Factors influencing the household water treatment adoption in rural areas in developing countries

Daniel, D.

DOI
10.4233/uuid:6f6e7a1b-65ac-4876-9531-24988a563e36

Publication date
2021

Document Version
Final published version

Citation (APA)
Daniel, D. (2021). *Factors influencing the household water treatment adoption in rural areas in developing countries*. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:6f6e7a1b-65ac-4876-9531-24988a563e36

FACTORS INFLUENCING THE Household Water Treatment ADOPTION IN THE RURAL AREAS IN DEVELOPING COUNTRIES

DANIEL

Factors influencing the household water treatment adoption in rural areas in developing countries

Factors influencing the household water treatment adoption in rural areas in developing countries

Dissertation

For the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus Prof.dr.ir. T.H.J.J. van der Hagen
chair of the Board for Doctorates
to be defended publicly on
Monday 22 February 2021 at 12:30 o'clock

By

DANIEL
Master of Science in Environmental Science,
IHE Delft Institute for Water Education, the Netherlands

Born in Bandung, Indonesia

This dissertation has been approved by the promotors.

Composition of the doctoral committee:

Rector Magnificus,	Chairperson
Prof.dr.ir. L.C. Rietveld,	Delft University of Technology, promotor
Dr. S. Pande	Delft University of Technology, copromotor

Independent members:

Dr.ir. E.S. Soedjono	ITS Surabaya, Indonesia
Dr.ir. D. van Halem	Delft University of Technology
Prof.dr. P. Osseweijer	Delft University of Technology
Prof.dr.ir. P. van der Zaag	Delft University of Technology / IHE Delft
Dr. S. Marks	EAWAG Zürich, Switzerland
Prof.dr.ir. J.P. van der Hoek	Delft University of Technology, reserve member

This research study was financed by the Indonesia Indonesia Endowment Fund for Education (LPDP).

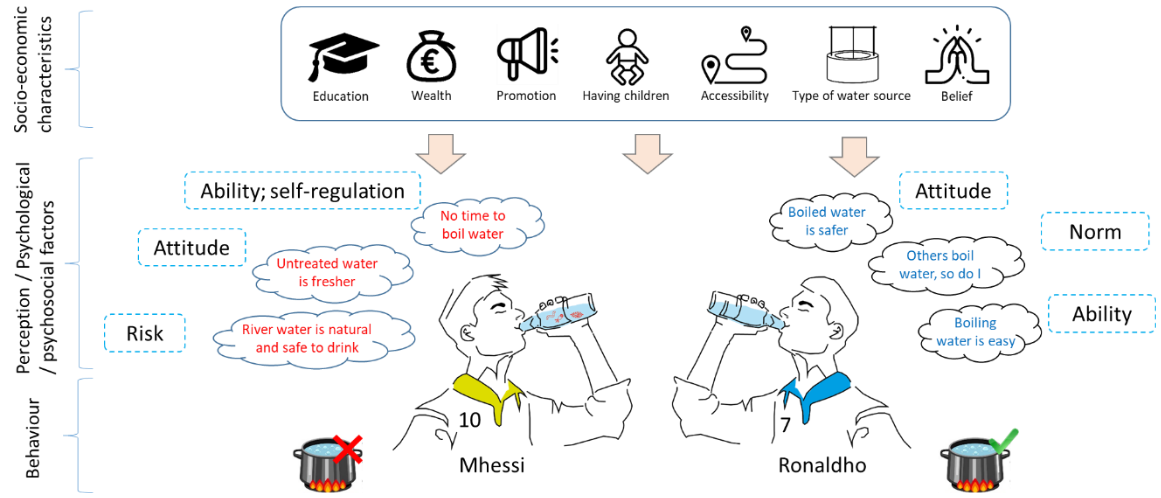
ISBN: 978-94-6384-200-6

Printed by: Proefshrift All In One (AIO) - the Netherlands

Email: danielhombing@gmail.com

CONTENT

Summary



- A conceptual framework of explaining household water treatment adoption -

Summary

Household water treatment (HWT), such as boiling, chlorination, and ceramic filtration, is an interim solution to solve the problem of unsafe drinking water at home, especially for households that do not have access to safe drinking water services. However, previous reports indicate that many people in low and middle-income countries (LMICs) do not use HWT regularly, i.e. still drink unsafe and untreated water. A behavioural study is needed to find reasons for these phenomena, which can help related stakeholders in designing appropriate interventions to increase the regular use of HWT.

A literature study was conducted to review factors that influence the adoption of HWT in developing countries. Afterwards, this study probed the relationship between social-economic characteristics (SEC), psychological or psychosocial factors, and the adoption of HWT in a household level. The analysis started from the assumption, which is supported by literature, that human behaviour is influenced by an individual's perceptions or psychological factors and the SEC of that person or household. While psychological factors directly influence the behaviour, SEC is considered to be an indirect influence of the behaviour, i.e. SEC influences psychological factors and then the behaviour. This assumption was then studied and translated into a novel approach to analyse the adoption of HWT in developing countries.

This novel approach was conducted using a Bayesian Belief Networks (BBN) model. Two locations were studied in Nepal and Indonesia. The RANAS (risk, attitude, norms, ability, and self-regulation) model was adapted as the psychological factors, being of importance for HWT adoption. The Nepal case study was first used to apply the BBN model, but with some limitations, such as incomplete RANAS factors and limited information on SEC. The second case study in Indonesia further aimed to overcome these limitations to have a more reliable BBN model. Both studies revealed critical SEC and psychological factors that influence the

HWT adoption. Examples of critical SEC were a mother's education, access to water, and belief. This study shows that attitude and norms were important psychological factors to drive the adoption of HWT. The variation of critical factors in both studies showed that there was no blueprint for successful adoption of HWT across all contexts or settings. Therefore, the intervention of HWT or water, sanitation, and hygiene (WASH) in general, must be adapted to local circumstances.

The next step in this study was to study endogeneity, which has rarely been discussed in the psychological studies, in particular in the WASH field. Endogeneity implies that there is a bi-directional effect between psychological factors and behaviour, i.e. psychological factors influence the behaviour but the behaviour influences back the psychological factors. If endogeneity exists, common statistical methods used to predict the behaviour, e.g. linear regression, should not be applied. This study found that endogeneity indeed existed in the case of HWT adoption. However, the methods to deal with endogeneity, such as two-stage regression analysis, could only be conducted when valid "instrument variables" were found. We used variables related to institutional performance as instrument variables.

Finally drinking water quality and hygiene practices, and sustainability of WASH services were studied in relation to HWT adoption. The results showed that the effect of HWT to improve the water quality was more prominent in the context of better sanitation and hygiene conditions. This suggests that combined interventions to improve the water quality should be applied rather than HWT alone. Factors that influenced the sustainability of WASH services were discussed under the five main clusters: financial, institutional, economical, technological, and social, where institutional performance was found to be the most critical for sustaining WASH services in rural areas in Indonesia.

Samenvatting

Household water treatment (HWT), zoals kokend water, chloreren en keramische filtratie, is een tussenoplossing om het probleem van onveilig drinkwater thuis op te lossen, vooral voor huishoudens die geen toegang hebben tot veilige drinkwatervoorzieningen. Eerdere rapporten geven echter aan dat veel mensen in low and middle-income countries (LMIC's) niet regelmatig HWT gebruiken, d.w.z. nog steeds onveilig en onbehandeld water drinken. Een gedragsstudie is nodig om redenen voor deze verschijnselen te vinden, die betrokken belanghebbenden kunnen helpen bij het ontwerpen van passende interventies om het regelmatige gebruik van HWT te vergroten.

Er is een literatuurstudie uitgevoerd naar factoren die van invloed zijn op de toepassing van HWT in ontwikkelingslanden. Nadien onderzocht deze studie de relatie tussen social-economic characteristics (SEC), psychologische of psychosociale factoren, en de adoptie van HWT in een huishoudelijke niveau. De analyse ging uit van de veronderstelling, die wordt ondersteund door literatuur, dat menselijk gedrag wordt beïnvloed door de percepties of psychologische factoren van een individu en de SEC van die persoon of dat huishouden. Hoewel psychologische factoren het gedrag rechtstreeks beïnvloeden, wordt SEC beschouwd als een indirecte invloed van het gedrag, d.w.z. SEC beïnvloedt psychologische factoren en vervolgens het gedrag. Deze aanname werd vervolgens bestudeerd en vertaald in een nieuwe benadering om de toepassing van HWT in ontwikkelingslanden te analyseren.

Deze nieuwe benadering werd uitgevoerd met behulp van een Bayesian Belief Networks (BBN) -model. Twee locaties zijn onderzocht in Nepal en Indonesië. Het RANAS-model (risk, attitude, norms, ability, and self-regulation) werd aangepast als de psychologische factoren, die van belang zijn voor de adoptie van HWT. De Nepal-casestudy werd eerst gebruikt om het BBN-model toe te passen, maar met enkele beperkingen, zoals onvolledige RANAS-factoren en

beperkte informatie over SEC. De tweede case study in Indonesië was verder gericht op het overwinnen van deze beperkingen om een betrouwbaarder BBN-model te hebben. Beide onderzoeken brachten kritische SEC- en psychologische factoren aan het licht die deb adoptie van HWT beïnvloeden. Voorbeelden van kritische SEC waren de opleiding van een moeder, toegang tot water en geloof. Deze studie toont aan dat de houding en de normen belangrijke psychologische factoren waren om de adoptie van HWT te stimuleren. De variatie van kritische factoren in beide onderzoeken toonde aan dat er geen blauwdruk was voor een succesvolle adoptie van HWT in alle contexten of omgevingen. Daarom moet de tussenkomst van HWT of water, sanitation, and hygiene (WASH) in het algemeen worden aangepast aan de lokale omstandigheden.

De volgende stap in deze studie was om de endogeneity te bestuderen, die zelden is besproken in de psychologische studies, met name in het WASH-veld. Endogeneity impliceert dat er een bi-directioneel effect is tussen psychologische factoren en gedrag, d.w.z. psychologische factoren beïnvloeden het gedrag, maar het gedrag beïnvloedt de psychologische factoren terug. Als endogeneity bestaat, de algemene statistische methoden die werden gebruikt om het gedrag te voorspellen, bijv. lineaire regressie, mag niet worden toegepast. Deze studie wees uit dat endogeneity inderdaad bestond in het geval van HWT-adoptie. De methoden om met endogeneity om te gaan, zoals tweetraps regressieanalyse, konden echter alleen worden uitgevoerd als geldige 'instrumentvariabelen' werden gevonden. We gebruikten variabelen gerelateerd aan institutionele prestaties als instrument variabelen.

