under 5. Furthermore, the rapid demographic growth in N'Djamena presents significant challenges in effectively managing waste, wastewater, and faecal matter [1].

The absence of large-scale wastewater treatment systems and insufficient solid waste collection hinder sanitation efforts, posing severe risks to public health and the environment [73]. The prevalence of

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waterborne diseases underscores the pressing need to improve the safety of drinking water and sanitation. Additionally, the healthcare industry is grappling with a dearth of qualified personnel and medical resources, emphasising the need for improvement. This study aimed to develop strategies for districts to combat waterborne diseases, focusing on their reduction, if not eradication, in the study area and other cities in Chad.

## Materials and Methods

*Study Area Description*

N'Djamena, located in the Chari-Baguirmi province, is Chad's political capital and largest city. Established in April 1900 and designated as a district in 1919, it is located on the eastern bank of the Chari River, bordering Cameroon where the Logone and Chari rivers converge. The terrain is predominantly flat, with slight natural slopes. The city spans 39,500 hectares of urbanised areas, divided into ten municipal districts, and boasts a population of 1,390,309 residents, growing at an annual rate of 3.61% as of 2018. N'Djamena experiences distinct seasons, with a dry period from November to April and a rainy season from May to October. The climate registers an average maximum temperature of 44.1°C and a minimum of 23.8°C. Recent years have seen an annual rainfall range from 584 mm to 990 mm. The study primarily focused on the 3rd and 9th districts, positioned between 12°6'0" and 12°0'0" North latitude and between 15°2'0" and 15°10'0" East longitude. These districts are further divided into thirteen quarters: Ambassatna, Ardep Djoumal, Djambalbarh,

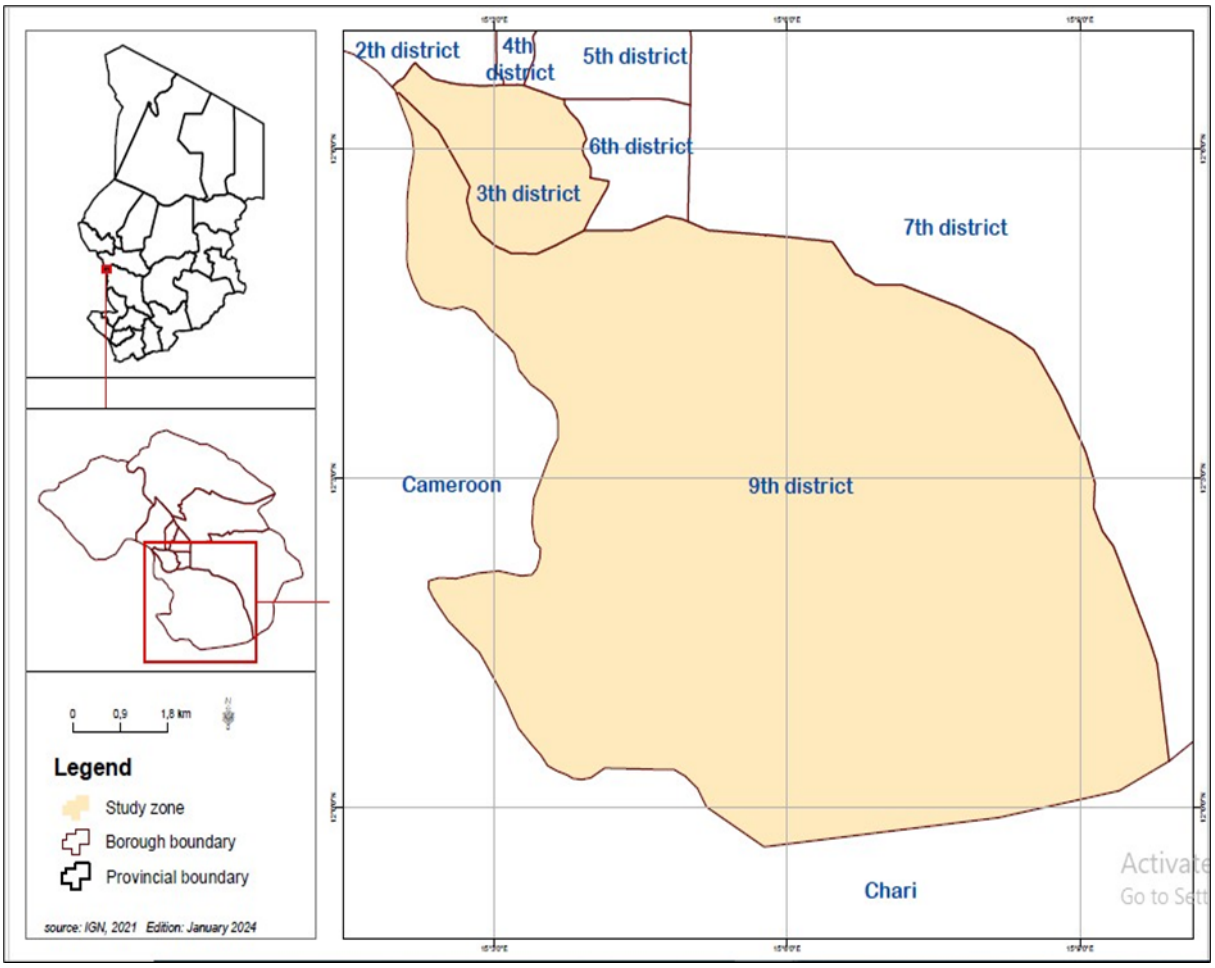


Figure 1. Geographical location of the 3rd and 9th districts of the city of N'Djamena (Republic of Chad)

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Gardolé1, Kabalaye, Sabangali, Digangali, Gardolé 2, Kabé, Ngoumna, Ngueli, Toukra, and Walia.

*Data collection*

The research process unfolded through a meticulous methodology, encompassing a survey of 395 households, focus group discussions, direct observations, interviews with investigators utilising Android phones, exchanges with the mayors of two municipalities, personnel responsible for Water, Sanitation, and Hygiene (WASH), semi-structured interviews with health district officials, municipal delegates, neighbourhood leaders, institutional actors, and the Chadian Water Company (STE). This approach involved a diverse sample of 57 men, 97 women, 22 teenage girls, 10 male students, and 22 female students. Furthermore, testimonials and life narratives related to waterborne diseases were collected. The analysis of interviews was bolstered by referencing various documents, including reports, laws, legislative texts, Water Code data, municipal decrees, and other relevant research sources. Additionally, epidemiologicaldata for 2019-2022 in the 3rd and 9th districts were obtained by scrutinising the daily consultation records of the Order of Malta Health Centre and the Mother and Child University Hospital. Data collection tools comprised household questionnaires, interview guides for key informants, and an observation checklist. This comprehensive methodological approach facilitated a profound understanding of the challenges and opportunities associated with water, sanitation, hygiene management, and waterborne diseases in the study area. It also promoted gathering diverse perspectives and expertise to enhance our analysis.

