LUND UNIVERSITY
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# Water, Sanitation, and Adverse Pregnancy Outcomes in Mali: A Study of Early Neonatal Mortality and Low Birth Weight

by

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This thesis investigates the link between the water and sanitation environment mothers are exposed to during pregnancy and adverse pregnancy outcomes in Mali, specifically early neonatal mortality and low birth weight. The motivation and contribution for this analysis is that little research has been done on this topic, specifically in the Sub-Saharan African region and with the combination of those two outcome variables. The study conducts a literature review and implements a quantitative analysis of microdata from the DHS program conducted in 2018 in Mali. The statistical analysis consists of four different logistic regression models for each outcome variable individually. The findings highlight that pregnant women and their children are particularly vulnerable to inadequate water and sanitation, with a higher risk of infection, more caloric expenditure, and stress, which in turn increases the risk of adverse pregnancy outcomes. The results of the thesis underline the importance and urgency of improving the water and sanitation environment in Mali in order to decrease related health risks for everyone but especially women and their offspring. This not only has the potential to improve early-life determinants but also adult health, hence increasing the overall quality of the Malian people's life-course.

*Keywords:* water, sanitation, WASH, adverse pregnancy outcomes, low birth weight, early neonatal mortality, Mali

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# List of Abbreviations

| | |
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| **APO** | Adverse Pregnancy Outcome |
| **BMZ** | German Federal Ministry of Economic Cooperation and Development |
| **DHS** | Demographic Health Survey |
| **JMP** | Joint Monitor Programme |
| **LBW** | Low Birth Weight |
| **SSA** | Sub-Saharan Africa |
| **UNICEF** | United Nations International Children’s Emergency Fund |
| **WASH** | Water, Sanitation and Hygiene |
| **WHO** | World Health Organization |

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# 1 Introduction

Despite water being the most essential resource on this planet, to this day 2.2 billion people throughout the world do not have access to clean and safe drinking water (UNICEF, n.d). In developed countries, water used to be an almost constantly accessible resource, but increasingly, this is not true for everyone. The issue is especially important in resource-poor countries such as emerging or developing countries. Without drinking water, a person could only survive for about three days, but not only that, without water we could not grow food to survive. Moreover, besides its importance for our basic survival, water is also needed for our daily hygiene and sanitation needs. In 2020, 3.6 billion people still did not have access to safely managed sanitation services (taking into account the final disposal of excreta), with 1.7 billion of those without access to even basic sanitation (access to latrines or flush toilets) (UNICEF, 2021b). This can result into devastating health effects for everyone but especially for children, pregnant women, and their fetuses, as the most vulnerable groups to WASH (Wash, Sanitation, and Hygiene) related diseases (Rocha & Soares, 2015). The increased health risk for women is understood to be driven by biological (health) differences between men and women but also gendered behavioral differences making women most vulnerable to diseases related to the WASH environment (Campbell et al., 2015).

Not only do diseases directly related to WASH remain a significant public health challenge worldwide, but adverse pregnancy outcomes (APO), such as preterm birth, low birth weight, and neonatal mortality, continue to be major public health concerns. Complications related to pregnancy and childbirth are estimated to have caused the death of 287,000 women in 2020, of which more than half occurred in fragile and humanitarian settings with Sub-Saharan Africa (SSA) and Southern Asia as the most affected areas (WHO, n.d-a). Further, the SSA region is predicted to also have the highest neonatal mortality rate in the world, with 43% global newborn deaths occurring in the region (WHO, 2022). Another estimation by the World Health Organization (WHO) predicts that more than 20 million children worldwide are born with a low birth weight, defined as a birth weight below 2500g (WHO, n.d-b). Although the rates of APOs are currently very high in developing countries, key interventions, such as improvements in water and sanitation infrastructure, health, and nutrition, are projected to lower those rates (Lehtonen et al., 2017).

All of this results in the following research questions, that this master thesis aims to answer: What is the impact of quality and access to water and sanitation (facilities) on the risk of adverse pregnancy outcomes, specifically offspring neonatal mortality and low birth weight (LBW), in Mali?

## 1.1 Motivation and contribution

Although many studies have been conducted on how children under five are affected by inaccessible and unsafe water, as well as sanitation facilities, not much research has been designated to investigating the relationship between maternal and neonatal health and WASH (Cameron et al., 2021). Many studies in the past have focused on the connection between childhood mortality (Ezeh et al., 2014), child stunting, diarrhea, and the WASH infrastructure (Fink et al., 2011). Previous studies that focused on women and water were mostly aimed at better understanding the economic and specific health consequences for women (Caruso et al., 2015). To comprehensively analyze the topic, it is essential to examine water and sanitation both separately and jointly (Campbell et al., 2015). However, the majority of studies have only focused on one or the other. Previous research has found that health issues linked to inadequate sanitation might undermine health advantages from better access to improved water sources (Geere, 2019), making it crucial to analyze the real association both individually and combined.

Further, this thesis provides a unique contribution to previous literature by focusing on a SSA country, Mali. While previous studies have primarily focused on Asia, particularly India (Baker et al., 2018; Padhi et al., 2015; Patel et al., 2019; Torondel et al., 2022), SSA, and specifically Mali, has received less attention despite its relevance. Mali is one of the poorest nations in the world, with very low human development (UNDP, 2022). At the same time, it is one of the fastest-growing nations in the world with a population growth rate of 3.2% annually (BMZ, 2023a). The WASH infrastructure is, despite several improvements over the past years, still characterized by low access to improved and safe water and sanitation sources (INSTAT & ICF, 2019). This makes Mali and its demographic and WASH structure an intriguing case study. The country context and background will be elaborated on in more detail in chapter three of this thesis.

Investigating the relationship between WASH and APOs is compelling and significant not only in terms of loss of life, including neonatal mortality, but also in understanding the potential impact of prenatal environmental exposures on a child's future well-being. The Fetal Origin Hypothesis is a crucial aspect to consider in this context. This theory by David Barker predicts that many health issues in adult life have their origin in the womb of the mother and the conditions the child was exposed to during the pregnancy. He predicts that this hypothesis holds true especially for infants who are born with a LBW because they failed to grow in the womb due to e.g. adverse circumstances during pregnancy (as opposed to preterm babies) (Barker, 2001). Moreover, Barker (2001) predicts that the mother's birth weight might have a strong influence on the birth weight of the child, underlying how much influence a mother and her own early-life determinants have on the health of her child. Other research on early-life determinants has shown that in-utero and early childhood conditions might influence long-term effects on schooling (Currie & Almond, 2011) and might be connected to cognitive impairment in later childhood (Baker et al., 2018). This shows that the environment a child is exposed to in-utero does not only potentially affect the child's (future) health but also human capital development in later life, underlying the importance of this topic not only from a humanitarian viewpoint but also an economic viewpoint. Furthermore, the possible intergenerational transmission of health, particularly in developing countries (Bhalotra & Rawlings, 2013), is another motivation to study this topic, as not only one but several generations might be affected by APOs.

## 1.2 Thesis outline

In order to answer the research question, the thesis will be structured as follows. First, a literature review will be conducted, including an introduction to the general importance of water and sanitation on health, as well as a general introduction to adverse pregnancy outcomes. Next, the country background of Mali will be presented and the choice for selecting Mali will be motivated. Subsequently, the thesis will develop a theoretical framework for the association between the WASH infrastructure and APOs. The methodology section will then present an introduction to the data, variables, and models. The empirical analysis and results will then be presented. The thesis will conclude with a discussion, including limitations and recommendations for future research. Finally, the thesis will end with a conclusion.

# 2 Literature Review

The following chapter provides an overview of the literature to date on APOs and water and sanitation. It will begin with a discussion of why the quality of and access to water and sanitation are important for the health of everyone, but especially for women. It will then provide an introduction to APOs. Finally, it will provide a theoretical framework on how water and sanitation can affect women's health during pregnancy, resulting in APOs such as early neonatal mortality and LBW.

## 2.1 General Background: Why does WASH matter?

As already mentioned in the introduction, water is one of the most essential resources in the life of a human. It plays a vital role in the daily life of everyone on this globe by being used for drinking, cooking, cleaning, and sanitation purposes. The lack of access to safe WASH goes beyond economic costs. It is also connected to severe humanitarian costs, including lost lives. To this day around 4,000 people each day die due to unsafe WASH systems around the world, with children under five making up for around 1,000 deaths (UNICEF, 2023b). Despite the private user costs still often being of a financial nature, most of the (long-term) costs are related to health penalties and opportunity costs paid by the user, especially women (Hunter et al., 2010). As women generally bear the main burden of fetching water if the household has no access to piped water (Geere & Cortobius, 2017), women and potentially also their children have to face the highest costs related to inadequate water (supply). The costs associated with sanitation are similar to those ones of water, as the costs also include fiscal, time, and health costs (Van Minh & Hung, 2011). In consequence, one can say that improved WASH infrastructures due to better quality and access can theoretically result in better health, improved school attendance, better economic outcomes, and in general a better long-term trajectory for humans in general, but especially women and girls.

In recognition of the importance of securing access to safe and reliable drinking water for everyone in the world, the United Nations General Assembly and the Human Rights Council acknowledged the right to sufficient, safe, accessible, and affordable water as a crucial aspect of binding international law in 2010. In 2015, the human right to sanitation, including physical and affordable access to sanitation, was also recognized as a human right by the United Nations General Assembly (UN Water, n.d.). Clean water and sanitation have been prioritized as Sustainable Development Goal 6, putting access and sustainable management of water and sanitation for all as a critical part of the Agenda 2030 (UN, n.d). As water is deeply interconnected with other aspects of sustainable development on this globe, such as food security, health, and (gender) equality, it is a crucial part of sustainable development in all areas. Due to this interconnection, prioritizing WASH on the political agenda and further researching the interconnection between WASH and other parts of sustainable development, in the case of this thesis, women's (reproductive) health, can potentially have a positive impact on not only one aspect of sustainable development but several.

## 2.2 General Background: Adverse Pregnancy outcomes

Pregnancies in the Western world are predominantly planned, and while complications do arise, they are typically manageable through available medical treatments. This results in generally positive outcomes for both the mother and child. But this is not true for the developing world; APOs are in fact far more common in resource-limited settings (Padhi et al., 2015). Adverse outcomes of pregnancies can affect both the child and the mother individually but also jointly. The most severe adverse pregnancy outcome mentioned in the literature is the death of the mother or her child (Kramer, 2003). Other types of APOs commonly mentioned in the literature are early neonatal mortality and LBW, both of which are major public health concerns in developing countries (Lawn et al., 2005; Mahumud et al., 2017).