Ten slotte werden de drinkwaterkwaliteit en hygiënepraktijken, en de duurzaamheid van WASH-diensten bestudeerd in relatie tot HWT-adoptie. De resultaten toonden aan dat het effect van HWT om de waterkwaliteit te verbeteren prominenter was in de context van betere sanitaire en hygiënische omstandigheden. Dit suggereert dat gecombineerde interventies om de waterkwaliteit te verbeteren moeten worden toegepast in plaats van HWT alleen. Factoren die van invloed waren op de duurzaamheid van WASH-diensten werden besproken onder de vijf hoofdclusters: financieel, institutioneel, economisch, technologisch en sociaal, waar institutionele prestaties het meest cruciaal bleken voor het ondersteunen van WASH-diensten in plattelandsgebieden in Indonesië.

Chapter 1
INTRODUCTION

- Examples of household water treatment used in East Sumba, Indonesia -

The United Nation Sustainable Development Goal (SDG) 6.1 aims to achieve the universal and equitable access to safe and affordable drinking water for all by 2030 (WWAP (United Nations World Water Assessment Programme), 2015). One of its main objectives is to have safely managed water in every household. However, the latest report mentions that almost one-third of the world population is still without safely managed water access (UNICEF and WHO, 2019), especially in Low and Middle-Income Countries (LMICs).

Household water treatment (HWT), by e.g. boiling, water filtration, or solar disinfection, is one of the methodologies of solving the challenge of having safe water at home, being an interim solution until households can have access to safely managed piped water (Ojomo et al., 2015). HWT has been effective in reducing water-related diseases in many low and middle income countries (LMICs) through hard technological interventions (Peal et al., 2010; Wolf et al., 2018). Yet, many households in rural areas in LMICs still do not use it regularly which diminish the health impact of HWT (Brown and Clasen, 2012). This suggests that providing hard interventions alone do not sustain the regular use of HWT and underlines the need to study human behaviour in order to influence the target group's behaviour (Peal et al., 2010; Sonego et al., 2013).

Many studies have been conducted in LMICs to understand the drivers behind the regular use or adoption of HWT (Fiebelkorn et al., 2012; Lilje and Mosler, 2017). These studies found critical socio-economic characteristics (SEC) and psychological or psychosocial factors that influence the adoption of HWT. However, SEC and psychological factors have been separately studied and have often ignored the relationships between them in influencing the HWT adoption or behaviour. While psychological factors are the "direct" drivers of behaviour, SEC can be seen as indirect drivers. Several studies have concluded that SEC is the root cause, i.e. the causes of the causes, of health-related behaviour (Adler and Newman, 2002; Braveman and Gottlieb, 2002; Manstead, 2018), emphasizing the need to include SEC and psychological factors in behavioural analysis. However, there are no guidelines on how to include and analyse the SEC and psychological factors in predicting the adoption of HWT in developing countries.

Several authors argue that the water, sanitation, and hygiene (WASH) sector is a complex system and a “system approach” is needed to analyse it (Eisenberg et al., 2012; Peters, 2014; Valcourt et al., 2020). The complex system means that many factors are involved, these factors are interconnected, and they have a collective impact on the outcome. There are chains of causes, i.e. the effect from the root causes on the main outcome is via various factors or variables.

Household water treatment is not the only factor that influence drinking water quality at home. Other factors play a role, such as, storage condition or the general hygiene situation at the household (Brick et al., 2004; Elala et al., 2011; Navab-Daneshmand et al., 2018). Therefore, the study on HWT should be accompanied by overall drinking water management and hygiene practices at the household, including drinking water quality analyses.

The efforts to increase the adoption of HWT cannot be separated from WASH services in general, for example, the provision of water supply or the availability of proper sanitation services in the area. That is because HWT cannot be regularly performed without easy access to water supply services and improper sanitation services reduce the health impact of HWT (Wolf et al., 2018). Therefore, the analysis of the sustainability of WASH services should be included in the study of HWT adoption in developing countries.

Considering the above, the main objective of the study presented in this thesis is to analyse factors that influence the adoption of HWT in rural areas in developing countries. The analyses cover three key aspects: behavioural analysis of HWT adoption, household drinking water quality and general hygiene practices, and the sustainability of WASH services.

Six main research questions (RQ) were formulated, which are answered in subsequent chapters:

RQ 1: What are the factors that influence the adoption of HWT in low-middle income countries?

- Factors influencing the adoption of HWT are discussed in chapter 2 based on a comparative study in various developing countries, while more influencing factors are described in chapters 3-6 and 8.

RQ 2: What are the relationships between socio-economic characteristics, psychological factors, and the adoption of HWT?

- Chapter 2 and 3 discuss the relationships between SEC, psychological factors, and the adoption of HWT. Methods that were used include a qualitative comparative analysis (QCA) and mediation analysis.

RQ 3: How do we analyse the adoption of HWT taking into account the relationships between socio-economic characteristics and psychological factors?

- Chapter 4 and 5 provide a “practical application” of analysing the adoption of HWT considering the answers to the previous RQs based on study cases from Nepal and Indonesia. A Bayesian belief network (BBN) was used in these chapters.

RQ 4: Is there a feedback effect or reverse causality from the adoption of HWT to the psychology of water use?

- Chapter 6 aims to find reverse causality on adoption in eight HWT studies in developing countries. The two-stage Instrument Variable (IV) regression was used in this chapter.

RQ 5: How do we assess the risk related to household drinking water quality and general hygiene practices?

- In chapter 7, sanitary inspection and drinking water quality data were used to assess the risks related to drinking water quality and WASH. The BBN method was utilised to analyse the data.

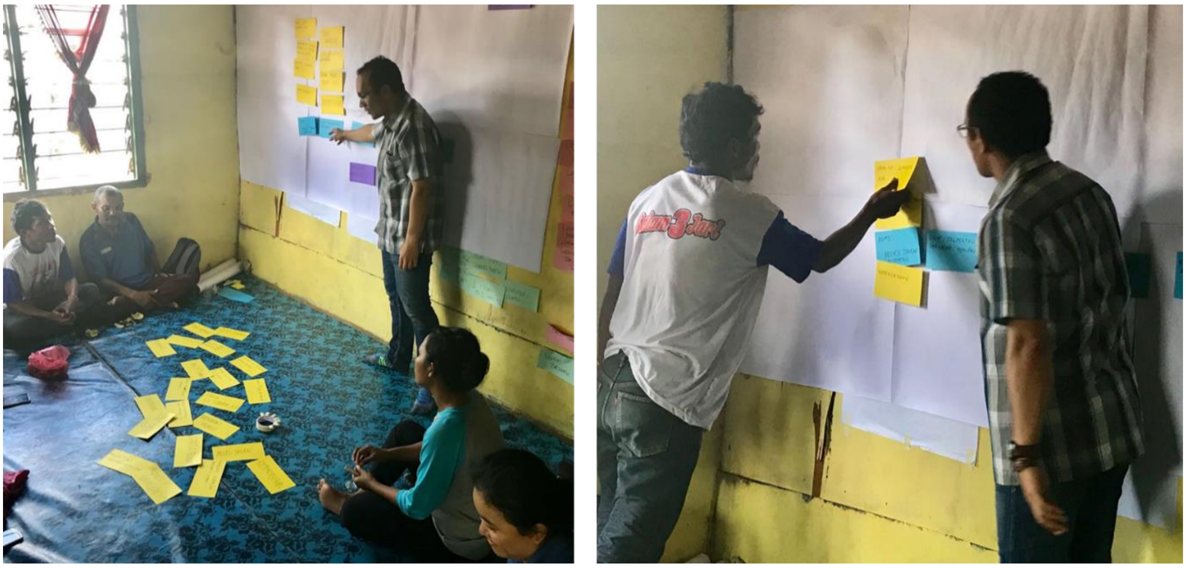
RQ 6: What are contextual factors contributing to the sustainability of WASH services in rural areas?

- In chapter 8, a qualitative analysis is presented to find contextual factors contributing to the WASH services. The data was taken from fieldwork in Indonesia.

Chapter 9 describes the conclusions and recommendations for future research in the topic of HWT adoption.

Chapter 2

Socio-environmental drivers and behavioural determinants of household water treatment adoption in developing countries



- Mapping factors influencing the adoption of household water treatment with village representatives in rural Indonesia-

This chapter is based on:

Daniel, D., Marks, S. J., Pande, S., & Rietveld, L. (2018). Socio-environmental drivers of sustainable adoption of household water treatment in developing countries. *Npj Clean Water, 1*(1). https://doi.org/10.1038/s41545-018-0012-z

Abstract

Household water treatment (HWT) can effectively reduce exposure to unsafe drinking water at home. Understanding the characteristics of target groups who successfully adopt HWT, such as perception about water quality and usefulness of HWT, income, or parental education, is essential for enhancing the adoption of HWT in developing countries. The objective of this study is to analyse the interactions between such socio-environmental characteristics and behavioural determinants, rather than a single characteristic, in order to explain the adoption of HWT. Five socio-environmental characteristics and behavior determinants (perception) were analysed using Qualitative Comparative Analysis (QCA) from 41 case studies in Africa, Asia, and South America. Results show that there is no single factor or characteristic that alone explains the adoption of HWT. QCA identified five pathways leading to high adoption of HWT. Perceived threat due to bad water quality is a pre-condition for three of the pathways. However, perceived threat does not alone explain adoption of HWT and must be accompanied by other conditions. Households connected to piped water schemes can also be potential HWT adopters as long as they perceive poor tap water quality. Finally, households who are able to afford the full cost of HWT tend to adopt it only when they neither have prior experience with HWT nor a connection to a piped scheme. Our findings highlight the necessity to analyse interactions between socio-environmental characteristics and behavior determinants of households in order to determine the adoption of HWT.

Keywords: household water treatment, qualitative comparative analysis, socio-environmental characteristics.