*Ethical protocol*

This research received approval from the Chad National Bioethics Committee (CNBT) in August2022. It included a detailed protection protocol outlining potential risks throughout the survey's lifecycle. Verbal consent was obtained from each participant, who was individually interviewed. All participants were fully informed of the voluntary nature of their participation and the confidentiality and anonymity of the provided information. Furthermore, participants were informed of their right to refuse to answer any question, terminate the interview at any time, or even decline to participate in the survey altogether.

*Legislative and Regulatory Framework*

Chad has established vital regulations governing national environmental, health, water, andsanitation-hygiene policies. However, the primary challenge lies not in the quantity or quality of these regulations but in their practical implementation and oversight. Several noteworthy and relatively recent documents are particularly relevant to this research.

*Law No. 014/PR/98 of August 17, 1998,* outlines the fundamental principles of environmental protection, establishes the foundations of the national environmental protection policy, defines the principles of sustainable environmental management, and aims to prevent any degradation. Its objective is to safeguard and enhance natural resources and improve the population's living conditions.

*Decree No. 904/PR/PM/MERH/2009 of August 6, 2009,* sets out regulations regarding environmental pollution and nuisances, clearly defining these issues. It also envisions the creation of a national technical committee responsible for monitoring and evaluating the implementation of international agreements related to pollution and nuisances. Furthermore, it establishes a coordination unit to oversee activities related to these issues and a technical control unit whose primary mission is to protect the environment against all forms of pollution and nuisances. Limited material and financial resources hinder the effective implementation of this implementing decree.

*Texts related to Public Health*

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*Law No. 014/PR/11 of February 28, 2011,* establishes the Public Hygiene Code. This code defines the standards regarding environmental hygiene, sanitation of public spaces, food establishments, food items, water, industrial and commercial facilities, residences, swimming pools, educational institutions, healthcare facilities, public and private buildings, as well as the natural environment, even though their implementation remains non-existent due to the lack of adequate sanitary infrastructure enabling monitoring and control in accordance with the standard provisions stipulated in the Public Hygiene Code.

*National Health Policy*

*The National Health Policy 2007-2015* was developed, validated, and adopted in May 2007 by all healthcare sector stakeholders and the Ministry of Health and Prevention. It is part of the government's social policy to provide quality healthcare services to the population. It provides healthcare professionals with a vision of healthcare development until 2015, with strategicdirections tailored to the country's context. Unfortunately, the financial, material, and human resources did not align with this National Health Policy.

*Texts related to Water and Sanitation*

*Law No. 16/PR/99 of August 18, 1999,* establishes the Water Code, governing the management of river, lake, and groundwater, as well as hydraulic works, as determined by the provisions of this code, subject to compliance with international agreements. All national water resources are acollective asset, part of the state's public domain, inalienable, and imprescriptible. Their exploitation requires authorisation and must comply with existing laws and customary law.

Article 117 stipulates that prior authorisation is required for any action that may alter water quality. This code includes several sections dealing with sanitation. Historically, sanitation has been considered a complementary measure, implemented as part of other activities, such as disease control or the establishment of drinking water supply programs. However, the necessary material and financial resources are not always allocated adequately to ensure its effectiveimplementation.

*Decree No. 615/PR/PM/ME/MSP/2010 of August 2, 2010,* defines quality standards for water intended for human consumption in Chad. Its purpose is to protect health by preventing adverse effects related to unsafe water. It applies to all water intended for human consumption in the Chadian territory, including bottled or other containers, except in certain circumstances. This decree does not cover natural mineral waters. Article 4 specifies that drinking water for human consumption must not harm consumers' health. It must not show signs of physicochemical, bacteriological, or biological pollution or contain toxic substances exceeding the standards established in the annexe to the decree. This decree is ineffective due to a lack of continuous monitoring of water quality: strict standards, treatment, awareness, and collaboration with health authorities to ensure the safety of drinking water.

*The Decree No. 330/PR/PM/MEH/2010 of January 20, 2015,* establishing the modalities for the transfer of state competencies to decentralised territorial authorities concerning the delegation of the public water service, has not been fully effective across the entire territory due to the absence of adequate accompanying measures.

The Drinking Water and Sanitation Master Plan (SDEA), established and adopted on April 30, 2003, with the support of UNDP-DAES, aims to achieve the access rate to potable water defined by the MDGs. However, this objective has not been achieved due to insufficient resources.

*Municipal Orders*

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The N'Djamena City Hall issued two significant municipal orders to improve sanitary conditions in the city: *Municipal Order No. 146/SG/DSTM/SUHA/96 of October 18, 1996,* making the construction of family latrines mandatory, and *Municipal Order No. 037/M/SG/DSTM/SHS/04 of February 17, 2004,* regulating the management of domestic,sewerage, and industrial wastewater in the municipality of N'Djamena. These two orders havenot yielded the desired results in changing the population's behaviour because no preparatory activities were undertaken beforehand for their implementation. For example, awareness campaigns, mobilisation, accompanying measures, monitoring, evaluation, and material andfinancial resources are lacking or limited.

*Municipal Order No. 145/M/SG/DSTM/SUHA/96 of October 18, 1996,* prohibits open defecation. The real factors hindering the enforcement of this order include a lack of adequate sanitary infrastructure, insufficient hygiene awareness and education, financial constraints for theconstruction of proper toilets, and implementation issues due to a lack of proper oversight and sanctions.

*Ordinance No. 014/PR/11 on the Hygiene Code*

Article 3 of this ordinance outlines its fundamental principles. It states that any natural or legal person who produces or holds waste in conditions that may harm the soil, flora, or fauna, alter landscapes, pollute the air or water, generate noise or odours, and, in general, harm human, animal, and environmental health, is obligated to ensure or have ensured their disposal inaccordance with the provisions of this law. However, this ordinance has implementation issues due to a lack of proper monitoring and adequate sanctions.

*Institutional Framework*

The Constitution of the Republic of Chad underscores the importance placed on safeguarding human health, the environment, water resources, sanitation, and hygiene. Dated March 31, 1996, and subsequently revised in 2005, 2018, and 2020, it explicitly lays out the following principles:

- Every individual has the right to a healthy environment (Article 47) ;
- The State and decentralised authorities have to ensure environmental protection (Article 48) ;
- The transportation, importation, storage, disposal, or discharge of toxic or pollutingsubstances are strictly prohibited in Chad.