The WHO defines LBW as a child that is born with a weight under 2500g (Kramer, 2003). It is estimated that around 20 million children around the globe each year are born with a LBW (Patel et al., 2019), with a substantial number occurring in developing countries (Mahumud et al., 2017). LBW is an often used indicator of neonatal health (Patel et al., 2019). Two main reasons are mentioned in the literature that might lead to LBW. The first reason is preterm birth, meaning that a child is born before the completed 37 weeks of pregnancy (Kramer, 2003). Another reason is intrauterine growth restrictions, caused by for example malnutrition of a mother, maternal diseases, or infections during the pregnancy (Resnik, 2002). Previous literature predicts that especially in developing countries intrauterine growth restrictions are the main driver for the high rates of LBW rather than preterm birth (Kramer, 2003). Other factors that might influence the likelihood of LBW, especially in developing countries, are maternal characteristics such as delayed conception, advanced maternal age, and inadequate antenatal care visits during and after the pregnancy (Mahumud et al., 2017). Some of these potential driving factors for LBW might be directly or indirectly related to the environment a mother is exposed to during her pregnancy, also making the WASH environment an important indicator to consider while discussing potential reasons for LBW, especially in resource-poor settings such as Mali.

Neonatal mortality is defined as the death in the first 28 days of a child. Early neonatal mortality is defined as the death of a child in the first week of their life (Lehtonen et al., 2017). During the neonatal period, children are the most vulnerable in terms of survival (UNICEF, 2023a). Infants face the highest risk of dying in this period at a global rate of 18 deaths per 1,000 live births in the year 2021. In absolute numbers, this means that globally around 6,400 children every day died in the neonatal period, in total around 2.3 million children in 2021 (UNICEF, 2023a). It is estimated that around 99% of neonatal deaths occur in low- and middle-income countries (Sankar et al., 2016), making Mali an interesting country case study, as one of the poorest countries in the world. Additionally, it is estimated that during the first three days of life, nearly 60% of all neonatal deaths occur (Sankar et al., 2016) and the first 24 hours are even predicted to account for 25-45% of all neonatal death (Lawn et al., 2005). This underlines the importance to use early neonatal death as an indicator compared to neonatal mortality, later in the analysis. Another reason to use early neonatal mortality instead of neonatal mortality is that early neonatal mortality is one type of adverse pregnancy outcome, as the main reason for the occurrence often has its origin in the womb. The major cause of (early) neonatal mortality is preterm birth, childbirth-related complications, infections (during the pregnancy), and birth defects (Lehtonen et al., 2017). Moreover, another indirect reason correlated to early neonatal mortality is a LBW of a child. It is estimated that LBW newborns account for 60-80% of neonatal deaths (Lawn et al., 2005). But LBW is not only considered as a reason for early neonatal mortality but also according to the Fetal Origin Hypothesis by Barker (2001), as mentioned earlier, considered to be connected to general health outcomes in later life, making it an interesting and important individual outcome variable for the analysis of this thesis.

## 2.3 Theoretical Framework: Water, Sanitation and Adverse Pregnancy Outcomes

The last two chapters considered water and sanitation individually and highlighted their importance. This chapter combines the two aspects in a theoretical framework to better understand the role that water and sanitation could play for APOs in a fragile environment like Mali. Moreover, this chapter aims to develop Hypotheses to be tested in the later quantitative analysis. The theoretical framework of this thesis will draw upon the work of Campbell et al. (2015) as a foundational framework. Campbell et al. (2015) developed a conceptual framework to provide a better understanding of the impact of WASH on health, specifically on maternal and reproductive health, as shown in Appendix A. This thesis will extend their framework with other previous research findings and maternal characteristics that might also play an important role in determining the likelihood of APOs. The chapter will be structured in the following way: First, the relationship between water and APOs will be elaborated. Second, the potential impact of sanitation on the health of pregnant women will be explained. And lastly, maternal and infant characteristics that might impact the odds of APOs will be introduced.

### 2.3.1 Water and adverse pregnancy outcomes

The source of water and also the way to treat water in order to make it safe and drinkable affects each and everyone, no matter which gender or age. Nevertheless, women are the ones most often responsible for the tasks surrounding the water treatment and the family’s water needs (Collins et al., 2019). This means that the contact and behavior towards water might differ between women and men, potentially making women more vulnerable to diseases associated with (contaminated) water. Therefore, the first health issues that will be considered in this framework are diseases related to water quality. Water can be contaminated with different substances, such as arsenic, fluoride, or other industrial and agricultural contaminants like metal or pesticides (Campbell et al., 2015). Exposure to those substances in the water during pregnancy is associated with a higher risk of spontaneous abortion, stillbirth, infant mortality, intrauterine growth restriction, and also LBW (Campbell et al., 2015; Hopenhayn et al., 2003). Moreover, also connected to the quality of the water is the source of drinking water (Geere & Hunter, 2020). The risk of suffering from diseases related to unsafe and contaminated water, such as diarrhea, is often associated to be highest with unimproved water sources (Ezeh et al., 2014). Therefore, the hypothesis resulting from this aspect is that the likelihood of APOs increases with using unimproved water sources during pregnancy, as the risk of adverse maternal health outcomes will increase with it.

Another aspect related to water, but more with the behavior and access towards water, is the collection of water. If water is not available on the premises, women and girls take on the task to collect water in 8 out of 10 households (WHO, 2017). For SSA estimations predict that roughly three-quarters of households need to collect water from sources located off-premises, with women and girls being responsible for fetching the water in 71% of these households (Geere & Cortobius, 2017). Due to their responsibility for collecting water, United Nations International Children's Emergency Fund (UNICEF) (2016) estimates that women and girls worldwide spend 200 million hours every day collecting water for themselves and their families. The estimated time spent on one roundtrip to collect water does differ between rural and urban areas. A roundtrip to collect water is predicted to be 33 minutes in rural areas and around 25 minutes in urban areas in SSA (UNICEF, 2016). This not only leads to an economic disadvantage for women, as they cannot take part in paid labor during the time of collecting water but also possible devastating health issues. The most typical transportation method for water is to carry the water on the head or back of children and women (Hunter et al., 2010). This can have substantial consequences for the health of the water carrier, like musculoskeletal disorders, such as spinal pain or joint problems, and other related disabilities (Geere et al., 2010). A case study conducted in Kenya, which specifically focused on women as water carriers, revealed that the task of fetching water is linked to negative health consequences such as back, abdomen, and chest pain, as well as fatigue and increased energy expenditure. Furthermore, women themselves in this case study attributed APOs, such as early delivery, stillbirth, and miscarriages to the task of water acquisition (Collins et al., 2019). Morover, previous research has found that pregnant women, women who have recently given birth, and women who carry infants while fetching water are particularly vulnerable to injuries related to water collection, especially on uneven terrain (Caruso et al., 2015).

An additional (health) aspect connected to water collection is the possible higher caloric expenditure due to long water trips (Collins et al., 2019). In developing countries, many women suffer from malnutrition and iron deficiency (Sorenson et al., 2011). Long trips for water collection, especially in times of water scarcity, might worsen those conditions and hence impose health risks not only for the woman herself but also for her (unborn) infant (Sorenson et al., 2011). Studies focused on SSA estimated that an average of 10% of a women’s daily caloric intake was spent on water collection (Campbell et al., 2015). This could be a risk factor for APOs as poor nutrition is an associated cause of LBW (Ramakrishnan, 2004). Previous research has found that maternal nutritional abnormalities, such as extreme under and/or malnutrition possibly lead to poor fetal growth, leading to lower birth weights (Resnik, 2002), which may also increase the risk of early neonatal mortality.

Another health risk that could be associated with inadequate access to water, and thus possible water scarcity leading to APOs, is stress. Women in western Kenya reported water acquisition as stressful, especially when water is scarce and they have to wait long hours for their turn to collect water (Collins et al., 2019). This psychological stress might increase the release of stress hormones leading to higher immune-inflammatory markers and consequently leading to APOs, such as premature labor (Baker et al., 2018). This shows that water scarcity and APOs might be deeply interviewed. This interrelationship was already witnessed in a study focused on Brazil focusing on the connection between birth outcomes and water scarcity. The results of the study show that a reduction in rainfall significantly increased infant mortality rates and the risk for LBW due to e.g., nutrient stress (Rocha & Soares, 2015). These findings motivate the choice of Mali as a case country, as Mali is predicted to be deeply affected by climate change and thus also by increasing water scarcity in the upcoming years (Jankowska et al., 2012), potentially worsening women's (health) conditions.

Another aspect linked to access to water is that quantitative studies reported a relationship between water collection and reduced uptake of prenatal care, implying worse pregnancy outcomes for both mother and child (Geere et al., 2018; Geere & Hunter, 2020). These findings show that health issues connected to water might not only be correlated with direct diseases, such as infections induced by water but also by indirect factors such as opportunity costs, in this case, health care, due to the responsibility of collecting water. Another study even found that women who are collecting water are more likely to leave their child at home alone for one or more hours, one or even several days per week (Geere & Hunter, 2020). This finding once again underscores how closely water infrastructure is linked to maternal and child health, not only in terms of water quality, but also in terms of access to water and water-related behaviors. The hypothesis arising from the theory and previous research findings on access to water is that the longer it takes a woman to fetch water each trip, the more likely she is to experience APOs.

### 2.3.2 Sanitation and adverse pregnancy outcomes

Everyone needs to use the bathroom, and hence a sanitation facility once in a while. Despite this need, the specific sanitation needs between men and women do differ (Kwiringira et al., 2014). First of all, for women access to a safe and adequate sanitation facility is important for their menstrual hygiene management and reproductive health (Sommer et al., 2013). As soon as women start menstruating, they need a place to manage their menstruation safely and hygienically. Without such a facility women and girls might be hindered from taking part in daily life activities, such as school or work, and hence hinder women's educational and economic opportunities (Sommer et al., 2013). Moreover, women might be subject to sexual harassment or gender-based violence on the way to or from a public toilet and open defecation, threatening the dignity and safety of women, especially in rural and unsupervised areas (Campbell et al., 2015; Pommells et al., 2018). In order to avoid those risks some women might restrict their fluid intake potentially leading to devastating health outcomes, such as the increased risk of urinary tract infections (Campbell et al., 2015). Additionally, when sanitation facilities are unimproved or not available women are usually responsible for the disposal of their children's waste, making women more vulnerable to diseases related to human excreta even of their own children (Campbell et al., 2015; Kwiringira et al., 2014). This shows that sanitation is not only connected to the safety and dignity of women but also to their (reproductive) health.