Introduction

Half of the world's population face severe water scarcity annually (Mekonnen and Hoekstra, 2016). This threatens the resilience of global water supplies and leads to high mortality and morbidity rate among children under the age of 5 years in developing countries, especially due to diarrheal diseases (Colombara et al., 2016). About 71% of global population had access to safely managed water services in 2017. However, there are still 844 million people who do not have access to at least basic drinking water services (WHO; UNICEF, 2017a). Moreover, about 40% of improved water sources are faecally contaminated or are at high risk of contamination (Onda et al., 2012).

The 2030 United Nation Agenda for Sustainable Development explicitly focuses on water and sanitation management (Sustainable Development Goal (SDG) 6). The target 6.1 aims to achieve universal and equitable access to safe and affordable drinking water for all by 2030 (WWAP (United Nations World Water Assessment Programme), 2015). The long term goal of SDG 6 is to provide safely managed drinking water meeting international standards for water quality (World Health Organization, 2011). However, financial, infrastructure and human capital constraints are likely to limit the implementation of the SDG 6 (Jagals, 2006; WHO, 2007; Hutton and Bartram, 2008; Johnston et al., 2010).

Household water treatment (HWT) technologies can safeguard public health in areas persistently challenged by efforts to achieve universal access to safe water (Clasen, 2009). Several types of HWT technologies have been used for decades, such as boiling, chlorination, and filtration (Lantagne et al., 2011; WHO Western Pacific Region, 2013). Furthermore, newer technologies have also been developed, such as biochar and gravity driven membrane based HWT (Peter-Varbanets et al., 2011; Gwenzi et al., 2017). HWT methods have been found to be more effective in improving household health than other types of water quality interventions, such as treating water at the point of collection or at the source (Clasen & Mintz, 2004; Padilla, 2012; Sobsey et al., 2008).

Previous studies have shown that only those households that regularly treat their water experience the maximum health benefits of HWT methods, i.e., a sustained reduction in the rate of diarrhea (Clasen et al., 2007). However, households often do not treat water regularly and even abandon HWT over time (Hunter, 2009; Schmidt and Cairncross, 2009b; Waddington and Snilstveit, 2009).

Socio-environmental characteristics, like parental educational level or local culture, and behavior determinants, like perceived health threat due to bad water quality or willingness and ability to pay for a HWT product, have been found to influence successful adoption of HWT (Figueroa and Kincaid, 2010; Mosler, 2012b; Dreibelbis et al., 2013). Behavior determinants are often called psychological or psychosocial factors. Previous variable-driven experimental research and meta-analyses on HWT interventions have focused on testing statistical associations between individual socio-environmental characteristics or behavior determinants and adoption of HWT (Hunter, 2009; Inauen et al., 2013; Loharikar et al., 2013). The question then is: do these characteristics and determinants *alone* influence the adoption of HWT? Or does an interaction between or combination of these characteristics and determinants best explain HWT adoption? If there is such combination, it has yet to be investigated, pointing to the necessity to understand how the socio-environmental characteristics may influence the adoption of HWT (Cairncross, 1992; Clasen, 2009).

Therefore, this chapter aims to: (1) determine whether a single or multiple interacting socio-environmental characteristics and behavioral determinants (called "conditions" in this chapter) best explain HWT adoption; and (2) if we cannot rely only on a single condition to explain adoption of HWT, we then describe how these conditions interact to influence the adoption of

HWT. The results presented in this study draw on an extensive literature review of HWT adoption case studies in less developed countries.

Methods

Qualitative comparative analysis

Qualitative comparative analysis (QCA) was used to comparatively analyse 41 case studies to identify combinations of conditions (called "pathways") leading to successful adoption of HWT. In QCA, all explanatory variables are called conditions. QCA provides: (1) necessity analysis to identify necessary conditions (i.e., a condition that must appear) to generate an outcome of interest, and (2) sufficiency analysis to identify one or more possible pathways for achieving the outcome of interest. The "goodness of fit" of necessary and sufficient conditions is assessed in terms of 'consistency' and 'coverage' scores. The consistency score measures the degree to which a condition explains a positive outcome. The coverage score measures the proportion of case studies that are explained by a specific pathway. Consistency and coverage score thresholds of 0.9 and 0.3, respectively, were used to determine necessary conditions. A consistency score threshold of 0.8 was used to determine sufficient conditions (Ragin, 2008; Legewie, 2013; Sehring et al., 2013)**.**

We used crisp set Qualitative Comparative Analysis (csQCA), which makes use of binary input data. Conditions are coded as bivalent logic based on prescribed thresholds, i.e. either present/true (1) or absent/false (0). CsQCA is the simplest method in QCA and may oversimplify the system, but is still capable of providing useful insight. This study made use of *fsQCA 2.5* software (*compasss.org*). All data were encoded in Excel and saved in *.csv* format as input to the software. The intermediate solution without prior assumption was used to perform the analysis.

Case selection

An extensive review of peer-reviewed literature on Household Water Treatment (HWT) interventions was conducted. The review was limited to articles written in English. We did not distinguish between real-world implementations, intervention trials, or interventions after an emergency situations, such as HWT interventions after flooding events. No restrictions such as location, type of HWT, year published or year conducted, were put on the selection of cases. The main inclusion criterion for case study selection was the assessment time, defined as the duration of time between introduction of HWT and measurement of its usage. All papers that described case studies with an assessment time greater than 12 months were eligible for inclusion.

In total 41 case studies met the inclusion criteria. These were published during 2003-2016, offered 5 main types of HWT technologies (chlorination, flocculation, filtration, UV light, and pasteurization) across 24 countries and 4 continents (Figure 1).

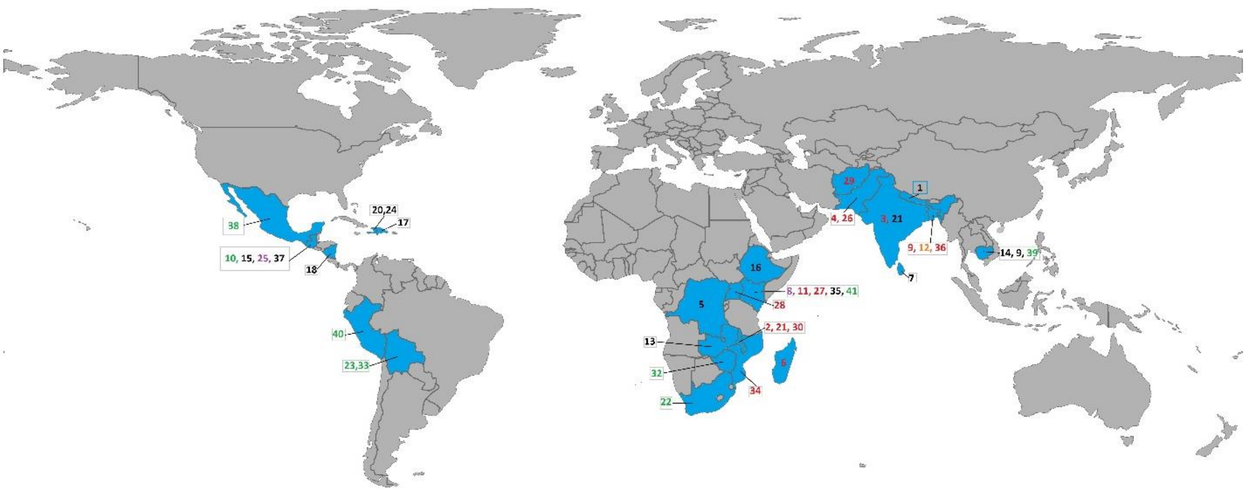


Figure 1. Locations of the case studies selected for QCA (i.e., including both successful and unsuccessful cases). The numbers indicate the case numbers. The color of the text indicates the type of HWT intervention. Black = filtration, red = chlorination, purple = flocculation, green = SODIS (UV light), orange = pasteurization.

Identifying causal conditions and the outcome

Five socio-environmental characteristics and behavior determinants (or conditions) were determined from the review and examined in this study: affordability to purchase a HWT product at full cost (AFFORD), perceived threat due to bad water quality (PERC), type of domestic water source (PIPE), existing household water treatment before the intervention or proportion of households who already used HWT (EXHWT), and parental education level (EDU). *PERC* and *AFFORD* represent behavior determinants, while *PIPE* and *EDU* represent socio-environmental characteristics of the community. *EXHWT* can represent both behavior determinant (descriptive norms according to RANAS (Mosler, 2012b)) and socio-environmental characteristics. These two elements (i.e., socio-environmental characteristics and behavior determinants) were analysed separately and considered to be of no distinct relation to each other (Dreibelbis et al., 2013).

The main criteria for the inclusion of conditions in the analysis were conformity with the literature, consistent availability of data across the case studies examined and added value to the analysis. The adoption rate of HWT was defined as the outcome variable (ADOPT). Since no standard definition of high adoption of HWT existed at the time of the study, we set 50% adoption rate as the threshold for high adoption of HWT. Table 1 summarizes the threshold for each causal condition and outcome variable. Each study case was assigned full membership (coding 1) or full non-membership (coding 0), and the membership score are reported in Table 2.

We did not include other factors that may influence adoption rate in this analysis, such as subsidies, intensive promotion activities, durability of the product, or household's preference for a specific type of HWT item. Most of the data were obtained from the literature, with missing relevant information obtained by querying the article's author or gathering information from other relevant studies in the same area.