The rigorous implementation of laws and regulations governing environmental protection, water, hygiene, and sanitation will significantly contribute to public health protection and the sustainable preservation of our environment while enhancing food security for the population. This will involve the collection and treatment of solid waste, faecal matter, secure wastewater, and rainwater, as well as the treatment of industrial wastewater, thereby ensuring water security. Furthermore, information campaigns on the Hygiene Code, implementing decrees, and establishing a health police force will be necessary to safeguard the population against waterborne diseases and other health risks. These efforts must be undertaken with determination and consistency to ensure a healthier future for all.

## Results and Discussions

*Categorisation of Water-Related Diseases*

Waterborne diseases arise due to deteriorating hygiene and sanitary controls [41]. These illnesses can be triggered by various microorganisms, such as bacteria, viruses, andparasites [64].

"Water-related diseases" refer to those contracted through ingestion or direct contact or diseases in

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which water is the habitat for larvae or parasites [94]. Categorising water- induced diseases is crucial for assessing public health risks, aiming to classify and understand diseases related to water contamination, whether by pathogens, chemicals, or other contaminants [60]. These diseases can have severe consequences for human health, and their categorisation is essential for implementing effective water management, prevention, control,and treatment strategies. However, these diseases can be broadly classified into three categories based on their health implications concerning water: waterborne diseases, vector-borne diseases linked to water, and waterborne-origin diseases [65].

*Waterborne Diseases*

Waterborne diseases, or water-related illnesses, are infections caused by the consumption or contact with water contaminated by pathogens such as bacteria, viruses, parasites, or other microorganisms [8]. They pose a significant health concern in many regions of the world, especially in developing countries where access to safe drinking water is limited and often associated with poor hygiene and sanitation conditions [133]. Preventing waterborne diseases involves improving the supply of clean drinking water, ensuring proper sanitation facilities, educating people about personal hygiene, and administering vaccines when possible [36]. Treatment depends on the specific disease but may include rehydration, the administration of antibiotics or antiparasitic drugs, and other supportive measures [21]. It is important to note that waterborne diseases can be deadly, especially in malnourished individuals or those with weakened immune systems (Ali, 2023). Therefore, proper prevention and management are essential to reduce the impact of these diseases on public health.

*Water-Related Vector-Borne Diseases*

Water-related vector-borne diseases are infections caused by pathogens such as bacteria, viruses, or parasites that are transmitted by aquatic organisms, such as *mosquitoes, flies, fleas*, or *mollusks* [117]. They remain a significant challenge in many regions, particularly developing countries where access to clean water and sanitation is limited [112]. Diseases like malaria (transmitted by the *Anopheles mosquito*) and *dengue* (transmitted by the *Aedes mosquito*) continue to inflict considerable suffering, with these vectors finding theirbreeding grounds in aquatic environments [79]. Changes in habitats and climatic conditions can promote mosquito proliferation and the spread of these diseases [19]. It is important to note that the prevention and control of these diseases often depend on improving access to clean drinking water, vector management, sanitation, and health education [35]. This study will be limited to waterborne diseases.

*Water-Origin Diseases*

The section aims to elucidate the concept of water-origin diseases and assess their severity in developing nations. The National Institute of Public Health of Quebec defines water-origin diseases as infectious or physicochemical ailments caused or presumed to be caused by water ingestion, contact, or inhalation. Pathogenic microorganisms like bacteria, viruses, parasites, and protozoa are common culprits, spreading through contaminated water, skin contact, or ingesting food prepared with untreated water [104]. Populations lacking access to safe water, sanitation, and hygiene practices are particularly vulnerable, as untreated faecal matter can contaminate freshwater sources and food [62]. Notable water -origin diseases include cholera, typhoid, polio, dysentery, diarrhoea, and hepatitis A and B. Humans and animalshost these pathogens [119].

The World Health Organization reports that around 2 billion people globally rely on water contaminated by faecal matter, posing a substantial risk to public health. Water-Origin Diseases are a

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Table 1. Some of the primary waterborne or water-related diseases observed in Chad

| Diseases | Causative agent(s) | Geographic area | Number of cases per year | Deaths per year | The number ofcases per year in the study area. | Deaths peryear in the study area | References |
|---|---|---|---|---|---|---|---|
| **Hepatitis A** | The virus spreads through the faecal-oral route via contaminated water, food, and person-to-person contact | On a global scale | 354 million | 7134 deaths (which represents 0.5% of the mortality attributed to viralhepatitis) in 2016 | 5% within the population. | 8 deaths | ( WHO .2020;Uwishema et al.,2022) |
| **Amoebicdysentery**<br>**Bacillarydysentery** | Caused by bacteria such as Shigella or Entamoeba histolytica, they are transmitted through the faecal-oral route, either by using contaminated water or food or through direct person-to-person contact. | On a global scale | 500 million per year. | | 17% of dysentery cases were in Chad, and 2908 were inthe study area. | 15 deaths among children aged 0-5 years. | (Guenzi etal., 2023; Abdullah Sabeeh &Khalaf, 2022) |
| **Typhoid andParatyphoid** | Caused by Salmonella enterica serovarTyphi (*S. Typhi*) and Salmonella enterica serovar Paratyphi (*S. Paratyphi*), this condition is primarily initiated by *S. Typhi and S. Paratyphi A and B* (and, *occasionally, S. Paratyphi C*), spreading through the faecal-oral route via contaminated water, food, or person-to-person contact. | Asia, Latin America, Africa | 11-21 million cases compared to6 million cases of paratyphoid fever | 128,000 to 161,000 deaths from Typhoid and 54,000 deaths from Paratyphoid | In 1953, there were cases in the study area. | 35 deaths | (Carey et al.,2023; OMS,2018; WHO.2018 ) |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Gastroenteritis** | Gastroenteritis is typically transmittedthrough contam inated water or food, whether bacterial, viral, or caused by internal parasites, protozoa, or pathogenic amoebas. | On a global scale | 3 to 5 billion | 2 million deaths | 275 deaths in the city of N'Djamena | 69 deaths inthe study area | (WHO.2017;(Hellysazet al., 2023) |
| **Diarrhealdiseases** | Caused by various microorganisms such as bacteria, viruses, or parasites, this infection spreads through contaminated water or food, as well as from person to person in cases of poor hygiene | On a global scale | 4 billion | 485,000 deaths | In 2019, 4.45% of the population and 3,948 cases were recorded in the study area. | 26 deaths inthe study area | (WHO.2017; WHO.2017) |
| **Malaria** | Caused by parasites of the genus Plasmodium and is transmitted by thebite of the female anopheles (*Anopheles sp.*). | Africa, Southeast Asia,India, South America | 247 millionin total, the vast majority (228 million, or 95%) in Africa. | 627,000 deaths, 96% of which (602,000) will be in Africa by 2021 | 21096 cases inthe study area | 3000 deathsin Chad and 267 deaths in the study area | (OMS, 2022; OMS, 2015; OMS/CHAD.2023) |
| **Cholera** | Caused by the bacterium Vibrio cholerae and spreads mainly throughcontaminated water and food. by thefaeces of an infected person (faecal-oral transmission) | South America, Africa, Asia | 1.3 - 4 million | 21,000 to 14,300 deaths | 450 cases in Chad in 2017 | 59 deaths inChad in 2017 | (Trolle et al., 2023; OMS,2017) |
| **Poliomyelitis** | The virus spreads by following the faeco-oral route, using contaminatedwater, foodstuffs or person-to-personcontact as vectors. | India, Near East, Asia, andWest and Central Africa | 12 | 3 | 115 from 2019 to 2020 | more than 80 children paralysed in Chad | (OMS/CHAD.2023; WHO, 2021;Liu etal., 2023;OMS, 2020) |