Especially pregnant women are known to be most vulnerable to health issues related to inadequate sanitation facilities, as they often need to use the toilet more often during their pregnancies. This more frequently use of (un)improved sanitation facilities, might expose them to the risk of infecting themselves with bacteria or other kinds of excreta-contaminated diseases for longer, and hence makes them most vulnerable to diseases related to sanitation (Campbell et al., 2015). Especially the use of shared sanitation facilities, such as (unhygienic) shared latrines poses a substantial risk for urinary tract infections for women (Kwiringira et al., 2014), which is known to be a common risk for APOs (Baker et al., 2018). Another health issue related to inadequate sanitation access is infection with hookworms. Hookworms are transmitted through skin contact with contaminated excreta (Bleakley, 2007), possibly making shared and unimproved sanitation facilities the biggest transmission risk. It is estimated that around 6.9 million pregnant women in SSA are infected with hookworm, which puts them at a high risk of hookworm-related anemia (Campbell et al., 2015). Consequently, a hookworm infection during pregnancy is associated with a lower infant birth weight and intrauterine growth restriction (Campbell et al., 2015), and hence also poses a substantial risk for early neonatal mortality. Similar to collecting water, women who do not have access to any kind of sanitation facility but must resort to open defecation might spend a significant amount of time seeking a safe and private place to open defecate. This might lead to injuries, fatigue, or also physical and mental stress, potentially increasing the risk of LBW (Baker et al., 2018). Due to all those reasons poor sanitation is seen to be a major contributor to APOs in the literature (Campbell et al., 2015; Padhi et al., 2015; Patel et al., 2019). Therefore, one of the main hypotheses of this thesis is that poor sanitation infrastructure increases the risk of early neonatal mortality and LBW significantly.

### 2.3.3 Other driving factors for adverse pregnancy outcomes

In addition to the water and sanitation infrastructure other factors such as maternal characteristics are known to affect the likelihood of APOs, and hence are important to mention for a comprehensive theoretical framework.

One of the most commonly discussed risk factors for APOs in the literature is maternal age. Studies have shown that either very young mother so mothers below the age of 20 (Fraser et al., 1995) or older mothers so above the age of 35 have the highest risk of APOs, such as LBW (Lee et al., 1988), stillbirth, preterm birth, and neonatal death (Lisonkova et al., 2010). The reason for this phenomenon mentioned in the literature is that with advanced maternal age, the risk for decreased fetal growth is increasing due to the biological aging of mothers (Lee et al., 1988). For young mothers on the other hand, the sociodemographic background is theorized to be a driving factor for a higher risk of APOs (Lee et al., 1988). Therefore, the assumption would be that the younger/older a mother is the more likely she and her infant are to experience APOs, such as early neonatal mortality or LBW.

Another factor known to be associated with APOs is parity. Parity is defined as the number of children a woman has given birth to in her reproductive years (Lin et al., 2021). Parity can be further classified into nulliparity (women who never delivered a newborn before) and multiparity (women who have delivered at least one newborn before) (Lin et al., 2021). Other studies have differentiated between nulliparity, multiparity, and grand multiparity (e.g. more than three children) (Bai et al., 2002). Because of these different definitions of parity, parity is often closely related to the age of the mother, as women with higher parity tend to be older. Moreover, women with greater parity are often associated to have a lower socioeconomic status (Bai et al., 2002). Results of previous literature show that nulliparity and grand multiparity have significant effects on the health of mothers and their infants (Bai et al., 2002), and are associated with a higher risk of e.g. LBW (Lin et al., 2021).

Another commonly discussed factor in the general literature on APOs but also specifically in the context of WASH, is the socioeconomic background of women or sometimes also more broadly the socioeconomic background of the household a child is born into. Studies that focused on childhood mortality in Nigeria and the impact of water and sanitation, found that in all age periods, children from poorer households had a significantly higher risk of mortality compared to children born into wealthier households. A possible explanation named by the authors is that resource-rich families might have more capital to invest in improved water and sanitation facilities compared to poorer households (Ezeh et al., 2014). Another commonly used indicator to measure the socioeconomic background is the education of the mother. Education seems to have a strong impact on the risk of APOs, meaning the higher the education level the lower the risk of preterm birth or low infant birth weight (Barker, 2001; Patel et al., 2019). A study explicitly focused on maternal education and child survival in developing countries found that with each year increase in the mother’s education the risk of under-five mortality declines by around 7-9% (Cleland & Van Ginneken, 1988). This shows that the socioeconomic environment of a mother is an important determinant for her chances of a strong and healthy baby.

In addition, place of residence, which may be related to a family's socioeconomic status, is an interesting factor to include in this framework. The reason to look at this indicator is that place of residence not only has the potential to determine the WASH environment but also the health (facility) environment a mother has access to during her pregnancy for antenatal care. As mentioned earlier, the time of a water trip might differ between rural and urban areas, with women in rural areas making longer trips exposing them to health risks for longer (Geere & Cortobius, 2017). Additionally, in rural areas women might have longer distances to health care facilities, potentially rising the burden to have regular checkups during pregnancy. A study focused on Mali found that the distance to the health facility and the often connected transportation barriers in rural areas hinder women to get antenatal care or even delivery assistance while giving birth (Gage, 2007). Other studies that focused on newborn health and included place of residence as a control variable found that newborns born to mothers living in rural areas had a significantly higher risk of neonatal death compared to newborns born to mothers living in urban areas (Ezeh et al., 2014). This leads to the assumption that women in rural areas might have a higher risk of APOs, compared to urban areas, due to e.g., infrastructure differences.

In order to also control for specific infant characteristics that might be driving factors for APOs, the sex of the child is included in this framework. Already during pregnancy biological differences in the sexes are seen. The death rate for male fetuses is significantly higher than that for female fetuses. Moreover, the likelihood of male fetuses being delivered prematurely is also significantly higher compared to female fetuses (Ingemarsson, 2003). This gender difference can also be seen in the gender ratios of neonatal mortality. Female newborns are described to have a biological survival advantage compared to male newborns in the neonatal period (Lawn et al., 2005), potentially leading to lower numbers of early neonatal mortality for girls. For LBW, the literature suggests that male infants have an advantage due to their Y-chromosome. Term male newborns are expected to be weighted between 150 and 200g more than their female counterparts (De Bernabé et al., 2004). Consequently, the assumption for the later analysis is that girls do have a lower risk for early neonatal mortality but a higher risk for a birth weight under 2500g compared to male newborns.

## 2.4 Hypotheses

The results of the literature review and the theoretical framework led to the following Hypotheses shown in Table 1, which will be tested in the later quantitative analysis.

*Table 1: Summary Hypotheses*

| Hypotheses | Variable | Description |
| --- | --- | --- |
| H1 | Drinking Water Source | The likelihood of LBW and early neonatal mortality is higher when using unimproved sources of drinking water. |
| H2 | Time to get to water source | The likelihood of LBW and early neonatal mortality is higher the longer the time spent on water collection in a household. |
| H3 | Sanitation Access | The likelihood of LBW and early neonatal mortality is higher when using unimproved sanitation facilities or practicing open defecation. |
| H4 | Control Variables | The likelihood of LBW and early neonatal mortality differs between maternal (age, parity, education, place of residence) and infant characteristics (sex of child). |

# 3 Country Context of Mali

This thesis will use Mali as a country example, in order to answer the research question of how the quality and access to water and sanitation affect the odds of APOs. Mali is a landlocked country in Western Africa. In the year 2018 (survey year of the data used later in the analysis), the total population was around 19.9 million (World Bank, n.d.-b). The majority of the population lives in the southern half of the country, due to the north being a desert area. Mali is one of the poorest nations in the world. It was ranked as 182$^{th}$ country out of 189 on the Human Development Index in 2018 (with the 1$^{st}$ rank being the best) (UNDP, 2018). In 2019, 49% of the total population was living below the extreme poverty line (USAID, 2019). The political situation in Mali is fragile. Despite a peace agreement, the security situation in Mali has remained critical, particularly in the north, where a conflict has broken out in the year 2012 (KfW, n.d.)

*Figure 1: Mali's Geographical Location*


Source: Google Maps (n.d.). *Mali*. Google. Retrieved 18.05.2023 from https://www.google.de/maps/place/Mali/

Several reasons motivate the choice of using Mali as a case study. One of the reasons for choosing Mali as the country for this specific analysis is the demographic composition of the population. Mali has one of the world's fastest-growing populations, with a fertility rate of 6.3 children in 2018 compared to 7.1 in 1987, indicating a slow but steady decline (INSTAT & ICF, 2019). It is estimated that 47% of Mali's population is below the age of 15, with an estimated growth of around 3.2% annually (BMZ, 2023a). The life expectancy at birth was estimated to be 59 years in 2018 (World Bank, n.d.-a). In addition, infant, child, and maternal mortality rates in Mali are high and even among the highest in SSA. The infant mortality rate for 2018 was 66 per 1,000 live births in Mali compared to an average of 54 in SSA (World Bank, n.d). Potential reasons for those relatively high mortality rates are limited access to and adoption of family planning, early childbearing (36% of women between the ages 15-19 are already mothers ), short birth intervals (median birth interval is 32.1, with at least 36 months significantly reducing the risk of infant deaths), and potentially even the prevalence of female genital cutting (89% of women aged 15-49 are circumcised) (INSTAT & ICF, 2019). The agricultural sector is the biggest (economic) sector of Mali, with the potential to even become the most important food provider in the Sahel zone. Despite this agricultural potential, it is estimated that one-third of Mali's total population is malnourished (KfW, n.d.).

Although there have been significant improvements to the water and sanitation infrastructure in Mali, nearly 3 in 10 households still only have access to an unimproved source of drinking water (INSTAT & ICF, 2019). An unimproved source of water is classified as an open water source that is unprotected from contamination (Hunter et al., 2010), and hence is bearing the biggest health risk. Moreover, a field study conducted in Mali found that access to safe water sources in real life is much lower than numbers predicted on paper (Martínez-Santos, 2017). Additionally, Mali is subject to sinking groundwater levels (BMZ, 2023b), making the population even more vulnerable to water-related issues such as water scarcity. Regarding sanitation infrastructure, 55% of households have access to improved sanitation, but more than one-third of the total households, still only have access to unimproved facilities, and 9% have no facilities at all (INSTAT & ICF, 2019). According to other sources, sanitation access is even lower with 80% of the total population without access to adequate sanitation facilities (BMZ, 2023a). Consequently, it is predicted that water contact and waterborne diseases such as malaria and diarrhea are the main causes of infant mortality (KfW, n.d.). According to UNICEF (2023), Mali has the sixth highest under-five mortality rate due to unsafe WASH relative to the child population (UNICEF, 2023b), underlying the assumption for a precarious WASH environment mothers and children are exposed to in Mali. All these factors highlight the importance of investigating further how water and sanitation facilities are connected to high infant mortality rates and, consequently, adverse pregnancy outcomes in Mali.