Table 1. Coding rubric developed to score outcome and causal conditions

Variables (causal conditions and outcome)	Coding scheme and threshold
Outcome: Adoption rate (ADOPT)	1: Adoption rate of HWT >50% 0: Adoption rate of HWT ≤50%
Perceive thread (PERC)	1: > 50% of households perceived their water is bad and causes diseases 0: ≤ 50% of households perceived their water is bad and causes diseases
Existing HWT before intervention (EXHWT)	1: >25% of households practicing any kind of household water treatment 0: ≤25% of households practicing any kind of household water treatment
Affordability (AFFORD)	1: >50% of households in the study area being able to afford the full cost of HWT products 0: ≤50 of households in the study area being able to afford full cost of the HWT products
Connection to pipe scheme (PIPE)	1: >50% of households in the study area draw water from a piped scheme 0: ≤50 of households in the study area draw water NOT from pipe scheme
Parental education level (EDU)	1: >50% parents in the study area had completed primary school 0: ≤50% parents in the study area had completed primary school

Table 2. Membership scores of 41 case studies

Case	Reference	Type of HWT	Location	ADOPT	PERC	EXHWT	AFFORD	PIPE	EDU
1	(Ngai et al., 2006, 2007)	Biosand filter (KAF)	Nepal	1	1	0	0	0	0
2	(Stockman et al., 2007)	Chlorination (Water guard)	Malawi	0	1	0	1	1	0
3	(Boisson et al., 2013)	Chlorination (NaDCC tablets)	India	0	1	1	1	0	0
4	(Luby et al., 2001)	Chlorination (Bleach)	Pakistan	1	1	1	0	0	0
5	(Boisson et al., 2010)	LifeStraw (Filtration)	DPC (Congo)	1	0	0	0	0	0
6	(Ram et al., 2007)	Chlorination (Bleach)	Madagascar	1	1	0	1	0	0
7	(Casanova et al., 2012a, 2012b)	Ceramic filter	Sri Lanka	1	1	1	1	1	0
8	(DuBois et al., 2010)	Flocculent disinfectant and sodium hypochlorite	Kenya	0	1	1	1	0	0
9	(George et al., 2016)	Chlorination (Aquatabs)	Bangladesh	0	0	1	1	1	1
10	(Arnold et al., 2009)	Combined treatment: SODIS, boiling, bleach	Guatemala	0	0	0	1	1	0
11	(Parker et al., 2006)	Chlorination (WaterGuard)	Kenya	1	1	1	1	1	1
12	(Gupta et al., 2008)	Chulli water purifier (filtration and heating)	Bangladesh	0	0	1	1	0	0
13	(Peletz et al., 2013)	LifeStraw (filtration)	Zambia	1	0	0	1	0	1
14	(Brown et al., 2009)	Ceramic filter	Cambodia	0	1	0	0	0	1
15	(Larson et al., 2016)	Tabletop carbon activated water filtration	Guatemala	1	0	0	1	0	1
16	(Earwaker and Webster, 2009)	Biosand filter	Ethiopia	1	1	0	0	0	1
17	(Aiken et al., 2011)	Biosand filter	Dominican Republic	1	1	0	0	0	1

18	(Fiore et al., 2010)	Biosand filter	Nicaragua	1	1	0	0	0	0
19	(Liang, K., Sobsey , M., and Stauber, 2010)	Biosand filter	Cambodia	1	1	0	1	0	0
20	(Sisson et al., 2013)	Biosand filter	Haiti	1	1	0	1	0	0
21	(Loharikar et al., 2013)	Chlorination (Water guard)	Malawi	1	1	0	1	1	1
22	(Du Preez et al., 2010)	SODIS (UV-light)	South Africa	0	1	0	1	1	0
23	(Mausezahl et al., 2009)	SODIS	Bolivia	0	0	1	1	1	1
24	(Duke et al., 2006)	Biosand filter	Haiti	1	1	0	1	0	1
25	(Reller et al., 2003)	Combination of (1) flocculants, (2) flocculants + vessel, (3) bleach, (4) bleach + vessel	Guatemala	0	0	0	1	0	1
26	(Luby et al., 2004)	Bleach+vessels	Pakistan	0	1	1	1	0	0
27	(Harris et al., 2009)	Chlorination (water guard)	Kenya	1	0	0	1	1	1
28	(Lule et al., 2005)	Chlorination (bleach)	Uganda	0	0	1	0	0	1
29	(Opryszko et al., 2010)	Chlorination (bleach)	Afghanistan	1	1	0	1	0	1
30	(Wood et al., 2012)	Chlorination (water guard)	Malawi	0	1	1	0	0	1
31	(Freeman et al., 2012)	Pureit (Cl and carbon filtration)	India	0	1	1	0	1	1
32	(Mosler et al., 2013)	SODIS	Zimbabwe	1	1	1	1	0	0
33	(Christen et al., 2011)	SODIS	Bolivia	1	0	0	1	0	1
34	(Wheeler and Agha, 2013)	Chlorine solution (Certeza)	Mozambique	0	1	1	1	0	0
35	(Fewster et al., 2004)	Biosand filter	Kenya	1	1	0	1	0	1
36	(Ercumen et al., 2015)	Chlorination (NaDCC)	Bangladesh	1	0	0	1	0	0
37	(Kallman et al., 2010)	Impregnated (silver) ceramic filter	Guatemala	1	1	1	1	1	1
38	(Gruber et al., 2013)	UV disinfection	Mexico	0	0	0	0	0	1
39	(McGuigan et al., 2011)	SODIS	Cambodia	1	0	0	1	0	1
40	(Hartinger et al., 2016)	SODIS	Peru	0	0	0	1	1	1
41	(du Preez et al., 2011)	SODIS	Kenya	1	1	0	0	1	1

Results

Necessity analysis

Necessity analysis assesses whether a factor is *compulsory* for the adoption of HWT. Table 3 shows the results of the necessity analysis for all conditions and their negation (negation indicated by a ~ symbol in front of the condition name). The characteristics with the highest scores were ~EXHWT (~ *practice HWT*, measured as ≤25% of households practiced household water treatment), followed by ~PIPE *(~ connected to pipe scheme*, measured as ≤50% of households had access to a pipe scheme), and PERC (*perceived threat*, measured as >50% of households perceived their water is bad and causes diseases). However, no condition had a consistency score above 0.9, indicating that no single condition was compulsory for successful implementation of HWT. Note that the consistency score measures how often a condition appears in the presence of the positive outcome. The higher the consistency score, the more often a condition appears in the presence of the positive outcome. Further, the condition AFFORD (*affordable to purchase HWT product*, measured as >50% of households were able to afford the full cost of HWT) had the same consistency score as PERC (*perceived threat)* but had a slightly lower coverage value (Table 3). On the other hand, the coverage score measures the proportion of positive case studies that are explained by a specific condition (in the case of necessity analysis) or the proportion of positive case studies which are represented by a specific pathway (in the case of sufficiency analysis).

Table 3. Consistency and coverage scores for each condition and its negation (indicated by ~). Necessity analysis revealed that no individual condition was deemed necessary for high adoption rate of HWT**.**

Conditions	Consistency score	Coverage score
Perceive threat	0.708	0.653
NOT perceive threat	0.291	0.466
Practice HWT	0.208	0.333
NOT practice HWT	0.791	0.730
Affordable to purchase HWT product	0.708	0.586
NOT affordable to purchase HWT product	0.291	0.583
Connected to pipe scheme	0.250	0.461
NOT connected to pipe scheme	0.750	0.642
Parents completed primary school	0.583	0.608
Parents NOT completed primary school	0.416	0.555

Sufficiency analysis

The second step of QCA is sufficiency analysis, which identifies possible combinations of socio-environmental characteristics of target households for successful adoption of HWT. Sufficiency analysis provides one or more combinations of conditions (hereafter called pathways) that together are sufficient to lead to an outcome of interest. From the 41 case studies examined, 24 had high adoption rates and 83% of these (20 cases, from 15 countries, see Figure 1) were explained by five pathways with a solution consistency score of 0.95. All five pathways exceeded the consistency score threshold of 0.8 (Figure 2), meaning that each were sufficient for explaining successful adoption of HWT.

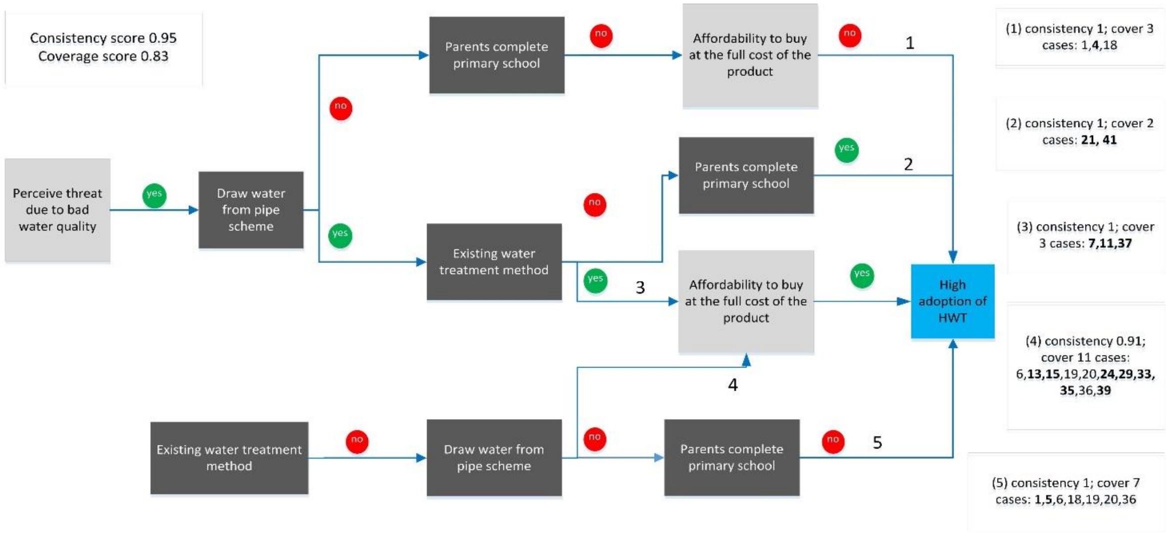


Figure 2. Five causal pathways leading to high adoption of HWT. Bold numbers indicate *unique coverage cases* (i.e., cases that can only be explained by a specific pathway). "Yes" means "set-membership" and "no" means or "non-membership". Grey boxes represent behavior determinants and black boxes represent socio-environmental characteristics. See Figure 2 for the country locations of the case studies.

The condition *perceived threat* (PERC) appeared in pathways 1, 2, and 3. Additionally, the condition PERC was also one of the top three conditions with the highest consistency score in the necessity analysis. Taken together, these findings suggest that PERC is a key condition to explain the adoption of HWT.