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significant challenge in developing countries, leading to high morbidity and mortality, especially among children under 5. Diarrheal diseases, with an estimated 1.7 billion casesannually, rank as the second leading cause of death in this age group worldwide [119]. Developing nations bear the brunt, with 18% of under-five deaths attributed to these diseases, predominantly in Africa and Southeast Asia [123]. Poor water quality and inadequate sanitation result in approximately 297,000 annual deaths in children under 5 due to diarrheal diseases [86]. Disposing of human waste in open areas exacerbates the issue, contributing to microbiological contamination of water [126]. Crucially, prevention hinges on enhancing access to clean water and adopting proper hygiene and sanitation practices. Addressing these challenges is vital to curbing the impact of water- origin diseases and improving public health in vulnerable communities.

*The Transmission of Water-Related Diseases*

Waterborne diseases primarily spread through drinking water or surface water contamination by pathogens (bacteria, viruses, parasites, chemicals) [77]. Transmission pathways include ingesting contaminated water, skin contact, consumingcontaminated food, exposure to wastewater, transmitting through vectors such as *flies*, andlacking personal hygiene [94].

*The key factors contributing to the proliferation of waterborne communicable diseases*

The main factors contributing to the proliferation of waterborne diseases include: Household hygiene: Poor hygiene in both individual and collective settings in disadvantaged areas facilitates pathogen transmission [32; 117]; Socioeconomic status of households: Precarious living conditions, such as overcrowding and close quarters, increase the risk of contagion [129]; Community living (markets, churches, hospitals, etc.): Gatherings in these environments can promote disease spread without adequate hygiene and prevention measures [131]; Quality of the drinking water supply network: Inadequate control of distributed water can lead to pathogen contamination [56]; Limited access to safe drinking water: Using untreated water raises the risk of waterborne diseases [78]; Inadequate water treatment and monitoring: Poor water treatment and insufficient quality monitoring expose the population to health risks [57]; Lack of health education: Insufficient awareness about personal hygiene, water purification, and environmental health also contributes to disease transmission ([142]; Overpopulation and population density: High population density can facilitate disease spread due to inadequate healthcare infrastructure to meet the population's needs [38; 117]; Failures in pumps, pipelines, and water purification facilities can expose populations to risks of waterborne diseases [78]; The lack of hygiene in washing vegetables and fruits before consumption, coupled with persistent community conflicts associated with certain beliefs and practices, are major factors contributing to the transmission of waterborne diseases [15; 24].

*The Environmental Impacts of Hygiene, Sanitation, and Sanitary Practices*

The environmental impacts of hygiene, sanitation, and sanitary practices are a major global concern, leading to significant repercussions on public health and the planet's sustainability [88]. Within the study area, observations reveal substantial quantities of solid and liquid waste scattered in streets, open spaces, gutters, and depressions. Among these wastes, biodegradable materials such as plant debris, leaves, branches, food remnants, and non- biodegradable items like plastic bags, packaging, tin cans, and glass bottles negatively affect the environment [33]. Furthermore, the presence of faecal matter in depressions, open spaces, and unregulated dumps, along with the untreated discharge of domestic wastewater and flush toilet effluents into stormwater drainage channels, intensifies soil and groundwater contamination, compromising water quality and biodiversity [4]. These wastes also

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detrimentally affect the living environment by emitting foul odours, while the proliferation of insects and rodents threatens residents' health (Suare Marcillo, 2012). Waterborne diseases, stemming from various factors such as contamination of drinking water, non-adherence to hygiene practices, the use of communal toilets, and the disposal of anthropogenic waste into water, spread throughout the districts [118]. Faced with these challenges, it is imperative to implement sustainable solutions involving effective management of potable water supply systems, improved hygiene practices, safe waste collection and disposal, promotion of modern sanitation facilities, and raising awareness of chemical risks. These measures will contribute to preserving public health and the environment, maintaining optimal sanitary conditions.

*Analysis of the Situation*

Unsafe water pollution has severe consequences on human health. According to the UNESCO World Water Development Report in 2021, approximately 829,000 people lose their lives annually due to waterborne diseases caused by non-potable water, lack of sanitation, and poor hand hygiene [25]. Among these deaths, nearly 300,000 are children under the age of five, accounting for 5.3% of all deaths in this age group [13]. However, in the study area, almost the entire population (99.8%) exclusively consumed water from taps and hand-powered pumps (PMH). The quality of this water is mainly compromised by the contamination of two physicochemical parameters (temperature and ammonium) and two bacteriological parameters (total coliforms and total aerobic flora), leading to a high prevalence of waterborne diseases. Furthermore, concerning tap water consumption, purified water, and bottled water, it has been established that tap water is a significant source of gastrointestinal diseases [80; 122], hindering nutrient absorption and causing malnutrition [113]. These findings align with those in Palestine, where individuals consuming municipal water directly face a higher risk of waterborne diseases such as diarrhoea than those using desalinated and filtered drinking water at the household level [5]. These effects are particularly pronounced in children [124]. According to epidemiological data from 2019 to 2022 obtained from the Order of Malta Health Centre in Wallia and the Mother and Child University Hospital in Gardolé, a significant