# 4 Data

In order to answer the research question at hand, this thesis uses a quantitative approach with secondary cross-sectional microdata. The data used is provided by the Demographic and Health Survey (DHS) Program. The DHS is a large-scale, nationally representative survey program that collects and disseminates data on population, health, and nutrition in developing and emerging nations. The program is funded by the US Agency for International Development (USAID). The program has been conducted in over 90 countries since its implementation in 1984, providing valuable information on a wide range of topics such as fertility, maternal and child health, family planning, HIV/AIDS, and gender-based violence (DHS, n.d-b). In order to collect data, the DHS program uses a standardized methodology and different questionnaires on a household, as well as individual level, for women and men individually. The surveys are normally conducted in five years intervals, which allows for cross-country comparisons and trend analysis over time (DHS, n.d-a). However, it is important to note that the DHS data might be subject to various sources of bias, including sampling bias, measurement bias, and potentially even recall bias.

The DHS dataset used for this analysis is the birth recode dataset of Mali carried out in 2018 during the seventh wave of the DHS. The information collected through the Women's questionnaire is used to generate a set of birth indicators, such as maternal and neonatal mortality ratios, captured in the birth recode dataset. The questionnaire is aimed at women between the ages of 15 and 49 who have given birth already at least once in their life to gain information on their pregnancy and birth history. Some specific information such as postnatal care, immunization, and health (among which birthweight) data, is only included for all births that occurred in the five years preceding the survey (DHS, 2020). Therefore, the sample for the analysis of the thesis differs between the outcome of early neonatal mortality and LBW. For both samples only de jure residents are included, as the analysis is based on the permanent household water and sanitation environment. The early neonatal mortality sample includes the full birth history of the interviewed women, as the sample size would become too small when only including birth that occurred in the last five years. The number of observations for this sample is 32,672 children (7,929 mothers), of whom 1,093 experienced early neonatal death. To analyze the relationship between LBW and water and sanitation, all children whose birth weight was known and hence who were born in the five years prior to the survey are included. Therefore, the number of observations for the birth weight models is smaller with 3,467 children (2,525 mothers).

## 4.1 Variables

In the following subsection, the variables used for the statistical analysis are explained in detail and the choice of variables is justified and motivated. The section ends with a table summarizing all variables.

### 4.1.1 Dependent Variables

The dependent variables used for the analysis of this thesis are birth weight and early neonatal mortality, as measures of APOs. The reason to choose those variables as indicators of APOs is that the theory predicts that both outcomes are closely connected to the environment women are exposed to during their pregnancies, and hence also potentially connected to the WASH environment. The first dependent variable used in the analysis is early neonatal mortality. As mentioned in the APO chapter, early neonatal mortality is defined as a child that was born alive but died in the first week of their life. The birth recode dataset of DHS includes a question if a child died and if yes when. In order to only include the children that died in the first week of their lives the variable is recoded into a binary variable, called early neonatal mortality. This variable either takes on the value (1) if the child died in the first week of their life or (0) if the child survived the first week.

The second dependent variable for the analysis of APOs is low birth weight. In the birth recode dataset of DHS, the birth weight is given as a numerical value in grams, for every live birth that occurred in the last five years prior to the survey. If the child was not weighed after birth or there is no information available, the birth weight is coded as unknown, and hence excluded from the analysis of this study. In order to measure APOs with LBW, the variable birth weight is redefined from a numerical variable into a binary variable. The new variable is called Low birth weight and takes on the value one (1) if the birth weight was below 2500g and zero (0) if the birth weight of the child was over or equal to 2500g, according to the definition of the WHO.

### 4.1.2 Independent Variables

For the statistical analysis, the models include three main independent variables, representing the water and sanitation quality and access women might be exposed to during their pregnancies. The first main independent variable represents the main source of drinking water for the households and hence also indirectly captures the potential quality of the water. The original variable is a categorical variable including different types of drinking water sources, like piped water, wells, springs, or rivers. In order to be able to understand the possible underlying health effects the author redefined the variable into two categories in accordance with the definition of the Joint Monitor Programme (JMP)/UNICEF of improved and unimproved drinking water sources. According to JMP improved drinking water sources can be either piped or non-piped but always have the potential to deliver safe water by the nature of their design and construction. Unimproved or no facilities are water sources that in the majority of the time would provide unsafe drinking water (JMP, n.d). This categorization of the variable makes it possible to understand how the general quality of the water might impact the dependent variables and also makes it easier to compare the outcomes between different individuals and samples.

The second main independent variable, trying to capture access to water, is the time to get to a water source. This variable gives the time to the next water source in minutes. The author recoded the variable into a categorical variable in order to make it more comparable and to eliminate the bias of changes in the water time as much as possible. The variable takes on the value (0) if the water source is on-premises, meaning no time needs to be spent on the water collection making it the most accessible category. If the time to get to the water source is between one to 15 minutes the variable takes on the value (1). If the water collection time exceeds 15 minutes the variable takes on the value (2). A reason to use 15 minutes as a cut-off point is UNICEF's water access definition. According to UNICEF a water source that is accessible within 15 minutes per trip, or 30 minutes per round trip, can still be considered a basic water service. A water trip to a water source that exceeds this time, so a trip above 15 minutes, is considered a limited water service making it the worst category (UNICEF, 2021a). Another reason to use this classification is that prior studies used the same (e.g. Baker et al., 2018) and hence it makes this study more comparable to existing literature.

The third main independent variable in the analysis is the type of toilet facility someone usually uses, which captures access to the sanitation environment. The type of toilet facility indicates how clean and hygienic the sanitation facility might be and hence indicates the difference in health risks associated to sanitation facilities. In the original dataset, the type of toilet variable has many different categories, like toilet, latrine, or open defecation. In order to make this variable more standardized a new variable with only three categories was created. The categories for the new sanitation source variable again use JMP/UNICEF definition for the classification of toilet facilities. Under this definition, improved sanitation facilities are facilities that are designed to safely and hygienically separate excreta from human contact. Unimproved facilities on the other hand are sanitation facilities in which humans can still get in contact with their or other people's excreta while using the facilities. The last category for the sanitation source variable is open defecation, meaning no sanitation facility at all (JMP, n.d). With the recoding of the sanitation variable, the author makes the outcomes again more comparable between different samples and studies. The weakness of this categorization (particularly improved and unimproved access) is that it is very similar to the drinking water source categorization, potentially capturing similar infrastructural characteristics. Hence, to account for this possible association in the statistical results and discussion, a bivariate association analysis is included in the descriptive statistics chapter.

### 4.1.3 Control Variables

The statistical models include control variables to account for other factors that may affect the risk of APOs. The theory behind these variables is discussed in detail in the third section of the theoretical framework. The first variable is the mother's age at the time of giving birth, which is categorized into 5-year intervals ranging from ages 15 to 49.

The second variable is birth parity. Parity is classified into three categories, according to the study of Patel et al. (2019), meaning the first is nulliparity, the second is multiparity (given birth to one child), and the third, grand multiparity (given birth to one or more children).

The third control variable is the mother's highest educational level attained, which is classified into four categories: no education, primary, secondary, and higher education. The reason to use the mother’s education as a variable of the socioeconomic background is that it first of all better captures the maternal characteristic, as the wealth of the household might be heavily influenced by the men, and hence education gives a better indication of the mother herself. Furthermore, the DHS wealth variable may be potentially correlated with the main independent variables of water and sanitation, as it is designed to capture the overall living standards of households, which includes factors such as the type of water access and sanitation facilities available (Pirani, 2014).

Another control variable is the place of residence, which is categorized into two categories: rural and urban. Lastly, a variable for infant sex is included to control for infant characteristics. This variable is binary, with male and female as categories. With the help of these variables, the author wants to control for the maternal and infant characteristics that might also substantially affect the risk for APOs. All variables are summarized in Table 2.

*Table 2: Summary of Variables*

| **Variable Name** | **Type** | **Description** |
|---|---|---|
| **Dependent Variables** | | |
| Early Neonatal Mortality | Binary | (0) Child survived the first week of life<br>(1) Child died in the first week of life |
| Low birth weight (LBW) | Binary | (0) Birth weight >= 2500g<br>(1) Birth weight < 2500g |
| **Independent Variables** | | |
| Drinking Water Source | Binary | (1) Improved drinking water source<br>(2) Unimproved drinking water source |
| Time to get to water source | Categorical | (1) On Premises<br>(2) Time up to and including 15 minutes<br>(3) Time more than 15 minutes |
| Sanitation access | Categorical | (1) Improved sanitation Facility<br>(2) Unimproved Sanitation Facility<br>(3) Open defecation |
| **Control Variables** | | |
| Mother's Age at birth | Categorical | (1) 15-49<br>(2) 20-24<br>(3) 25-29<br>(4) 30-34<br>(5) 35-49 |
| Parity | Categorical | (1) Parity 1 - Nulliparity<br>(2) Parity 2 - Multiparity<br>(3) Parity 3 - Grand multiparity |
| Mother’s Education | Categorical | (1) No Education<br>(2) Primary Education<br>(3) Secondary Education<br>(4) Higher Education |

| | | |
|---|---|---|
| Place of Residence | Binary | (1) Urban<br>(2) Rural |
| Sex of Child | Binary | (1) Male<br>(2) Female |

## 4.2 Statistical models

In order to answer the research question at hand the data was analyzed using a binary logistic regression or also known as a logit model. A logit model is commonly used in the context of estimating the likelihood of an event taking place, such as having a LBW or not. Therefore, the reason to use this type of regression is the categorical nature of the chosen (dependent) variables, elaborated on in the last section. Another reason to choose this type of regression model is that it is a commonly used model in similar studies like this thesis (Baker et al., 2018; Padhi et al., 2015; Patel et al., 2019). In order to interpret the coefficients, odd ratios were used. This means that for categorical variables with more than two categories, the coefficient shows the difference in the predicted possibilities for one category in relation to the base category, given that everything else stays equal. Moreover, for the full sample, so for the early neonatal mortality models (1-4), clustered standard errors were used. The reason for this decision is that in the sample several children might have been born to the same mother, making it important to cluster for shared characteristics of the same mother.