Pathway 1 represents low-income households with low education levels who did not depend on piped schemes for their main drinking water needs. Pathway 1 also reveals that high education of household members is not always necessary for successful adoption of HWT. For example, a case from Pakistan (case study 4)described that awareness programs, such as intensive water, sanitation, and hygiene (WASH) promotion activities delivered by NGOs, health care, or government, led to successful adoption of HWT in low income poorly educated households. Additionally, the case study from Nepal (case study 1) emphasized that the target group highly appreciated the benefits of water filters, as demonstrated by a study participant who said "the filtered water appears clearer, tastes better, and smells better than the raw water" (Ngai et al., 2007).

Pathways 2 and 3 represent households that also doubted the quality of water from their piped scheme. Cases in Pathway 2 suggest that higher education levels may lead to greater awareness of the health threats from poor water quality. Even though the households corresponding to Pathway 2 had a high awareness about water quality, the reason they did not treat their drinking water before the intervention is unclear. Moreover, the study in Malawi (case study 21) showed that continuous promotion by highly motivated health workers after the project finished, in combination with high levels of support from government, effectively achieved sustained HWT practices.

In contrast with Pathway 2, households in Pathway 3 had prior experience with treating their water. For example, in case 7 from Sri Lanka and case 37 from Guatemala, most households had already adopted the norm of boiling their drinking water before switching to ceramic filters that were distributed for free during an intervention. Since the pathway shows that households could afford more expensive products, apparently perceiving the benefits of a new HWT method played a role in their decision to replace their prior HWT method. Case 11 in Kenya revealed that appropriate promotion activities also played a role in successful adoption of HWT. In this case study, a liquid chlorine solution called *WaterGuard* was promoted throughout the country and also integrated with an antenatal program.

Cases within Pathway 4 featured households that were dependent on non-piped sources and did not have prior experience with HWT but could afford a HWT product. For 7 case studies in this pathway, either perception of threat posed by poor water quality or high parental education level appeared as additional conditions that positively contributed to HWT adoption. Cases 6

(Madagascar), 19 (Cambodia), and 20 (Haiti) had low education levels but high perception of threat due to drinking untreated water. A high usage rate of chlorine solution was achieved because "almost all villagers were aware of the household disinfection strategy, and this knowledge was similar across literacy and socioeconomic strata" (Ram et al., 2007). But cases 13 (Zambia), 15 (Guatemala), 33 (Bolivia), and 39 (Cambodia) showed the opposite, where households had a high education level but low perception of threat due to poor water quality.

Only one case can be categorized as being covered uniquely by pathway 5 (case 5 in the Democratic Republic of Congo). In case 5, households did not have a prior treatment method, did not have a piped water connection, and parents had not completed primary school. Nevertheless, the intervention led to a successful adoption. This exception may be explained by the free delivery of the product and a positive attitude of the people towards the product. The study mentions that the households liked the product because it improved the aesthetic quality (88% of total intervention households) and taste (92%) of water.

Discussion

Our analysis revealed that no single condition could alone explain adoption of HWT. Instead, complex interactions among 5 socio-environmental condition explained the adoption of HWT for 20 cases across 15 countries. These findings support the conclusion of a study by Clasen et al., which states that "level of effectiveness may depend on a variety of conditions that research date cannot fully explain" (Clasen et al., 2007). Another important observation from this research is the interaction between socio-environmental characteristics and behavioral determinants (i.e., psychological factors), as seen in Pathways 1, 3, and 4 (see Figure 2). In pathway 1, for example, the type of water sources households used (socio-environmental characteristics) appeared to influence their perception of their quality (psychological factor) and influence their decision to use a HWT product. Several conceptual theories have attempted to link socio-environmental characteristics with psychological factors, e.g. IBM-WASH (Dreibelbis et al., 2013), health belief model (Rainey and Harding, 2005), a model of communication for water treatment and safe storage (Figueroa and Kincaid, 2010), and RANAS (Mosler, 2012b). But analysis of such interactions remains a challenge.

Based on our analysis, households' perception that their own water quality is bad and risky to drink cannot alone explain the successful adoption of HWT. Yet these findings suggest that this condition is the most important precursor for successful adoption of HWT. Of 24 successful adoption cases, 17 cases (71%) reported high perception of the risk of drinking untreated water. This finding aligns with several previous studies which concluded that negative perception of the quality of the water source is essential for successful adoption if HWT (Harris, J., 2005; Nagata et al., 2011). This finding is also in line with a previous analysis from 10 countries, which concluded that negative perception of the quality of the water source caused households to purchase HWT products (Johnstone and Serret, 2012).

The condition *do not practice* HWT (~EXHWT) also showed high consistency with the outcome of successful adoption of HWT. However, Pathway 3 featured cases where successful adoption was possible among households already practicing water treatment. Under such conditions, case details revealed that households perceiving the benefits of a new and affordable treatment method was an key driver for high adoption of new HWT. We suggest that to maximize the likelihood of successful adoption in locations where water treatment is already being practiced, HWT implementers should target locations where existing treatment methods are not desirable and where households are willing and able to pay for a more effective product.

Conclusion

Our comparative analysis reveals several insights for the implementation of HWT interventions. First, a system level approach that considers socio-environmental characteristics and behavioural determinants of households is needed when designing a HWT intervention program in less developed countries. Second, the absence of prior water treatment practices was the most consistent condition associated with successful adoption of HWT. We recommend that interventions should target unserved regions where households do not have any prior experience with HWT, i.e. the focus should not be to introduce a new method of HWT to replace an existing HWT practices. Still, households already practicing treatment may decide to adopt a new HWT method if it is affordable and confers tangible benefits over the existing method.Hence, implementers should also focus on this target group. Third, perception of water being risky to drink is a consistent precursor to successful adoption of HWT. Thus we recommend that assessing the perception of households should be the focus of any pre-intervention program. If households do not perceive water quality as bad, education and awareness programs should be initiated before the introduction of HWT. Lastly, two pathways showed that people who draw water from piped schemes could adopt HWT if they perceive that water quality is bad. This suggests that HWT is not a competitor for piped schemes, but instead serves to complement it. Piped water suppliers should include HWT implementation if they cannot guarantee clean water at the point of collection.

Chapter 3

The effect of socio-economic characteristics on the household water treatment adoption via psychological factors

- Household interviews using a smartphone in rural Nepal and Indonesia -

This chapter is based on:

Daniel, D., Pande, S., & Rietveld, L. (2020c). The effect of socio-economic characteristics on the use of household water treatment via psychological factors: a mediation analysis. *Hydrological Sciences Journal*. https://doi.org/10.1080/02626667.2020.1807553

Abstract

Household water treatment (HWT) can solve the issue of consuming unsafe drinking water at home. Household socio-economic characteristics are often assumed influencing the use of HWT via psychological factor. However, no study has rigorously tested such an assumption. We aim to fill the gap by a cross-sectional study in a rural area in Sumba Timur, Indonesia (N = 256). Using mediation analysis, we demonstrated that psychological factors mediated the relationship between socio-economic characteristics and the use of household water treatment. Additonally, socio-economic characteristics strongly influenced the psychology of household water treatment usage. Furthermore, the use of HWT asked from different angles allowed more degrees of freedom to better assess the true status of the HWT usage, via the Principal Component of the household's answers. This chapter concludes that "causal" relationship pathway from socio-economic characteristics to the use of HWT via psychological factors is a realistic assumption when assessing the influence of socio-economic characteristics on HWT.

Keywords: mediation analysis, household water treatment, behavioural analysis, RANAS psychological frameworks

Introduction

The United Nations Sustainable Development Goals aim “by 2030, [to] achieve universal and equitable access to safe and affordable drinking water for all” (WWAP (United Nations World Water Assessment Programme)/UN-Water, 2018). This aim means that every house has a connection to sufficient and 24 hours available water supply, inexpensive, and free from major water contaminations. Even though the progress looks promising, the latest report by World Health Organization (WHO) and United Nations Children's Fund (UNICEF) (2017a) mentions that 2.1 billion people (29% of the global population) still are not connected to such an access. Moreover, Bain et al. (2014a) have estimated that 1.8 billion people have access to faecally contaminated water sources.

Household water treatment (HWT) is one of the methods to improve water quality at household level, e.g., by boiling, water filtration, or chlorination. HWT is especially helpful if the water source is contaminated (Sobsey et al., 2008). Studies have found that if household practices HWT correctly and regularly, it can reduce the risk of water-related diseases, such as diarrhoea (Brown and Clasen, 2012; Wolf et al., 2018). However, many households still do not practice HWT regularly. This puts these households at risk of contracting water borne diseases because they still drink untreated water (Hunter et al., 2009). Thus, there is a need to understand why people still do not use HWT.

Previous studies have found that socio-economic characteristics are strongly associated with the use of HWT. Wealthier households with higher education level were more likely to treat water in Bhutan (Rahut et al., 2015), Cameroon (Fotue Totouom et al., 2012) and India (Dasgupta, 2004). Other associations are with perception that untreated water is safe (Williams et al., 2015), no social pressure from community (i.e., norm) to use HWT (Lilje et al., 2015), or negative feelings towards treated water due to its taste (Orgill et al., 2013). The latter examples are often called as psychological factors or behavioural determinants, which are defined as one's thoughts and feelings that influence behaviour (Macleod and Davey Smith, 2003).

A system level approach to explain the use of HWT is needed, which combines socio-economic characteristics and psychological factors (Dreibelbis and Winch, 2013; Daniel et al., 2018). Seimetz et al. (2016) and Stocker and Mosler (2015) have combined socio-economic characteristics and psychological factors in their analysis using multivariate linear regression, treating both elements at the "the same level." A new approach has been proposed by Daniel et al. (Daniel et al., 2019), using Bayesian belief network (BBN) that depicts a causal relationship between variables. The authors modelled a "causal" relationship wherein socio-economic characteristics influenced the use of HWT through psychological factors. This indirect pathwaysis also partly suggested by RANAS (risk, attitude, norms, ability, and self-regulation) psychological theory. RANAS theory suggests both direct and indirect pathways between socio-economic characteristics and output behaviour (Mosler, 2012a; Contzen and Mosler, 2015). However, other studies outside water, sanitation, and hygiene (WASH) have found evidence only for indirect pathways (Gecková et al., 2005; Wells and Harris, 2007; Rodriguez et al., 2014; Martinez et al., 2018).