prevalence of water-related diseases has been recorded among women of childbearing age and children aged 0 to 5. These diseases primarily include diarrhoea (3948 cases), dysentery (2908 cases), skin infections (650 cases), typhoid (1953 cases), abdominal pains (1250 cases), and malaria (21096 cases). It is also concerning to note the number of deaths associated with these diseases, including 267 deaths from severe malaria, 69 deaths of gastrointestinal origin among children aged 0 to 5, and 103 deaths due to typhoid fever. Pathogens can also transmit these diseases from inadequate sanitation facilities, unfavourable piping conditions, and water supply system architecture conducive to the growth of microorganisms [110], even within the microbial communities present in drinking water distribution systems, leading to waterborne diseases [56]. Consumption of contaminated water, open defecation, ruptures, or leaks can trigger low-pressure events, and when repaired, pathogens can enter the systems [40; 76]. Additionally, the lack of adequate services for the disposal of faecal matter, solid and liquid waste, and climatic conditions plays a crucial role in epidemics [78]. Climate can introduce contaminants into water sources through runoff during intense precipitation or floods [147]. Moreover, temperature variations ranging from 30-45 °C can alter the dynamics of microbes in pipelines, and pathogens present can be released into moving water [20], along with inadequate hygiene practices. All these factors support the obtained results, revealing that most surveyed households attribute these diseases to poor drinking water quality (50%), inadequate hygiene practices (28%), and unsanitary

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conditions (19%). In comparison, others (3%) could not provide a specific response to this question.

These two districts face inadequate healthcare systems due to various socio-economic reasons. Thus, this area will bear a heavy burden in terms of morbidity by the end of 2022, with an observed increase in cases of waterborne diseases. Unfortunately, most of the budget allocated to the health, water, and sanitation sectors is mainly invested in poorly designed or unfinished water projects, leading to groundwater pollution [109]. Moreover, a significant portion of these funds is allocated to purchasing medications and operating various technical services [37]. However, the misappropriation of public funds has reached alarming levels in this environment [94]. Preventive measures have not been implemented, such as hygiene promotion, mobilisation, awareness, and accompanying actions to alleviate the populations affected by these diseases [124]. Furthermore, collaboration to reduce or eradicate high-morbidity waterborne diseases has not been undertaken between different districts of the city of N'Djamena in partnership with development actors. A more coordinated approach and cooperation between districts and stakeholders could significantly mitigate this urgent public health issue [142].

Adhering to the following recommendations can significantly mitigate or eliminate the risk of waterborne communicable diseases:

*Water treatment for consumption*

In the study area, drinking water treatment poses a significant challenge due to limited resources and constraints on access to energy for boiling-based disinfection. Therefore, we advocate and strongly encourage the adoption of simpler, cost-effective, and less energy-intensive alternative techniques.

*Chlorination*

Ensuring a safe and clean water supply is the most crucial preventive measure to reduce the risk of waterborne diseases [41]. Free chlorine has proven to be the most widely used and practical disinfectant for purifying water intended for human consumption [82]. It is an effective and cost-efficient method for eliminating pathogenic microorganisms in water, such as bacteria and viruses, except for Cryptosporidium spp and certain species of mycobacteria (Bloom & Reenan, 2013). Adding just a few milligrams of free chlorine per litre of water for about thirty minutes generally inactivates nearly 100% of enterobacteria and viruses [52]. In addition to disinfection, chlorination can also contribute to maintaining water quality by preventing the growth of algae and bacteria in drinking water distribution systems [56]. This helps prevent biofilm formation and ensures clean water throughout the distribution network [144]. However, it is crucial to monitor and manage the process to minimise undesirable effects, such as by-product formation [105]. When chlorine reacts with organic matter in water, it can produce by-products such as trihalomethanes (THMs), which can harm health at high concentrations [82]. Thus, ensuring the supply of high-quality drinking water requires careful management of these processes.

Table 2. Chemical agents and contact times for making drinking water potable

| Chemical agents | Dose | Contact time in minutes |
|---|---|---|
| Sodium hypochlorite (commonly known as bleach): NaOCl | 0.5 -2.0 (mg/L) | 30-60 |
| Aquatabs® | 1 tablet: 3.5 mgper litre | 30 |

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These WHO guidelines may vary depending on local conditions, water characteristics, and other factors.

*Solar Disinfection*

Exposing drinking water to sunlight for several hours (typically 6 hours) can destroy bacteria, viruses, and parasites [70]. This can be achieved using transparent plastic bottles filled with water [120].

*Filters*

Water filters prevent waterborne diseases by removing contaminants and making drinking water safer [35]. Using activated carbon or membrane filters can render waterpotable and safe for consumption [87]. Therefore, to ensure that water remains clean and safe for drinking, it is essential to store it in suitable containers equipped with taps to prevent any subsequent contamination [23]. It is important to note that the effectiveness of water filters can vary depending on the quality of the water source and regular filter maintenance [43]. It is highly recommended for health authorities and water management experts in municipalities to conduct a thorough assessment to determine the most suitable filtration system [44]. Furthermore, the selected filters must be certified to meet the water quality standards established by the World Health Organization and the national guidelines of Chad.

The filter featured in Figure 2 is available in certain outlets and is occasionally offered at affordable prices in local markets in Ndjamena. We recommend promoting, subsidising by the government, and utilising it in the study area after the health regulatory services approve it.

*Moringa Wood*

Figure 2.Water Filter

Moringa seeds, a common plant in the study area, can be used for water decontamination [47]. Crushed moringa seeds can be added to water to act as a natural coagulant, removing suspended particles [121]

*Measures to be taken for Containers Intended for Household Drinking Water Storage*

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The grant or free distribution of water containers, cooking pots, and fuel in sufficient quality and quantity to the most impoverished households should play a significant role in reducing the risk of diseases such as typhoid fever, dysentery, diarrhoea, and more. This would ensure the preservation of stored clean water and the proper preparation of food [66].

*Optimising the Quality of Drinking Water*

To monitor and collect data on drinking water quality provided by the Chadian Water Company (STE), it is imperative to establish a real-time monitoring system for water quality indicators using sensors [112]. These sensors should be installed at the most frequently used water fountains [143]. The data collected will then be used to quickly detect abnormal fluctuations in water quality, allowing for effective intervention in resolving the issue of drinking water contamination [74]. For frequently used human-powered pumps (HPPs), municipalities should be equipped with portable rapid analysis kits to determine precisely the water quality consumed by households in their jurisdictions [131]. This will require training WASH agents, well operators, and water point managers on sensor data handling and interpretation and using these portable analysis kits [67]. Based on the collected data, targeted interventions can be planned, such as water treatment, water point disinfection, distribution of hygiene kits, geolocation of clean water distribution points, and identification of high-risk areas [71]. Based on the collected data, targeted interventions can be planned, such as water treatment, water point disinfection, distribution of hygiene kits, geolocation of clean water distribution points, and identification of high-risk areas [91]. Regular meetings should be organised to plan and coordinate interventions, including the temporary or permanent closure of heavily polluted or contaminated water points, among other measures [46] . Additionally, municipal authorities must routinely monitor drinking water quality and take immediate action to address identified issues.