The statistical analysis consists of four different models for each outcome variable. The first model solely considers the water variables, including water source and water trip. The second model focuses on the sanitation environment and only includes sanitation access as an independent variable. The third model is a joint analysis of all three main independent variables, including both water and sanitation. The fourth model is the most comprehensive model, incorporating control variables to account for other potential factors that may impact LBW or early neonatal mortality additionally to the WASH environment. Furthermore, for early neonatal mortality, a fifth model is added. The fifth model consists of the same variables as the fourth model but only includes children born five-years prior to the survey, and hence the same sample as for the LBW analysis. This is done to account for any potential differences between the two samples.

The equation for the fourth and hence the most comprehensive model is the following:

$$\Pr(Y_i|X_i) = \beta_0 + \beta_1 watersource_i + \beta_2 timewatertrip_i + \beta_3 sanitationaccess_i + \beta_4 ageofmother_i + \beta_5 parity_i + \beta_6 educationofmother_i + \beta_7 placeofresidency_i + \beta_8 sexofchild_i + \varepsilon_i$$

The outcome variable Y in the equation is either early neonatal mortality or LBW. The independent variables $\beta_1$ to $\beta_3$ are the main independent variables, while the rest of the displayed variables are control variables. The last term, $\varepsilon_i$, stands for the error term.

# 5 Results

The following section presents the results of the statistical analysis, which are divided into three main subsections. First, descriptive statistics on the variables used are presented. Additionally, a bivariate association table for the two independent variables – water source and sanitation access – is displayed. In the second subsection, the results for the early neonatal mortality outcome variable are presented. The third and last section depicts the results of the models, capturing the odds for low birth weight as an indicator of APOs.

## 5.1 Descriptive Results

The following table displays the sample characteristics for the full sample and the last five years sample of the DHS birth recode dataset of Mali in 2018.

*Table 3: Descriptive Statistics*

| Variables | Sample Percentage Full Sample | Number of Observations Full Sample | Sample Percentage Last Five Years Sample | Number of Observations Last Five Years Sample |
|---|---|---|---|---|
| Total number of observations | | **32,672** | | **3,467** |
| **Main Dependent Variables** | | | | |
| Early neonatal Mortality | | | | |
| Died in the first 7 days | 3.35% | 1,093 | 1.85% | 64 |
| Survived first 7 days | 96.65% | 31,579 | 98.15% | 3,403 |
| | | | | |
| Low Birth weight | | | | |
| Below 2500g | - | - | 17.45% | 605 |
| Above 2500g | - | - | 82.55% | 2,862 |
| | | | | |
| **Main Independent Variables** | | | | |
| Drinking Water Source | | | | |
| Improved water source | 69.68% | 22,766 | 83.36% | 2,890 |
| Unimproved water source | 30.32% | 9,906 | 16.64% | 577 |
| | | | | |

| | | | | |
|---|---|---|---|---|
| Time to get to water source | | | | |
| On premises | 29.25% | 9,556 | 39.37% | 1,365 |
| Time up to 15 min | 49.80% | 16,272 | 46.03% | 1,596 |
| Time more than 15 min | 20.95% | 6,844 | 14.59% | 506 |
| | | | | |
| Sanitation Access | | | | |
| Improved Sanitation Facility | 51.48% | 16,819 | 66.37% | 2,301 |
| Unimproved Sanitation Facility | 36.60% | 11,959 | 28.44% | 986 |
| Open Defecation | 11.92% | 3,894 | 5.19% | 180 |
| | | | | |
| **Control Variables** | | | | |
| Age | | | | |
| 15-19 | 24.89% | 8,131 | 17.28% | 599 |
| 20-24 | 29.66% | 9,690 | 26.56% | 921 |
| 25-29 | 22.79% | 7,446 | 24.81% | 860 |
| 30-34 | 14.28% | 4,666 | 17.59% | 610 |
| 35-49 | 8.38% | 2,739 | 13.76% | 477 |
| | | | | |
| Parity | | | | |
| Parity 1 | 24.27% | 7,929 | 20.71% | 718 |
| Parity 2 | 20.07% | 6,558 | 19.47% | 675 |
| Parity 3 or more | 55.66% | 18,185 | 59.82% | 2,074 |
| | | | | |
| Education | | | | |
| No Education | 79.60% | 26,006 | 56.85% | 1,971 |
| Primary | 10.92% | 3,567 | 15.17% | 526 |
| Secondary | 8.68% | 2,835 | 24.98% | 866 |
| Higher | 0.81% | 264 | 3.00% | 104 |
| | | | | |
| Place of Residence | | | | |
| Urban | 23.82% | 7,782 | 39.54% | 1,371 |
| Rural | 76.18% | 24,890 | 60.46% | 2,096 |
| | | | | |
| Sex of Child | | | | |
| Male | 51.06% | 16,683 | 51.20% | 1,775 |
| Female | 48.94% | 15,989 | 48.80% | 1,692 |

The full sample includes all observations (of de jure residents) from the survey (32,672 children) while the last five years model only includes children born in the last five years prior to the survey (3,467 children). Looking at the main dependent variables, the percentage of infants who died in the first seven days of life was higher in the full model (3.35%) compared to the last five years model (1.85%), which underlines the importance of considering the full sample for the analysis on early neonatal mortality. In the five years sample, the percentage of infants with LBW was around 17%, making the sample representative.

For the main independent variables, the percentage of households with an improved drinking water source was around 70% in the full model, and even a bit higher in the five-years sample (83.36%). The distribution of the duration of a water trip between the two samples was similar, with approximately 50% having a water trip between zero and fifteen minutes, the next largest group having water on-premises, and the smallest group in both samples being in the category of having a water trip over fifteen minutes. The distribution of sanitation access did differ between the two samples, but the overall distribution was also similar here, with the majority of women answering that they had access to an improved sanitation facility and the minority practicing open defection. Among the control variables, the distributions of variables in the two samples were relatively similar with some differences in the exact percentages. In the age categories for both samples, the age group between 20 and 24 was the biggest. The oldest age group of 35-49 was the smallest, with few variations in the percentages. In Mali, most women did not attend school and belonged to the no-education category. In the five-year sample, the secondary education group was the second biggest group, while in the full sample, primary education was the second largest group. In both samples, only the minority of women received higher education, with only 0.81% of women in the full sample and 3% in the five-year sample. The difference in the parity distribution between the two samples is relatively small, with parity three (grand multiparity) being the largest group, nulliparity (parity 1) being the second largest, and the parity two (multiparity) group the smallest category. In both subsamples, the majority of women lived in rural areas with 76.18% in the full sample and with 60.46% a little less in the five-year sample. The distribution of the control variable, sex of the child, was almost the same between the two samples. This is in accordance with the general assumption that the fraction of females born is always slightly lower than the fraction of male births. In conclusion, while there are differences in the specific distributions of variables between the two samples, the majority of the variables have a similar percentage distribution between different categories. The main difference between the full model and the last five-years sample is the observation number and the percentage of children subject to early neonatal mortality, with the full model including a greater percentage of children who died in the early neonatal period.

### 5.1.1 Bivariate association Analysis

Table 4 displays the bivariate association analysis, using a Pearson's Chi-square test, between the two main independent variables water source and sanitation access for the full sample. The same table for the last five-years sample can be found in Appendix B. The reason to include this table, as mentioned earlier, is that the two variables might capture similar infrastructural effects, as often households who have access to improved water sources also have access to improved sanitation facilities (Geere, 2019).

*Table 4: Bivariate Association between Water source and Sanitation access*

| | | Sanitation access | | |
|---|---|---|---|---|
| Water Source | Improved | Unimproved | Open defecation | Total |
| Improved source of drinking water | 13,690 | 7,346 | 1,730 | 22,766 |
| | 60.13% | 32.27% | 7.60% | 100% |
| Unimproved source of drinking water | 3,129 | 4,613 | 2,164 | 9,906 |
| | 31.59% | 46.57% | 21.85% | 100% |
| Total | 16,819 | 11,959 | 3,894 | 32,672 |
| | 51.48% | 36.60% | 11.92% | 100% |
| | | Pr chi2= 0.000 | | |

Table 4 displays a strong association between those two variables. When considering the water sources, it can be seen that individuals who had access to improved sources of drinking water (such as piped water or protected wells) also had better access to improved sanitation facilities. Among individuals who relied on improved water sources, a significant majority (60.13%) also had improved access to sanitation, while 32.27% had unimproved access, and only 7.60% practiced open defecation. Conversely, individuals who relied on unimproved drinking water sources such as surface water or unprotected wells had less access to adequate sanitation facilities. Only 31.59% of this group had improved access to sanitation, while 46.57% had only unimproved access and 21.85% resorted to open defecation. This association between the variables might drive the results of the statistical analysis as the two variables might capture the same effect when both are included in the models. Nevertheless, despite this strong bivariate association between the two independent variables (P-value of chi2 = 0.00) it is still important to consider the water and sanitation infrastructure together in the later analysis, as not all households with improved water access also necessarily had improved sanitation facilities, and vice versa. Further, as shown in the literature review, theory predicts that both the water source and sanitation source have a substantial influence on the odds of APOs. It is also predicted that health problems connected to unimproved sanitation facilities might undermine any health benefits from better and safer access to drinking water sources, making it important to include both sanitation and water (Geere, 2019). Therefore, it is valuable to consider the sanitation variable not only as a direct factor on APOs, but also as a potential confounding factor.

## 5.2 Empirical Results

The following section will be distributed into two sub-chapters. The first sub-chapter will elaborate on the empirical results for the early neonatal mortality outcomes. The second sub-chapter will elaborate on the empirical results for the models of LBW.

### 5.2.1 Early Neonatal Mortality

The results of the models for early neonatal mortality are displayed in Table 5. The standard errors for Models 1 to 4 were, as mentioned earlier, clustered for the mothers, as one woman might have given birth to several children in the full sample. In Model (5) the standard errors were not clustered due to the smaller sample size and the fact that the majority of mothers only had one child in the last five years sample. The coefficients shown in the table are odds ratios. If the coefficient shows a (1) in the category, it was used as the base category. It is important to mention that using odds ratios only makes it possible to compare results within a variable and not between variables, given everything else being equal.