To our knowledge, there is no study from the WASH field investigating potential "causal" pathways connecting socio-economic characteristics, psychological factors and WASH related behaviour. Therefore, the objective of this chapter is to start filling this gap. We hypothesize that the household's socio-economic characteristics (SEC) are mediated by psychological factors that influence the behaviour of using HWT (Figure 1). Moreover, we hypothesize that better socio-economic characteristics of respondents generate more favourable psychological factors, that result in higher chance of using HWT.

We used data from a cross-sectional study of a rural area on Sumba island, Indonesia, and analysed them using mediation analysis. Sumba is one of the poorest locations in Indonesia with high frequency of open defecation and limited access to clean water (Sungkar et al., 2015). Mediation analysis (sometimes called path analysis) is intended for understanding the relationship between two variables via inclusion of a third variable, called the mediator variable (Mackinnon et al., 2007). In this chapter, mediation analysis was used to understand the mechanisms of how socio-economic characteristics influence the use of HWT, whether socio-economic characteristics directly influence the use of HWT or this influence is mediated by mediator variables called RANAS psychological factors.

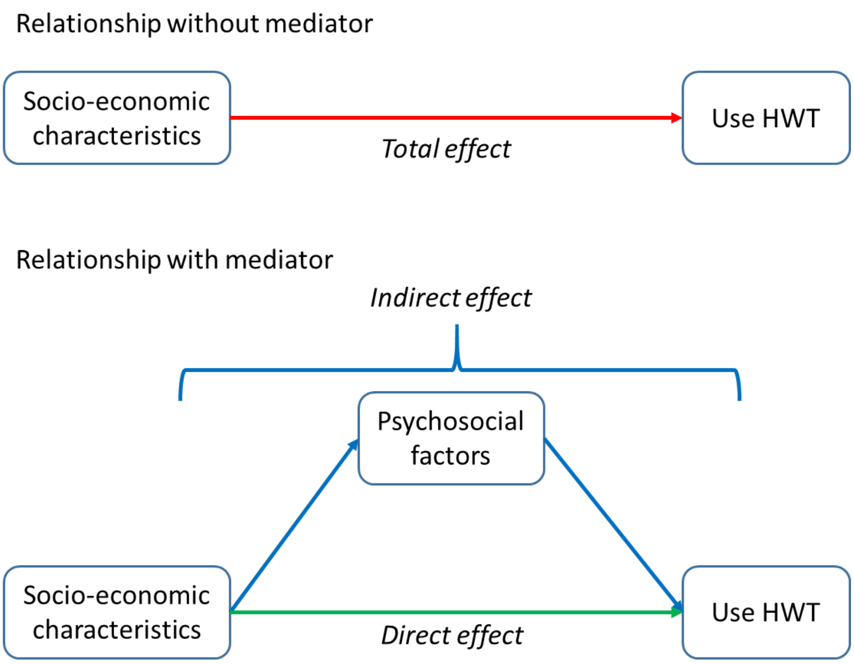


Figure 1. Hypothetical pathways of the mediation analysis: direct influence of socio-economic characteristics on the use of HWT (green arrow) or indirect pathway via psychological or psychosocial factors (blue arrow).

Methods

Ethics statement

The study setting, including the questionnaire, were approved by the Human Research Ethics Committee of Delft University of Technology and was authorised by the Agency for Promotion, Investment and One-Stop Licensing Service at the province (East Nusa Tenggara) and district (East Sumba) level. Participation was voluntary and written informed consent was obtained from all respondents. Informed consent was also obtained from the village head before the field survey.

Study setting

A cross-sectional study was undertaken in August 2018 in nine villages in the district of Sumba Timur, Province Nusa Tenggara Timur, Indonesia (Figure 2). We initially targeted a sample size based on the methodology of (Krejcie and Morgan, 1970; Wilson Van Voorhis and Morgan, 2007) (check supporting information S1 in (Daniel, et al., 2020b) for more information). In total, 377 households were randomly selected during transect walk within each village. The questionnaires were developed in English and translated into Bahasa Indonesia by the first author. Six local people who are familiar with the location were hired to conduct the interviews. Training and pilot tests were conducted before the survey.

A structured household interview was in the Open Data Kit (ODK) platform on smartphone (https://opendatakit.org/). Its content, especially the psychological-related questions (Table 1), was inspired by RANAS theory (Contzen and Mosler, 2015). The questionnaire covered household's socio-economic characteristics, WASH knowledge and perception, health status, WASH-related behaviour, e.g., HWT use, hand washing, sanitation, and ended with structured observations. Most of the psychological-related questions were measured by a five item Likert scale as described later, while the socio-economic variables were categorical. The target respondents, where possible, were mothers who were primary caregivers in the households. In case of mother was not available at that time, we interviewed the father or the oldest person in that house.

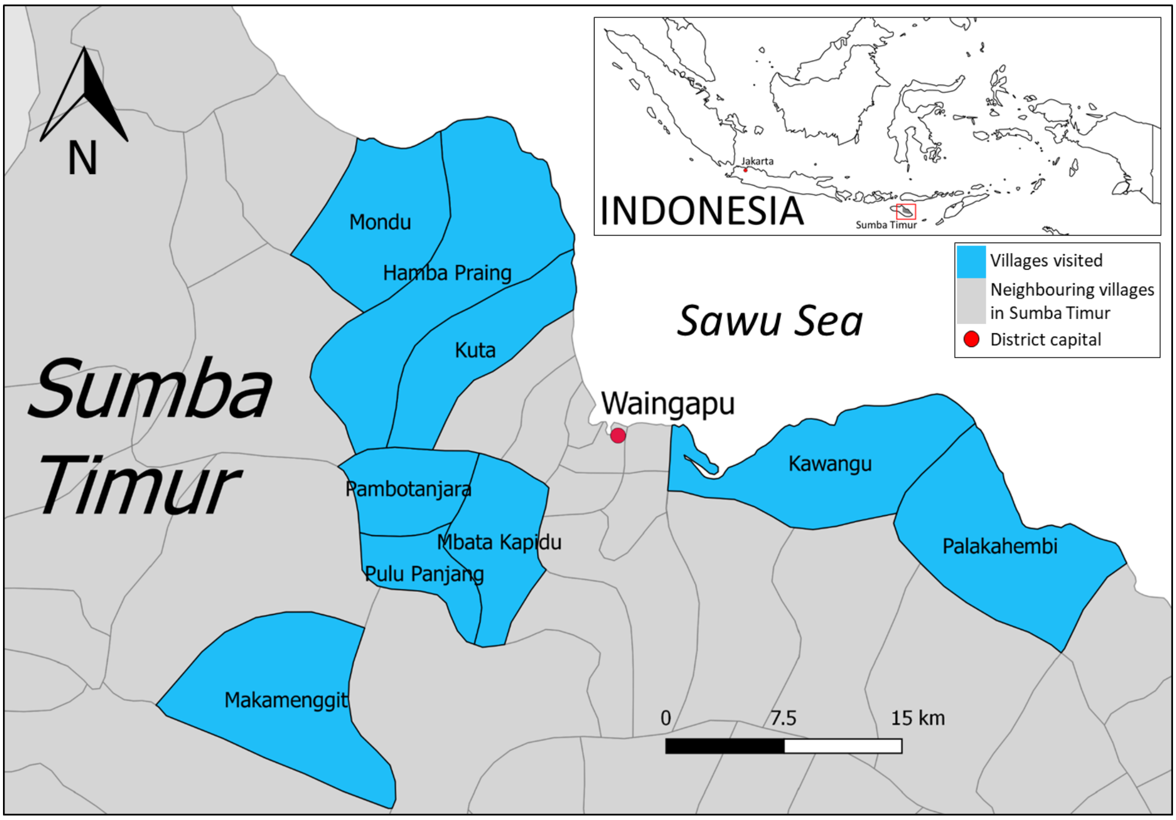


Figure 2. Location of sample communities in district Sumba Timur, Indonesia; drawn using QGIS (QGIS Development Team, 2017).

Variables of the mediation analysis

Socio-economic characteristics

Variable *Socio-economic characteristics* (*SEC*) was a combination of six socio-economic characteristics: *education level of the respondent or the mother, household head's education* *level, wealth index, WASH promotion, accessibility*, and *access to water*. These *six socio-economic characteristics* have often been used in health and demographic surveys in a country level (ICF, 2018). We assumed that these variables were a reasonable representation of respondents' SEC based on literature as described later.

Figueroa and Kincaid (2010) mentioned that *access to water, access to WASH products*, and *mother's education* are critical contextual and socio-demographic predictors of HWT use. *Accessibility* was measured by the relative difficulties (measured by time) to reach the main market, i.e., difficult or easy access. Variable *access to water* was measured by the walking time needed to collect water, i.e., go and return. Other studies further mentioned that analysing the decision making process in a household is also necessary (Nauges and Berg, 2009; Dubois et al., 2010). We used the variable *household's head education level* to represented them. We assume that the higher the level of education of a household head is, the more rational the process of decision making in the household and lead to higher the chance of the household choosing to use HWT. Both *mother* and *household head's education* were measured in years of education completed. *Wealth* represents economic ability of the family to use HWT and lack of it is often mentioned as one of the main reasons why households decide not to use HWT (Roma et al., 2014). *Wealth* was created from household assets as explained later. Households who are exposed to WASH promotion have been reported to be more likely to use HWT (Mosler et al., 2013; George et al., 2016). However, the data about WASH promotion is difficult to get from common demographic surveys. Therefore, we used *frequency of watching TV* to represent this variable and was measured by the frequency of watching TV daily.

In the mediation analysis, we combined these six variables to better measure the levels of respondents' socio-economic conditions, called *SEC*. We assumed that the variable *SEC* can measure the level of "readiness" of households to adopt HWT, i.e., better SEC will facilitate more "favourable" psychological factors and higher probability of using HWT.

RANAS psychological variables

The RANAS model has proven capable of explaining any WASH-related behaviour, for example, the use of HWT (Inauen et al., 2013; Sonego et al., 2013; Lilje and Mosler, 2017), handwashing behaviour (Seimetz et al., 2016), hygiene practice (Stocker and Mosler, 2015). Other fields outside WASH also use RANAS, e.g., the Ebola prevention behaviour (Gamma et al., 2017). We used five psychological factors of the RANAS model: *Risk*, *Attitude*, *Norm*, *Ability*, and *Self-regulation* (Mosler, 2012a). *Risk* represents one's perception and knowledge of health risks. *Attitude* expresses positive or negative opinions toward a behaviour. *Norm* represents perceived social pressure regarding the behaviour. *Ability* represents one's confidence in his or her ability to execute the behaviour. *Self-regulation* represents factors that are responsible for the continuation of the behaviour, i.e., self-management. Each RANAS factor contained sub-factors and the questions were at this sub-factor level (Table 1).