*Health Education*

Health education is vital in preventing and eradicating water-related diseases in our study area, which faces significant health challenges due to the quality of drinking water and sanitation [12]. To combat these diseases effectively, it is imperative to raise awareness among the population about good hygiene practices, proper sanitation, and responsible water management [142]. Here are some key points to consider:

*Awareness of the Importance of Clean Drinking Water*

Households need to be informed about the risks associated with consuming untreated water from unreliable sources like the Logone and Chari rivers and the benefits of having access to safe drinking water [72].

*Promotion of Basic Sanitation*

Personal hygiene and waste management are crucial to prevent waterborne diseases [78]. Educational programs should promote using latrines, proper excreta disposal, and regular handwashing, especially before meals and after using the toilet [126]. Disinfecting excreta with cresol sodium without a sewage system and fly control is a vital concern for hygiene and public health [90].

*Training healthcare professionals and peer educators.*

Training healthcare professionals and local peer educators is essential to disseminate water health knowledge effectively [145]. They can convey accurate information and raise community awareness [54].

*Access to Information*

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Radio, television, and social media should be harnessed to disseminate health education messages on clean water, sanitation, and hygiene [95]. Well-crafted media campaigns can reach a broad audience [63].

*Community Engagement*

Active involvement of residents in planning and implementing health education programs is crucial, as households must be encouraged to improve their health conditions by taking responsible steps for positive behaviour change [11].

*Monitoring and Evaluation*

Collecting data on hygiene practices, waterborne disease rates, and progress in implementing health education programs is crucial to measuring the impact of interventions and making necessary adjustments [50]. Health education will be vital in combating waterborne diseases [31]. Providing accurate information and promoting proper hygiene practices can significantly reduce the spread of these diseases and improve the quality of life for vulnerable populations [61]. However, this approach

Table 3. Institutional Strategy for Excreta and Wastewater Management

| **Districts** | | |
|---|---|---|
| **Excreta and wastewater** | | |
| **Methods and Techniques for the Sanitary Disposal of Excreta and Wastewater** | | |
| **Level 1** | Improved Toilets | Disposal of Excreta and Greywater Separately |
| **Level 2** | CondominiumCollection Networks | Disposing of Excreta and Greywater Together |
| **Responsibilities** | **Coordination: The central city hall** | |
| | Housekeeping - Mason - Septic Tank Cleaner | |
| | Ministry of the Environment, Fisheries, and Sustainable Development(MEFSD) - Ministry of Water and Sanitation (MWS) - Ministry of Territorial Administration, Decentralization, and Good Governance (MTADGG) - Ministry of Infrastructure and Decongestion (MID) - Ministry of Territorial Planning, Housing, and Urban Development (MTPHUD) | |
| **Financing** | **Level 1** | Households - Non-Governmental Organizations (NGOs) - Donors - Individuals - Neighborhoods |
| | **Level 2** | The State and its development partners |
| **Priority** | **1-Level 1** | |
| | **2-Level 2** | |
| **Goal to achieve** | Reducing the risk of contact between excreta and the population while eliminating sources of contamination, such as stagnant water, is vital for preserving public health. | |
| | Protecting the receiving environment and groundwater to ensure efficient capture of water supply systems for the production of safedrinking water | |
| | Reuse | |
| | Securing collection networks and ensuring effective treatment prior to discharge into the receiving environment | |

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must be supported by investments in water infrastructure and sanitation to achieve sustainable results [41].

*At the Institutional Level*

The STE and the personnel responsible for water supply and sanitation in municipalities must ensure compliance with hygiene standards at water distribution points and fountains following the requirements specified in the contract with water point operators in all districts [107]. Municipal authorities responsible for WASH should incorporate water code requirements into company contracts [67]. These requirements should become critical elements from the infrastructure design and construction phase, such as small-scale water supply systems and sanitation facilities [115]. This approach will ensure the effective implementation of water-related standards and regulations, delivering high-quality WASH services to households [27]. Municipal authorities should enhance the skills of water supply technicians and well managers in sanitation and water hygiene to maintain the quality of drinking water produced [67]. Establishing ongoing cross-sector collaboration, particularly between the fields of hydraulics and health, is of paramount importance. Active involvement of municipalities remains essential for achieving these objectives [41]. Standardising the technical inspection methods employed in the hydraulic sector, including an online component for accessing these standards and procedures [92].

*Condominium Collection Networks*

The study area is facing significant challenges in managing excreta and wastewater. These challenges are exacerbated due to its rapid growth and urbanisation, necessitating an innovative and sustainable approach to address this issue [107]. That is why we propose the condominium network. The condominium network is a wastewater management system that collects, treats, and reuses wastewater at the neighbourhood level [30]. It is an integrated approach that efficiently and cost-effectively manages excreta and wastewater, with the potential solution being implementing condominium wastewater management networks while minimising environmental impacts [68].

Key advantages of the condominium network compared to the conventional model include:

- Efficient collection of wastewater using an underground pipeline network;
- Treatment of collected wastewater locally in treatment plants tailored to the population size served [51]
- Reuse of treated water for irrigation, landscaping maintenance, or safe discharge into the environment, contributing to water resource conservation [34].
- More cost-effective to implement and maintain, making it more accessible for rapidly growing urban communities [3].
- Community participation: Encourages active involvement of residents in the system's management and maintenance, strengthening a sense of community responsibility and ownership [26].
- Each block comprises 30-40 households [48].
- The operation of this system will be the responsibility of autonomous municipalities led by a Condominium Committee, and its maintenance will be ensured by the same committee [127].

*Regarding Municipal Responsibility*

Responsibilities for solid waste management include collection, sorting, recycling, and

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environmentally responsible disposal of waste [34]. Municipal authorities must establish adequate infrastructure, such as sorting centres and sanitary landfills, and develop regulations to encourage source reduction and public awareness [84]. In the case of excreta and wastewater, ensuring proper sanitation systems is essential [106].This includes constructing and maintaining sewage networks and wastewater treatment plants and promoting improved household toilets [45]. The primary responsibility in this area also falls on local authorities, working in collaboration with public health stakeholders, to establish the following coordination and management structure [28].