*Table 5: Logistic regression Results for Early Neonatal Mortality*

| **Main Independent Variables** | Model (1) | Model (2) | Model (3) | Model (4) | Model (5) |
|---|---|---|---|---|---|
| Drinking Water Source | | | | | |
| Improved source of drinking water | 1 | | 1 | 1 | 1 |
| Unimproved source of drinking water | 1.07 | | 1.03 | 0.95 | 0.70 |
| | | | | | |
| Time to get to water source | | | | | |
| On premises | 1 | | 1 | 1 | 1 |
| Time up to 15 min | 1.23** | | 1.19* | 1.07 | 1.72* |
| Time more than 15 min | 1.21* | | 1.18 | 1.06 | 1.95* |
| | | | | | |
| Sanitation Access | | | | | |
| Improved Sanitation Facility | | 1 | 1 | 1 | 1 |
| Unimproved Sanitation Facility | | 1.27*** | 1.23** | 1.15 | 2.00** |
| Open Defecation | | 1.14 | 1.08 | 1.03 | 1.15 |
| | | | | | |
| **Control Variables** | | | | | |
| Age | | | | | |
| 15-19 | | | | 1.44*** | 0.82 |
| 20-24 | | | | 1 | 1 |
| 25-29 | | | | 0.77** | 0.42** |
| 30-34 | | | | 0.82 | 1.01 |
| 35-49 | | | | 0.97 | 0.87 |
| | | | | | |
| Parity | | | | | |
| Parity 1 | | | | 1 | 1 |
| Parity 2 | | | | 0.77*** | 0.53 |
| Parity 3 or more | | | | 1.04 | 1.17 |
| | | | | | |
| Education | | | | | |
| No Education | | | | 1 | 1 |
| Primary | | | | 1.04 | 1.79* |
| Secondary | | | | 0.82 | 1.51 |
| Higher | | | | 0.31 | omitted |
| | | | | | |
| Place of Residence | | | | | |
| Urban | | | | 1 | 1 |
| Rural | | | | 1.47*** | 1.08 |
| | | | | | |
| Sex of Child | | | | | |
| Male | | | | 1 | 1 |
| Female | | | | 0.74*** | 0.995 |
| | | | | | |
| Number of observations | 32,672 | 32,672 | 32,672 | 32,672 | 3,363 |
| Prob > chi2 | 0.08 | 0.013 | 0.018 | 0 | 0.003 |

*Note: ***p < 0.01, **p < .05, *p < 0.1*

Table 5 presents the results of five different regression models that examine the determinants of early neonatal mortality. All models besides the fifth use the full birth history of women, resulting in a sample of 32,672 children. Additionally, all models were statistically significant at least at the 10% level.

Model (1) accounted exclusively for the water infrastructure, including water source and water trip as independent variables. The results show that using an unimproved source of drinking water compared to an improved source of drinking water did not have a significant effect on early neonatal death. On the other hand, having to do water trips increased the odds of early neonatal death by 1.23 times for trips up to fifteen minutes (significant at the 5% level) and 1.21 times for trips of more than fifteen minutes (significant at the 10% level), compared to having water on the premise. In Model (2), which considered only sanitation, a child born to a mother who did not use improved sanitation was 1.27 times more likely to die in the first week of life than a child born to a mother who had access to improved sanitation, keeping everything else equal. This difference was significant at the 1% level. The difference between infants of mothers practicing open defecation and improved sanitation facilities was insignificant (OR:1.14).

Model (3) examined the joint effect of the main predictors, water source, water trip, and sanitation access. The results show that the association between the water source and early neonatal mortality remained insignificant. For the water trip variable, the category of a trip of more than fifteen minutes lost its significance when adding the sanitation facility variable. Having a trip of up to fifteen minutes remained significant with a higher risk for early neonatal mortality (OR: 1.19) compared to women who had water on premises. Further, infants who were born to mothers who only had access to an unimproved sanitation facility had an increased risk of dying in the early neonatal phase (OR: 1.23), with the difference being statistically significant at the 5% level.

Model (4) incorporated additional control variables, accounting for maternal and infant characteristics, to assess whether the effects remain consistent. In this model, all main independent variables that describe the WASH environment of a mother were statistically insignificant. The control variable for age of the mother, on the other hand, was an important determinant of the likelihood of early neonatal mortality. An infant born to a mother between the ages 15-19 had 1.44 times higher odds of dying in the first week compared to the reference category of mothers between the ages 20-24. For children born to mothers in the age groups

25-29 (OR: 0.77) the likelihood of early neonatal mortality was decreased compared to the base category, keeping everything else equal. Those differences were statistically significant at the 1% and 5% levels, respectively. Also, multiparity, as one category of parity, was statistically significant at the 1% level. The results show that having given birth to one child decreased the odds of early neonatal mortality (OR: 0.77), while grand multiparity (given birth to two or more children) increased the likelihood of early neonatal mortality (although being statistically insignificant). The mother's education was a statistically insignificant determinant of early neonatal mortality in this analysis. Nevertheless, looking at the coefficients, the odds of neonatal death might have declined as the education categories increased. The place of residence, as the last maternal characteristic in the model, significantly affected the odds of early neonatal mortality. A child born to a mother residing in a rural area had higher odds of dying in the first week (OR: 1.47) compared to a child born to a mother residing in urban areas. This difference between the places of residence was statistically significant at the 1% level. Considering the last control variable, the sex of the child, the difference between the probability of a girl dying in the first week of life compared to a boy was statistically significant at the 1% level. For girls, the odds of early neonatal mortality were reduced by 0.74 times compared to boys.

The Model (5) included the same variables as Model (4) but was run for the last-five-year sample, leading to a lower observation number of infants (3,363). Despite the lower observation number, the model was statistically significant. Interesting to mention is that in this model, in contrast to the bigger sample, water trip and sanitation access were statistically significant, at least at the 10% level. In this model, only the mother's age at birth and education were statistically significant control variables. The other control variables (parity, place of residence, and sex of child) were statistically insignificant.

### 5.2.2 Low Birth Weight

The results of the four logit regression models examining the relationship between LBW and several independent variables are presented in Table 6. All four models used the same sample of 3,467 children who were born in the five years prior to the survey. Additionally, all models were statistically significant at the 1% level.

*Table 6: Logistic regression Results for Low Birth Weight*

| **Main Independent Variables** | Model (1) | Model (2) | Model (3) | Model (4) |
|---|---|---|---|---|
| Drinking Water Source | | | | |
| Improved source of drinking water | 1 | | 1 | 1 |
| Unimproved source of drinking water | 1.35*** | | 1.11 | 1.02 |
| | | | | |
| Time to get to water source | | | | |
| On premises | 1 | | 1 | 1 |
| Time up to 15 min | 1.27 | | 1.14 | 1.07 |
| Time more than 15 min | 1.77*** | | 1.51*** | 1.43*** |
| | | | | |
| Sanitation Access | | | | |
| Improved Sanitation Facility | | 1 | 1 | 1 |
| Unimproved Sanitation Facility | | 1.79*** | 1.69*** | 1.61*** |
| Open Defecation | | 2.59*** | 2.28*** | 2.10*** |
| | | | | |
| **Control Variables** | | | | |
| Age | | | | |
| 15-19 | | | | 0.88 |
| 20-24 | | | | 1 |
| 25-29 | | | | 1.03 |
| 30-34 | | | | 0.82 |
| 35-49 | | | | 0.8 |
| | | | | |
| Parity | | | | |
| Parity 1 | | | | 1 |
| Parity 2 | | | | 0.8 |
| Parity 3 or more | | | | 0.81 |
| | | | | |
| Education | | | | |
| No Education | | | | 1 |
| Primary | | | | 1.002 |
| Secondary | | | | 0.76** |
| Higher | | | | 0.75 |
| | | | | |
| Place of Residence | | | | |
| Urban | | | | 1 |
| Rural | | | | 1.2 |
| | | | | |
| Sex of Child | | | | |
| Male | | | | 1 |
| Female | | | | 1.4*** |
| | | | | |
| Number of observations | 3,467 | 3,467 | 3,467 | 3,467 |
| Prob > chi2 | 0 | 0 | 0 | 0 |

*Note: ***p < 0.01, **p < .05, *p < 0.1*

In Model (1), the odds of LBW for infants born to mothers who used an unimproved source of drinking water were significantly higher (OR:1.35) at the 1% level, compared to mothers using an improved source of drinking water. Furthermore, the odds of LBW for infants born to mothers who had a water trip of more than 15 minutes were also significantly increased (OR: 1.77), compared to the base category, which had water on the premises. This difference was statistically significant at the 1% level. However, the odds of LBW for infants born to mothers who had a water trip of up to 15 minutes (OR: 1.27) were not significantly different from those born to mothers who had water on their premises.

Model (2), which depicted the sanitation environment, showed that the risk of LBW increased with the mother using unimproved sanitation facilities (OR: 1.79) and practicing open defecation (OR: 2.59). These differences were statistically significant at the 1% level, compared to the base category of using improved sanitation facilities.

In the comprehensive water and sanitation model (Model (3)), the water source variable lost its significance in contrast to Model (1), meaning that water source is not a significant determinant of LBW when also accounting for access to sanitation in the model. However, the association between water trip and LBW remained significant, showing that infants born to mothers who needed to collect water for more than 15 minutes had a higher likelihood of being born with a LBW (OR: 1.51), significant at the 1% level. Moreover, sanitation access stayed statistically significant at the 1% level. The odds of LBW for infants born by mothers using an inadequate sanitation facility, unimproved sanitation (OR: 1.69), and open defecation (OR:2.28) were significantly higher compared to women using improved sanitation facilities.

In the last Model (4), the control variables for the maternal and infant characteristics have been added. Despite the addition of the control variables, having a water trip of more than 15 minutes remained a driving factor for higher odds of a LBW (OR: 1.43) and was statistically significant at the 1% level, compared to the base category, water on the premises. The sanitation access categories stayed significant at the 1% level after controlling for maternal and infant characteristics. The risk of LBW increased with using unimproved sanitation facilities (OR: 1.61) and open defecation (OR: 2.10). The control variables age of the mother, parity, and place of residence were insignificant in determining the odds of LBW when taking the WASH environment into account. The secondary education category was significant at the 5% level with reduced odds of giving birth to a low-birth-weight infant (OR:0.76) in relation to having no education. Lastly, female infants had 1.4 higher odds of being low weighted at birth compared to male infants. This difference between the sexes was statistically significant at the 1% level. This shows that throughout all models, the type of sanitation facility and the length of the water trip affected LBW as an indicator of APOs, even after controlling for maternal demographic and socioeconomic characteristics.

# 6 Discussion

This thesis had the aim of understanding if there is an association between maternal water and sanitation access and behavior and APOs. For the analysis, the thesis utilized DHS data from Mali collected in 2018. The results of the regression models indicate that the type of sanitation facilities and the duration of water trips undertaken by women may significantly impact pregnancy outcomes for both the mother and her infant. Other causes for APOs, such as maternal and infant characteristics have also been studied during the analysis. The discussion chapter will be divided to discuss the association between APOs and water, sanitation, and other maternal and infant characteristics. It is crucial to note that due to the survey nature of the data, the water and sanitation environment analyzed is based on the information provided on the day of the interview. As a result, the discussion is based on the assumption that the WASH environment from the point of collection has not substantially changed from the environment during the pregnancy period.