Output variable: *Use HWT*

Four variables were used to better measure the level of the use of HWT: percentage of water treated daily, frequency of drinking raw water daily, habit to perform HWT, and observed (confirmed) HWT at that moment. The first three were from respondent's answers during the interview and the latter was from observation of the enumerator after the interview ended. The output variable was called *use HWT*. By combining multiple answers, we tried to minimize the bias of self-reported behaviour, which may overestimate the practice of HWT (Schmidt and Cairncross, 2009a).

Data analysis

We removed 121 data due to missing values in some of the psychological data in the questionnaire results. Thus, in total 256 respondent's data were used for the analysis (68% of the total sample). Since all psychological variables in the questionnaire were at RANAS sub-factor level, Principal Component Analysis (PCA) was performed to create one latent variable representing a specific RANAS factor by using its first principal component. For example, there are three sub-factors related to RANAS factor *Norm* in the questionnaire: descriptive norm, injunctive norm, and personal norm. The first principal component combines those three into one variable representing factor *Norm*. Similarly, the output variable *use HWT* was created from three answers and enumerator's observation using its first principal component (see section *output variable*).

The principal component of information on household assets was also used to create the relative wealth index. We assumed that the first principal component, called *wealth*, measures the wealth index of the respondents, as suggested by Houweling et al. (2003). Finally, *wealth* was then combined with other five socio-economic characteristics (see section *socio-economic characteristics*) in another PCA to create the variable *SEC*.

In PCA of the variables above, Cronbach's α value was used to evaluate how representative the principal components are of the underlying variables. A principal component is deemed acceptable if Cronbach's $\alpha > 0.7$ (Tavakol and Dennick, 2011).

Mediation analysis hypothesizes that the independent variable is the cause of the mediator variable, which in turn causes or influences the dependent variable (Mackinnon et al., 2007).

Mediation occurs when the strength of the relationship, measured by the corresponding regression coefficient, between the independent and the dependent variable is reduced or becomes insignificant when the mediator variable is included as a predictor (Figure 1). In mediation analysis, three terms are commonly used: total effect, direct effect, and indirect effect. Total effect can be defined as: (1) the effect or influence of the independent variable (alone), as quantified by the regression coefficient, on the dependent variable *without* the presence of any other external or mediator variables; or (2) the sum of the indirect and the remaining direct effect of an independent variable on a dependent variable in a mediation analysis. Direct effect represents the effect of the independent variable on the dependent variable *in presence* of (i.e. controlling for or keeping fixed) the mediator variables. This is obtained by regressing the latter with the dependent variable and obtaining the regression coefficients as the corresponding effects. Lastly, indirect effect is the effect of the independent variable on the dependent variable through a mediator variable. Indirect effect is estimated by the difference between total effect and direct effect (Pearl, 2001; Rucker et al., 2011; Hayes, 2018). The mediation can be either "partial" (the direct effect is lower than total effect but *still* statistically significant) or "total" (the direct effect is lower than total effect but *not* statistically significant).

The principal component analysis (PCA) and other statistical analyses were performed using IBM SPSS statistics 25. The mediation analysis used IBM SPSS AMOS 24. The path analysis used bootstrapping with 2,000 resamples to estimate the bias-corrected 90% confidence interval.

Table 1. Descriptive statistics of psychological factors. M = mean, SD = standard deviation

Psychological factors		Example question	Scale	M(SD)
Risk	Vulnerability	How high do you feel is the risk that you will get diarrhea if you drink untreated water?	1-5	2.9 (1.0)
	Health knowledge (1)	What are the causes of diarrheal diseases?	1-5*	1.9 (0.9)
	Health knowledge (2)	Do you know the indication of children getting diarrhea?	1-4*	1.4 (1.2)
	Severity on life	Imagine you have diarrhea, how severe would be the impact on your daily life?	1-5	3.2 (1.1)
	Severity on a child under 5 years	Imagine your child below 5 years has diarrhea, how severe would be the impact on his life and development?	1-5	3.6 (1.2)
Attitude	Health benefit	How certain are you that always treating your water will prevent you from getting diarrhea?	1-5	3.4 (1.1)
	Like taste	How much do you like the taste of treated water?	1-5	3.9 (1.1)
	Affective belief	How much do you enjoy the moment when you treat your water?	1-5	3.9 (0.9)
Norm	Descriptive	How many of your neighbours treat their water?	1-5	3.0 (1.1)
	Injunctive	People who are important to you, how do they think you should always treat your water before consumption?	1-5	3.5 (0.8)

	Personal	How strongly do you feel an obligation to yourself to always treat your water before consumption?	1-5	3.8 (1.2)
Ability	Self-efficacy	How certain are you that you will always be able to treat your drinking water before drinking?	1-5	3.3 (1.0)
	Recovery self-efficacy	Imagine that you have stopped treating your water for several days, how confident are you that you would restart treating your drinking water again)?	1-5	3.3 (1.1)
	Maintenance self-efficacy	Imagine that you have much work to do. How confident are you that you can always treat your water?	1-5	3.3 (1.0)
Self-regulation	Action control	How much do you pay attention to the resources needed to treat the water?	1-5	3.6 (0.9)
	Remembering	Within the last 24 hours: How often did it happen that you intended to treat your water and then forgot to do so?	1-5	3.8 (1.2)
	Commitment	How important is it for you to treat the water?	1-5	3.8 (1.0)
	Coping planning	Could you tell me how do you deal with the obstacles that hinder you to treat water?	1-0*	0.5 (0.5)

*For *health knowledge*, the scale is based on the correct items mentioned by the respondents; for *coping* planning, 1 = has clear solution, 0 = no clear solution.

Results

Socio-demographic characteristics of the respondents

Most of our respondents (85%) were the mothers, and the rest were the father or available oldest person at that moment. During the household's visits, 107 households (42%, n = 256) claimed that they always drink treated water. However, we observed 168 respondents (65%) using HWT at the time of visit. Almost all of the respondents (235 respondent; 92%) mentioned boiling as the main HWT method they used. Surface water was used as a main water source by 147 respondents (58%), 85 respondents (33%) relied on a piped system, and others (9%) relied on commercial, potable water, e.g., refill water, or non-potable water, e.g., water tanker. Only 55% of the respondents answered that they need less than 5 minutes to get water per trip, while 30% of them needed more than 15 min walk to get water.

About half of the respondent (127) did not have children under the age of five. About half of the respondents (55%) attended primary school, while 11% did not have any formal education and 22% had at least high school education. Similar statistics applied to household's head education level: 58% attended primary school, followed by 20% who had at least high school education, 10% had secondary school education, and 12% had no education at all. Half of the respondents (54%) answered that they hardly ever watch TV, while 31% do it often or very often. The proportion of respondents who lived in relatively easy and difficult accessible areas were almost equal, 51% and 49%, respectively. Most of the respondents (85%) had no-concrete house wall, 93% had a permanent roof (not from straw or mud), and 66% had non-permanent floor (earth or soil).

Principal component analysis

The Principal Component of the six socio-economic characteristics obtained from PCA is called *SEC* (Table 2). The corresponding high value of Cronbach's α suggested that these variables were sufficiently related to, or "in agreement" with, each other. We then associated the variable *SEC* with the level of readiness of people to adopt HWT, meaning that higher the value of SEC is, the readiness of people to adopt HWT is also higher. The PCA applied on all RANAS psychological factors, except *Self-regulation*, also demonstrated high values of Cronbach's α. The low score of Cronbach's α corresponding to PCA of *Self-regulation* factors implies that the principal component might not be valid enough to represent the level of a household's self-regulation. The PCA on the output variable *use HWT* yielded one principal component with a high percent explained variance (62%, Table 2) and a high score of Cronbach's α.

Table 2. A summary of the principal component analysis (PCA).

Variables	KMO*	χ^2	% variance	Cronbach's α
SEC	0.722	587	45	0.703
Risk	0.744	753	60	0.805
Attitude	0.755	622	69	0.846
Norm	0.679	212	67	0.734
Ability	0.737	716	84	0.905
Self-regulation	0.663	109	44	0.535
Use HWT	0.765	449	62	0.729

*Kaiser-Meyer-Olkin value greater than 0.5 is considered acceptable for PCA.

Mediation analysis

Table 3 showed the one-to-one relationship test between all variables. All Pearson Correlation coefficients had a significant and positive relationship between all other variables. This indicates that a higher the level of one variable is associated with a higher level of the other variable. The positive correlation between all psychological variables suggested an "agreement" between them, e.g., if a households has high level of perception of risk, it is expected to have a high level of perception of other psychological variables.

Table 3. Pearson correlation between all variables.

	SEC	*Risk*	*Attitude*	*Norm*	*Ability*	*Self-regulation*	*HWT*
SEC		0.222**	0.275**	0.284**	0.144*	0.455**	0.295**
Risk	0.222**		0.498**	0.518**	0.535**	0.465**	0.471**
Attitude	0.275**	0.498**		0.599**	0.647**	0.693**	0.791**
Norm	0.284**	0.518**	0.599**		0.652**	0.650**	0.701**
Ability	0.144*	0.535**	0.647**	0.652**		0.613**	0.703**
Self-regulation	0.455**	0.465**	0.693**	0.650**	0.613**		0.712**
HWT	0.295**	0.471**	0.791**	0.701**	0.703**	0.712**	

** $p \leq 0.01$; * $p \leq 0.05$

Figure 3 reveals that *SEC* had a significant and positive relationship with all psychological variables (see also Table 4 no 1-5). This implies that *SEC* can be used to explain the level of psychological variables. We found that better *SEC*, i.e., higher readiness level, results in more favourable psychology of households with regards to using HWT. Moreover, compared to other psychological variables, *Self-regulation* had the strongest correlation with *SEC* (β =0.455; $p \leq$ 0.001). This implies that those households that have favourable socio-economic conditions display higher levels of self-regulation. This is further reinforced by the correlation tests between *SEC* and all four sub-factors of self-regulation (see Table 1 for the sub-factors), which show significant ($p \leq 0.05$) and positive correlations.