*Sources of Financing*

Securing funding for these initiatives is a substantial challenge. The study area is proposed to explore various funding sources, including government funds such as budgetary support and municipal grants [108]. Public-private partnerships focusing on sanitation projects and support from NGOs and associations are also viable options [42]. Another avenue is seeking international grants from organisations like AFD (French Development Agency) and BAD (African Development Bank). Creating a dedicated fund for sanitation management is also suggested [115]. This fund could be fuelled by diverse means, including waste and habitat taxes, infrastructure usage fees, and voluntary contributions from businesses and citizens [83]. This diversified approach would mobilise varied financial resources, ensuring a robust foundation for the sustainable financing of sanitation initiatives [18].

*Institutional Strategy for Managing Waterborne Diseases in Healthcare Centres and Hospitals*

Waterborne diseases pose a significant public health challenge in Chadian cities, affecting children aged 0-5 years and the entire population, irrespective of social class (Guarango, 2022). Their impact is reflected in high annual prevalence rates, hospitalisations, and, unfortunately, fatalities. The coordinated and sustainable management of waterborne diseases in healthcare centres and hospitals [103], especially in vulnerable areas like the 3rd and 9th districts of N'Djamena, requires the implementation of effective institutional strategies, despite limited resources, to mitigate their impact on public health [39]. Here are some suggested solutions:

Table 4. Institutional Strategy for Managing Rain water

| | |
|---|---|
| **Districts** | |
| **Rainwater** | |
| Methods and Techniques for Rainwater Drainage | |
| **Level 1** | Construction of drainage channels in front of residences |
| **Level 2** | Condominial collection networks |
| **Responsibilities** | **coordination: The central city hall** |
| | State - Municipality - Neighbourhoods - Households |
| | Ministry of Environment, Fisheries, and SustainableDevelopment (MEFSD) - Ministry of Water and Sanitation (MWS) - Ministry of Infrastructure and Decongestion (MID) - Ministry of Land Planning, Housing, and Urban Development (MLPHUD) |
| **Financing** | State and its development partners |
| | State grant to municipalities - Household (Waiving property tax fees for households for two years in connection with the construction of drainage channels inneighbour-hoods)-Funders-Donors |

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| | |
|---|---|
| **Priority** | **1-Level 1** |
| | **2-Level 2** |
| **Goal to achieve** | Minimise impact, reduce run-off, and evacuate rainwater safely. |

Table 5. Institutional Strategy for Solid Waste Management

| | | | | | | |
|---|---|---|---|---|---|---|
| | **Districts** | | | | | |
| | **Solid Waste Generation at the Community Level** | | | | | |
| | Methods and Techniques for Solid Waste Elimination | | | | | |
| **Level 1** | Environmental Education: Implementing educational programs to raise awareness among the population about the environmental impacts of solid waste and promoting responsible behaviours | | | | | |
| **Level 2** | Strict Regulation: The implementation of the application decree for the stringent sanitation code aims to oversee waste management and enforce environmental standards for both businesses and municipalities | | | | | |
| **Level 3** | Incineration | Composting | Primary collection (initial household waste collection) and secondary collection (sorting and grouping of waste) | Tertiary collection (ittransports non-recyclable waste to its final destination while adhering to environmental regulations) | Secure Treatment-Disposal | Transformation-Recycling |
| **Level 4** | Circular Economy: Promoting the adoption of circular economic models where products are designed to be recycled, repaired, or reused, thereby minimisingwaste generation | | | | | |
| **Responsibilities** | **Coordination: The central city hall** | | | | | |
| | Ministry of Environment, Fisheries, and Sustainable Development (MEFSD) -Ministry of Water and Sanitation (MWS) - Ministry of Territorial Administration, Decentralization, and Good Governance (MTADGG) - Ministry of Infrastructure and Decongestion (MID) - Ministry of Territorial Planning, Housing, and Urban Development (MTPHUD)-Households-Municipalities | | | | | |
| **Financing** | Households-Municipalities-Ministry of Vocational Training, Trades, and Microfinance (MFPMM) - Ministry of Youth and Entrepreneurial Leadership (MJLE) | | | | | |
| | Financial aid from the State to municipalities - Development partners - Non-Governmental Organizations (NGOs) - Private and Semi-governmental Enterprises - Associations, etc. | | | | | |
| **Priority** | **1** | **1** | **1** | **2** | **2** | **3** |

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| | |
|---|---|
| **Goal to achieve** | Eliminate all sources of contamination between waste and the population to ensure water safety and public health. |
| | Promoting on-site recycling |
| | Promote the transformation and reuse of materials at the end of their lifecycle. |

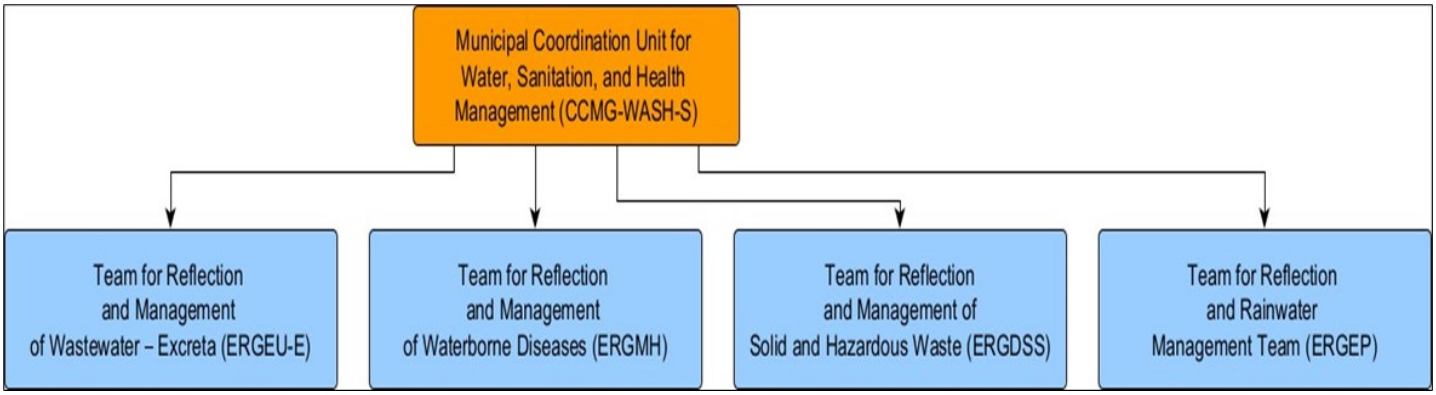


Figure 3. WASH-Health Management Coordination Plan

*Vaccinations*

Due to the high prevalence of waterborne diseases in the study area, it would be desirable for households to be vaccinated per the [141] recommendations. These guidelines emphasise the crucial role of vaccinations against waterborne diseases in preventing potentially severe infections [77].