## 6.1 Adverse pregnancy outcomes and water

The results of the statistical analysis in this thesis showed that water environment had a weaker influence on both early neonatal mortality and LBW than predicted based on previous research and theory. For early neonatal mortality, the water source did not have a significant impact on the likelihood of a child dying in the first week of life. The type of water source had a significant impact on the birth weight of a child, when only the water environment (type and time to get to a water source) was included. However, the association between LBW and the water source lost its significance when adding variables controlling for the sanitation environment, as well as maternal and infant demographic and socioeconomic characteristics. Nevertheless, at least for LBW as a pregnancy outcome, the coefficient of the variable still indicated that the risk of LBW increases when using unimproved drinking water, possibly indicating a higher infection risk and other related health issues for those who use unimproved water sources, leading to an increased risk of LBW (Campbell et al., 2015).

The rather weak associations between the water source and APOs in this study could be attributed to the strong association between the water source and sanitation facility variable (as discussed in chapter 5.1.1). Therefore, it is possible that by adding the sanitation access variable to the full model, sanitation weakened the effect and significance of the water source, as both variables capture a similar effect of improved or unimproved WASH sources. Another explanation might be that an improved water source does not necessarily equal safe drinking water and hence the real water quality difference between improved and unimproved sources is not captured in the used variable. The results of a case study in Mali found that access to improved water did not ultimately correlate with access to safe water (Martínez-Santos, 2017). This could mean that women in Mali might have had access to improved water sources but still only had access to contaminated or unsafe water, exposing them to water-borne diseases related to unsafe water. Therefore, despite the weak significance of the results, one could still draw the conclusion that the drinking water source, given not only improved but also safe water, might be an important determinant for the odds of APOs in accordance with the theory discussed in the literature review.

The time spent getting to the water source, as another indicator of the water environment, had a significant influence on both early neonatal mortality and LBW, as predicted by previous research findings (Baker et al., 2018; Campbell et al., 2015; Collins et al., 2019). Especially for LBW, the likelihood of APOs increased significantly with the time of a water trip. This association between the time of the water trip and LBW remained significant even in the fourth model, which also considered sanitation access and control variables. In Model (4) (i.e. the full sample), the association between the water trip and early neonatal mortality was not as strong or statistically significant when adding control variables. Nevertheless, in Model (5) (using the smaller sample of only children born in the five years preceding the interview), the association between the water trip and the odds of early neonatal mortality remained significant, with the coefficient implying the more time a woman spends on a trip to collect water, the higher the odds of early neonatal mortality for her offspring. This difference between Model (4) and (5) might be attributed to the difference in the descriptive statistics but it might also indicate that the WASH environment in Model (5) depicts the actual environment during pregnancy better, due to being collected closer to the time of pregnancy.

Based on the findings of previous literature, that women are the water carries in the majority of times (Geere & Cortobius, 2017; Sorenson et al., 2011), the findings of the thesis confirm the assumption that the more time a women spends on collecting water the higher the health risks for her and her unborn child. The underlying reasons behind this increased health risk might be the greater likelihood of injuries, physical and mental exhaustion, and reduced maternal and fetal nutrient intake connected to an increased energy expenditure while collecting water for a long time (Baker et al., 2018). Consequently, the results of the thesis support Hypothesis 2 and confirm that the odds of LBW and early neonatal mortality are increased with longer water trips. This underlines the importance of not only a safe water source but also an accessible water source in order to reduce APOs in a resource-poor setting such as Mali.

## 6.2 Adverse pregnancy outcomes and sanitation

The results of this thesis show that the sanitation environment had a strong and significant impact on the risk of APOs in Mali, in line with previous findings focused on other countries (Padhi et al., 2015; Patel et al., 2019). For almost all Models (besides Model (4) for early neonatal mortality, which controlled for water access and background characteristics and considered the full sample of children) sanitation access had a significant association with APOs. For early neonatal mortality, the use of unimproved sanitation facilities, such as facilities in which the user might encounter (contaminated) excreta of other people, was associated with a statistically higher risk of early neonatal mortality. Although the coefficient for open defecation was not significant, the coefficients still imply that the likelihood of early neonatal death was higher for this group than for infants born to mothers who used improved sanitation facilities. For LBW, on the other hand, both categories for sanitation were significant in all models. This means that mothers who both used unimproved sanitation facilities and practiced open defection had infants who had a higher risk of being born with LBW. Open defecation was associated with the highest risk of an infant being born with LBW. These findings are in accordance with the literature that the sanitation environment has a direct impact on the risk of APOs due to related health issues, such as urinary tract infections and higher caloric expenditure connected to the use and access of inadequate sanitation facilities (Baker et al., 2018; Kwiringira et al., 2014; Patel et al., 2019).

A noteworthy finding concerning the sanitation environment is that although the likelihood of LBW rose with open defecation, the odds of early neonatal mortality decreased compared to using unimproved facilities (without the difference for early neonatal mortality being statistically significant). This phenomenon could be explained by previous findings. Barker et al. (2018) found a positive association between the likelihood of LBW and open defection due to the physical and mental stress associated with searching for a secure and private location to defecate for a woman. Another study focused on the likelihood of child death found that using any type of toilet other than a flush toilet was connected to a higher risk of child death. Further, they found that the risk for child death was higher among children using non-flush toilets compared to children practicing open defection due to a greater exposure to an unhygienic environment in unimproved sanitation facilities because of e.g. a greater risk of being exposed to other people's excreta (Geere & Hunter, 2020). Applying the results of these previous findings to the context of APOs in Mali, it could mean that for mothers practicing open defecation the (urinary tract) infection risk might be lower compared to using non-flush toilet (unimproved facilities) due to less contact with other people' excreta and bacteria, hence resulting in a lower risk for early neonatal morality. On the other hand, the risk for LBW might be higher for those practicing open defecation, as LBW is theorized to be driven by other factors, such as more caloric expenditure and stress connected to searching a private and safe place to openly defecate (Baker et al., 2018). In conclusion, no matter which specific factors are driving the association between sanitation and APOs, the sanitation environment of a mother does have an important impact on her infant's mortality and morbidity, with improved sanitation facilities being the most optimal solution, as predicted in Hypothesis 3. This underlines the importance of increasing access to improved sanitation facilities in order to decrease related health risks to inadequate facilities.

## 6.3 Adverse pregnancy outcomes and other associated causes

Even though this thesis aimed to better understand the relationship between water, sanitation, and adverse pregnancy outcomes, it also includes findings on other associated causes that might affect this relationship. The analysis included control variables in Model (4) (& Model (5)) in an attempt to understand whether the outcomes for water and sanitation remained robust after considering additional maternal and infant characteristics in the model. Despite some significant results, none of the control variables are statistically significant throughout all models and for both outcome variables. Nevertheless, there are still some interesting findings to discuss.

Despite previous research findings (Bai et al., 2002; Fraser et al., 1995; Lin et al., 2021), in this study the age of the mother and parity were only weak drivers for the odds of APOs. Only in Model (4) for early neonatal mortality were multiparity and two categories of age statistically significant. Despite the weak association of age at birth and parity, the findings for early neonatal mortality underlie the theory that the odds of APOs are first high for those with lower age and nulliparity, and then decrease with older ages and multiparity, before they slightly increase again with highest maternal age and grand multiparity, as predicted by previous researchers (Bai et al., 2002; Fraser et al., 1995). Despite previous research predicting the same association for LBW (Lin et al., 2021), this study found no statistically significant results for either age of mother nor parity.

Other findings contradicting previous research, (Barker, 2001; Patel et al., 2019) were that maternal education was only weakly associated with the likelihood of APOs in Mali and that the risk of APOs appears to be higher among mothers who attended primary school than among women with no education. One possible reason could be found in Mali's poor education system. Estimations by the German Federal Ministry of Economic Cooperation and Development (BMZ) predict that in Mali, only 60% of school-aged children actually go to school and of those, only around 50% finish primary school. Additionally, it is estimated that more than two thirds of the adult Malian population cannot read or write (BMZ, 2023a). These figures show that although a woman in Mali has attended elementary school, this does not necessarily mean that she has significantly improved her educational knowledge. This means that Mali might be an exception to the prediction that the mother’s level of education directly reduces the odds of APOs (Patel et al., 2019), as Mali’s educational system is underperforming. Nevertheless, with higher education the coefficients of the variable still indicated a decreased risk in APOs, implying that only with more than primary education the actual health benefits found in previous studies are visible.

The results for place of residence seems to be driving factors for APOs in accordance with previous research findings (Ezeh et al., 2014). For early neonatal mortality, infants born in rural areas had higher mortality risks. For LBW the coefficient, despite being statistically insignificant (p-value = 0.102), showed a higher risk for adverse health outcomes. The difference between the results of the outcome variables might be affected by the fact that less women were living in rural areas in the smaller sample, as discussed in the descriptive statistics. Furthermore, another explanation for the variation might be found in the difference in the (health) infrastructure between rural and urban areas. As mentioned in the literature review, women living in rural areas in Mali might have higher barriers to receiving antenatal care or delivery assistance (Gage, 2007), implying higher health risks for both mother and infant. Moreover, when further analyzing the data and looking at previous research, the majority of malnourished women in Mali seem to be living in rural areas (Eozenou et al., 2013). As nutrition during pregnancy is known to be an important factor for fetal growth (Resnik, 2002), this could be another explanation for the differences between the likelihood of APOs between rural and urban areas.

Another factor that was significantly affecting the likelihood of APOs (in Model (4) for both outcome variables) in Mali is the sex of the child. The results show that while female infants do have a survival advantage compared to male infants, they do have a higher likelihood of being born below a weight of 2500g. Hence, these results support the theory behind infant characteristics and APOs elaborated on in the literature review (De Bernabé et al., 2004; Lawn et al., 2005).

In conclusion, one can say that there are many driving factors for the occurrence of APOs. For early neonatal mortality, the association between water and sanitation was less significant when controlling for sanitation access as well as infant and maternal characteristics. For LBW as an APO, the association between water (trip) and sanitation facilities was a driving factor. The weak association between the water source and sanitation facility might have been driven by the association between the two independent variables, and hence, despite the results, water source is still possibly an important factor for maternal and child health in the real world. Subsequently, these findings suggest that women and infants exposed to inadequate water and sanitation infrastructure have a higher likelihood of experiencing APOs. Therefore, the results of this thesis underscore the urgency of investing in WASH infrastructure to prevent the occurrence of APOs, especially in the developing world, potentially saving lives and improving health and early-life outcomes for children born into resource-scarce settings like Mali. Potential improvements in early-life health and outcomes for children could not only improve later-life health as predicted by the Fetal Origin Hypothesis (Barker, 2001). It could also lead to improvements in human capital development, as previous research has discovered a close connection between in-utero and early childhood conditions and later-life outcomes (Currie & Almond, 2011).

## 6.4 Limitations and future research

Even though the study found significant results, the study has several limitations that need to be acknowledged. Firstly, due to the nature of the data, survey data, the water and sanitation variables capturing the WASH environment were measured at the time of the interview. Therefore, the real WASH environment during the pregnancy might have been different. This limitation means that the sample focused on the five years prior to the survey is more credible. The smaller sample reduces recall bias and makes the water and sanitation variables better indicators of the actual WASH environment during pregnancy because they are measured closer to the time of pregnancy. Another limitation associated with using two samples for the analysis is the variation in sample characteristics, e.g. the percentage of people living in rural and urban areas. These variances potentially influenced differences in the results between the two samples. However, for a representative sample size, it was necessary to include women's full birth histories in the analysis as the size of the smaller sample for early neonatal mortality was relatively small, with only 64 infants who died in the early neonatal period.

Additionally, a specific limitation of the water trip variable in this study is that it only accounts for one trip. Therefore, the variable may not accurately represent the actual time spent on water collection each day, as some individuals may have to make several trips per day. Furthermore, the variable provided by the DHS only captures the time to get to the water source. This means that the waiting time might not always be included in the answers by the respondent, meaning that for some of the mothers the actual time spent on collecting water might even be more due to long waiting times at water sources. Another limitation of the data itself is that the variable for the drinking water source is not necessarily connected to the actual quality of the water but only gives an indication of the possibility of being of good quality. The same issue exists concerning the nature of the sanitation variable. Connected to this is the strong association between the two independent variables water source and sanitation access due to the nature of the chosen variables. Nevertheless, specific variables capturing the actual quality (which potentially would have decreased the association between the variables) have not been available in the DHS dataset, making it impossible to include them in this study.

Moreover, recall bias might be another problem that limits the validity of the results, as mothers could have incorrectly recalled the exact day of their infant's death or specific birth weight. Another limitation of this study is that it did not include all possible control variables. Some other variables that could affect the likelihood of APO are drug abuse, violence during the pregnancy, type of work, nutrition, and general maternal health (Baker et al., 2018; Kramer, 2003). Connected to this limitation is the limited information on conditions soon after birth, like post-partum fever or infections, that might affect the odds of early neonatal mortality (Cameron et al., 2021). The choice of socioeconomic status being captured by the mother’s education could also be considered a limitation of the study, as the results were weakly significant and sometimes even contrary to previous findings. Therefore, for future research, it would be good to include another indicator capturing the socioeconomic status, like a wealth variable that is constructed differently from the one provided by the DHS, meaning a variable that does not consider the water and sanitation infrastructure in the construction. Furthermore, this thesis only focused on one specific country in SSA, limiting the generalizability of the results.

To overcome at least some of the limitations, future research should include a specific water quality variable as well as a variable including the total time spent on a water trip (including waiting time). Linked to this, it would be important to include a variable capturing the person usually collecting the water. The DHS does include a question on who the water bearer of the household is but the question is not asked during the data collection, making it impossible to include. Hence, for future research, it would be beneficial to actually collect the data on the regular water bearer of the household. Another question that would be beneficial to include in future questionnaires would be a question on the priority of water use. This question should include how the use of water is distributed between drinking, cooking, and hygiene and also between the different household members, so if e.g., water needs of men are prioritized above children’s and women’s needs.

Further, if possible, a field study that follows pregnant women throughout their pregnancies would be beneficial to better understand the real relationship between water and sanitation infrastructure and APOs. It would be particularly interesting to compare regions within a country, or countries with different water and wastewater infrastructures, and possibly even countries or regions that are differently affected by climate change. Climate change and different dry and wet seasons have already been seen to be connected to APOs, making it an interesting aspect to consider in future research. Additionally, in future research, it would be interesting to investigate the differences between the residential environments. This study included the place of residence as a control variable but did not run full models only for urban or rural areas, as the sample size would have become too small. Nevertheless, it would be interesting to focus on this environmental difference in future studies as the WASH infrastructure is predicted to be different between rural and urban areas, possibly influencing the association between WASH and APOs. With the replication of this study in more countries and/or for more time points within a country, and/or future studies including the mentioned points above, one could get an even deeper insight into how the (maternal) health of women and infants are affected by the WASH infrastructure. This would be crucial for a more effective targeting of policy and infrastructure investments for people in need.

# 7 Conclusions

This study investigated the association between the WASH environment a mother is exposed to during her pregnancy and the adverse pregnancy outcome she and her infant might experience due to an inadequate water and sanitation infrastructure in Mali. In order to capture this association, the thesis used early neonatal mortality and LBW as outcome variables as a unique contribution to existing literature. Previous findings have mainly been focused on the association between APOs and WASH in Asia, specifically India, but few to no studies have been focused on the SSA region, particularly Mali, and included early neonatal mortality and LBW as outcome variables. The findings of the literature review revealed that pregnant women and their infants are most vulnerable to inadequate water and sanitation environments. The main reason mentioned for this association is the increased risk of infection, higher caloric expenditure, and stress related to the quality and access to water and sanitation sources. The theoretical framework that was developed also included, besides the WASH infrastructure, maternal and infant characteristics (such as maternal age, socioeconomic status, and the infant's sex) as possible risk factors for APOs.

In order to study the real association, the thesis used a quantitative analysis utilizing microdata from the DHS program, conducted in 2018 during the seventh wave of the DHS. The methodology consisted of logistic regression models, a common statistical tool for analyzing this type of association. The results provide an interesting insight into the health outcomes of pregnant women connected to the WASH environment in Mali. They show that it is important to increase access to safe water on-premises as well as improved sanitation facilities in order to reduce the associated health risks as much as possible for everyone, especially pregnant women and their infants. Such interventions could not only lead to many saved (infant) lives, in fact 1,000 children every day die due to unsafe water and sanitation infrastructures, but they could also lead to better later life health, which is not only beneficial from a humanitarian point of view but also economically. Improved health could potentially lead to a better human capital development, potentially leading to a better economic development for whole nations.

In conclusion, this study underscores the importance and urgency of improving the WASH environment in resource-poor settings like Mali. By addressing the limitations and potential biases of this study in future research, one could further strengthen the understanding of the association between the WASH environment and maternal and offspring health and take even more effective measures to improve access to safe water and sanitation facilities. Despite this study focusing on a developing country, the results show how deeply our health is connected to the water and sanitation infrastructure, underlying the importance of water stewardship not only in SSA but also in every other region of the world.

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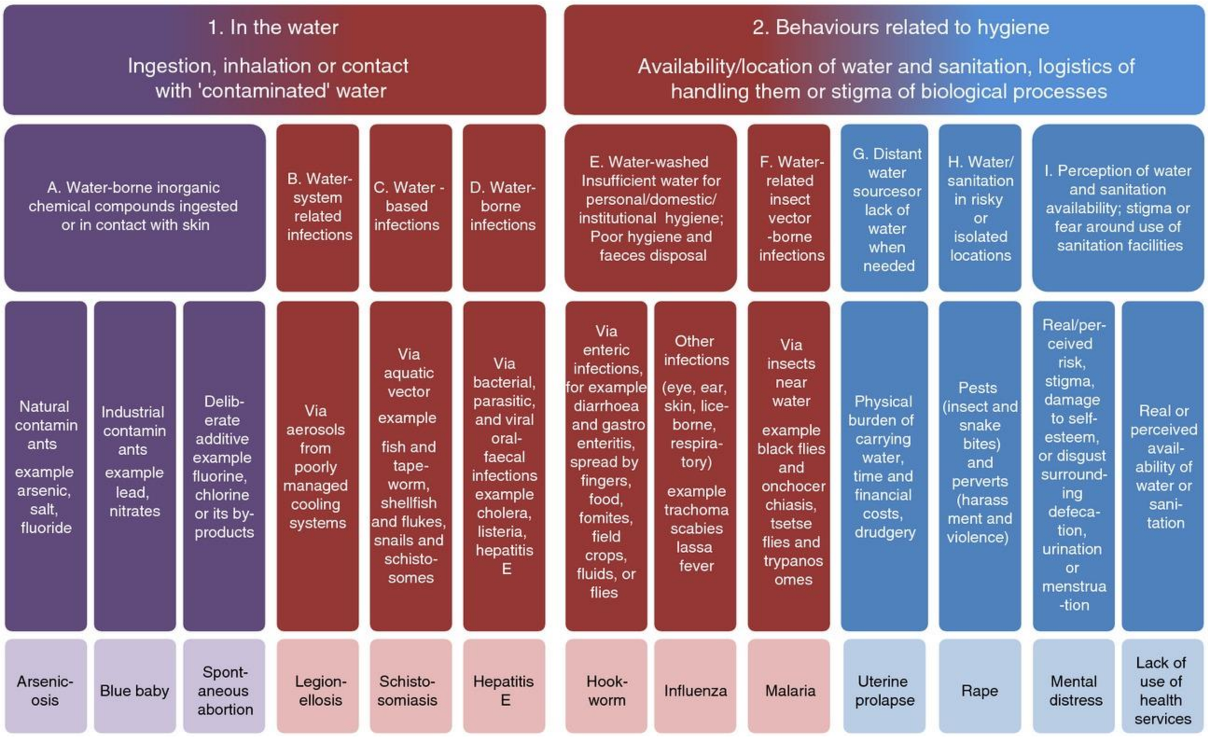
# Appendix A

Campbell et al. Conceptual Framework linking WASH with maternal and reproductive health:




Source: Campbell, O. M., Benova, L., Gon, G., Afsana, K., & Cumming, O. (2015). Getting the basic rights–the role of water, sanitation and hygiene in maternal and reproductive health: a conceptual framework. *Tropical medicine & international health*, *20*(3), 252-267. https://doi.org/10.1111/tmi.12439

# Appendix B

Bivariate association between sanitation access and source of drinking water for the last-five years sample prior to the survey:

| | | Sanitation access | | Total |
|---|---|---|---|---|
| Water Source | Improved | Unimproved | Open defecation | |
| Improved source of drinking water | 2,076 | 708 | 106 | 2,890 |
| | 71.83% | 24.50% | 3.67% | 100% |
| Unimproved source of drinking water | 225 | 278 | 74 | 577 |
| | 38.99% | 48.18% | 12.82% | 100% |
| Total | 2,301 | 986 | 180 | 3,467 |
| | 66.37% | 28.44% | 5.19% | 100% |
| | | | | |
| | | Pr chi2= 0.000 | | |