*Cholera:* The oral cholera vaccine (OCV) and Vaxchora are recommended [77].

*Typhoid:* The injectable Typhim (Vi) and the oral Vivotif (Ty21a) vaccines are recommended [77].

*Polio:* The oral attenuated virus vaccine (OPV) and the inactivated vaccine (IPV) have played a significant role in nearly eradicating the disease [29].

*Hepatitis A:* The vaccine against hepatitis A (Avaxim, Epaxal, etc.) is recommended [146].

*Hepatitis B:* The vaccine against hepatitis B (Engerix-B, Heplisav-B, etc.) is recommended [69].

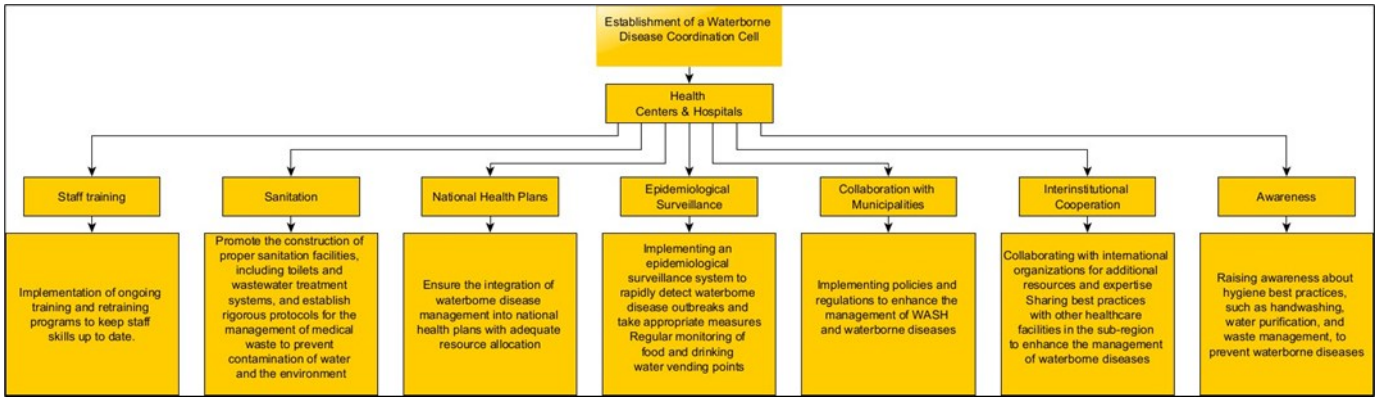


Figure 4. Waterborne Disease Management Plan in Hospitals and Health Centers

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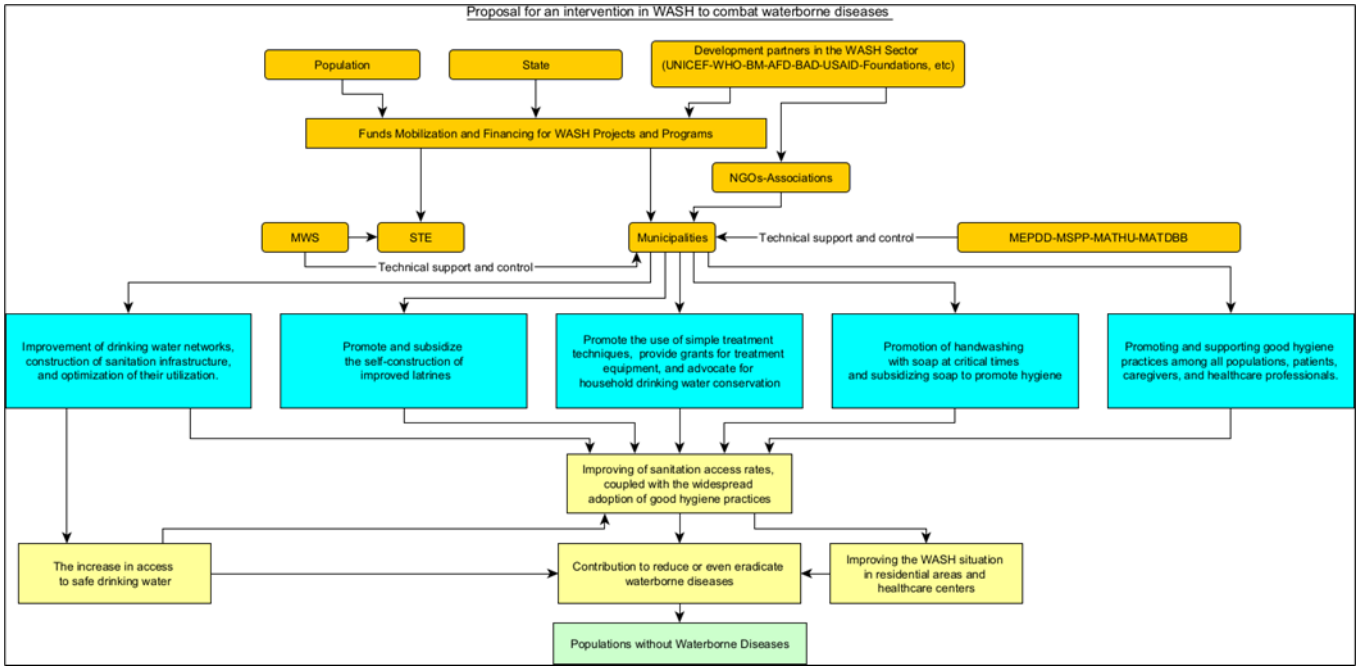


Figure 5. Action plan aimed at combating waterborne diseases in the study area

## Conclusion

Water, an essential resource often underestimated, is crucial for every human being on Earth. However, its significance is marred by its role as a vector for pathogens like bacteria, viruses, and parasites. This has led to a growing concern, prompting efforts to analyse and treat water before consumption. Despite the willingness to access safe drinking water, its cost remains a barrier, compelling many to rely on available sources. Water-related diseases, especially impacting women of reproductive age and children under 5, continue to be a leading cause of global death and illness, particularly in sub-Saharan Africa.

To address this challenge, decision-makers must invest wisely in sustainable infrastructure in water, sanitation, and health sectors for optimal public health outcomes. Transparency and community participation are vital for success, fostering health education and resilience to water- related health risks. This approach creates awareness about water's importance in daily life and the preservation of the immediate environment. The multidimensional and collaborative approach, with active involvement from the local population, is crucial for the long-term success of eradicating waterborne diseases in the 3rd and 9th districts of Ndjamena.

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## Conflicts of interest

The authors declare no conflict of interest.

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