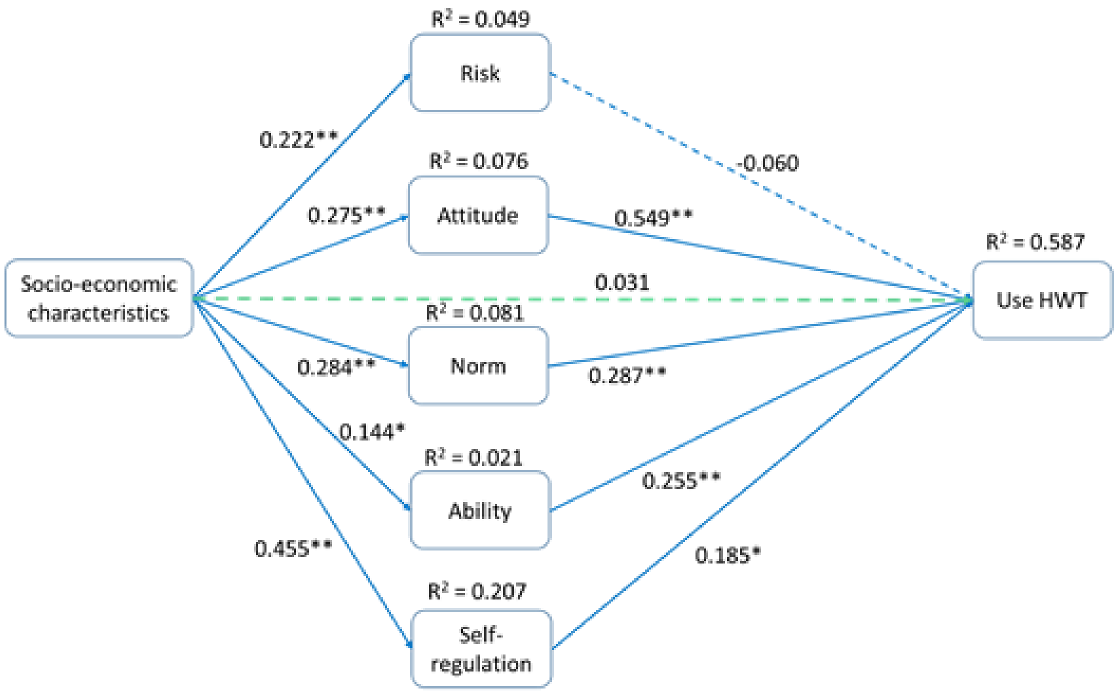


Figure 3. The summary of the mediation analysis; scheme following the RANAS concept. Dashed line indicated insignificant association and solid line indicated the significant association. **significant at the 0.01 level; *significant at the 0.05 level. R^2 is the variance explained by the predictor(s).

Table 4. Maximum likelihood estimates for the assumed underlying pathways.

No	Independent variables	Dependent variable	B	S.E	β	LB	UB	R^2
1	*SEC*	*Risk*	0.208	0.055	0.222**	0.122	0.308	0.049
2	*SEC*	*Attitude*	0.263	0.050	0.275**	0.189	0.349	0.076
3	*SEC*	*Norm*	0.278	0.051	0.284**	0.199	0.361	0.081
4	*SEC*	*Ability*	0.128	0.053	0.144*	0.048	0.239	0.021
5	*SEC*	*Self-regulation*	0.462	0.051	0.455**	0.378	0.527	0.207
6	*SEC*	*Use HWT*	0.023	0.037	0.031	-0.051	0.113	0.587
	Risk		-0.048	0.038	-0.060	-0.138	0.020	
	Attitude		0.426	0.048	0.549**	0.445	0.640	
	Norm		0.218	0.044	0.287**	0.194	0.385	
	Ability		0.213	0.066	0.255**	0.133	0.401	
	Self-regulation		0.135	0.049	0.185**	0.076	0.303	

B = Unstandardized coefficient, β = Standardized coefficient, S.E = bootstrap error, LL = lower bound for, CB = Upper bound for, both for β, 90% Confidence Interval, Bias-corrected bootstrap for CI (bootstrap 2000), *$p \leq 0.05$, **$p \leq 0.001$.

Table 5. Total, direct, total indirect, and specific indirect effects of *Socio-economic characteristics* (*SEC*) on *use HWT*.

No.	Predictor	B	S.E	β	LB	UB
1	*SEC* → *use HWT* (total effect)	0.275	0.051	0.371***	0.261	0.465
2	*SEC* → *use HWT* (direct effect)	0.023	0.037	0.031	-0.051	0.113
3	*SEC* → *use HWT* (total indirect effect)	0.252	0.042	0.340***	0.259	0.429
4	*SEC* → *Risk* → *Use HWT*	-0.010	0.009	0.013	-0.027	0.002
5	*SEC* → *Attitude* → *use HWT*	0.112	0.025	0.151***	0.075	0.155
6	*SEC* → *Norm* → *use HWT*	0.060	0.017	0.082***	0.037	0.092
7	*SEC* → *Ability* → *use HWT*	0.027	0.014	0.037**	0.011	0.059
8	*SEC* → *Self-regulation* → *use HWT*	0.062	0.024	0.084**	0.025	0.105

Significance: *** $p \leq 0.001$; ** $p \leq 0.01$. LB and UB for B (Unstandardized coefficient). "Total indirect effect" is the sum of indirect effects of all five pathways from *SEC* to *use HWT* via *Risk, Attitude, Norm, Ability, and Self-regulation*. The variables *use HWT, Risk, Attitude, Norm, Ability, and Self-regulation* are variables in reduced form based on Principal Component Analysis of a larger set of outcome and psychological variables. See section *Data analysis*.

The mediation analysis revealed that the direct effect of *SEC* on the use of HWT was not significant (p value > 0.05, Table 5 no. 2), but the total indirect effect was significant ($\beta = 0.340$, Table 5 no. 3). This shows that psychological variables mediate the relationship between *SEC* and *use HWT*. As indicated by the largest β value when comparing the five pathways (Table 5, no. 4-8), *Attitude* was the most significant pathway in our assessment ($\beta = 0.151$, Table 5 no. 5). We also noticed that the pathway through *Risk* is not significant, which is indicated by the negative β value.

Discussion

We demonstrated that the influence of a household's socio-economic characteristics on the use of HWT is mediated by psychosocial variables. The mediation analysis showed that indirect influence was significant while direct influence was insignificant. Therefore, a "causal" relationship pathway of socio-economic characteristics influencing water use behaviour via psychosocial charac- teristics can be used to interpret the use of HWT. Other studies outside WASH domain have also found similar results, such as in context of smoking behaviour (Gecková et al., 2005; Martinez et al., 2018) and adolescents' behaviour (Rodriguez et al., 2014).

The findings suggest a possible mechanism of how people's characteristics may influence the behaviour: household's socio-economic conditions shape their psychology first, which in turn influences the process of HWT adoption. The results also confirm our hypothesis that favorable socio-economic conditions of households, e.g., higher education, wealthier, or easier accessibility, positively influences the psychology of HWT adoption.

Moreover, the direct effect of *SEC* on the use of HWT, which became insignificant when regressed with *use HWT* in the presence of psychological factors, suggests that the socio-economic characteristics should not be measured at the "same level" as psychological factors. This has also been emphasized in some psychological frameworks, such as a model of communication for water treatment and safe storage behaviour (Figueroa and Kincaid, 2010) and health belief model (Rainey and Harding, 2005). Socio-economic characteristics should be considered as predictors of psychological factors in future studies, e.g., by using a two level regression analysis or two layers in hierarchical Bayesian Belief Networks.

Comparing five pathways from *SEC* to *use HWT*, the pathway through *Attitude* is the most significant ($\beta = 0.151$, Table 5 no. 5). A previous mediation analysis also found that attitude positively influence the water consumption behaviour (Schlegelmilch et al., 2016). It means that, in our case, emphasizing the benefits and positive experiences of using HWT by HWT users to non-user is necessary to influence the sustainable use of HWT. Examples include informing the target group that water quality has improved after treatment (water quality testing before-after HWT) and explaining using HWT has long term benefits (Lucas et al., 2011).

The Cronbach's α of all principal components were between 0.7 – 0.9 and considered "acceptable" for a PCA (Tavakol and Dennick, 2011). It means that variables on which PCA was performed were well correlated and that the extracted principal components were reliable representatives of the variables. Low Cronbach's α for the sub-factors of *Self-regulation* means that the principal component of the sub-factors was not a reliable and a consistent representative of a household's "self-regulation". Lilje and Mosler (2018) reasoned that *Self-regulation* is indeed difficult to measure among the respondents who have no experience with HWT, i.e., in our case, only 42% claimed to be a HWT user. This may explain the low Cronbach's α for *Self-regulation*.

Variable *SEC* explains very well *Self-regulation* compared to other psychological variables. Since the results of PCA for *Self-regulation* is not "trustworthy", we estimated the correlations between each of the four sub-factors of *Self-regulation* and *SEC*, and found all to be significant ($p \leq 0.05$) and positive correlation. Since *Self-regulation* is a factor that drives sustainable use of HWT, it seems that the six socio-economic characteristics that we used are necessary facilitators of consistent use of household water treatment. For example, economic ability and easily accessible location could facilitate *coping planning* and *action control*, while education and promotion could facilitate *remembering* and *commitment*.

In contrast, principal component *use HWT* had a high Cronbach's α and explained variance. This implies that combining self-reported and observed answers to whether a household uses HWT is a better approximation of the true behaviour than considering only one of the answers. In our case, we used three questions and one observation, inquiring about the same behaviour of using HWT. A respondent might give an answer to a question which might not represent their true situation, e.g., self-reported behaviour overestimates the actual behaviour (Schmidt and Cairncross, 2009a). That could either be because they do not understand the question, e.g. the questions may be too technical for uneducated people, or that they give a dishonest answer due to some ulterior motives, e.g., in lieu of a gift. Our result suggests that combining multiple answers could overcome this issue and provide a better assessment of the behaviour.

There are some limitations that need special attention. First, variable *SEC* explains only a small variance of psychological factors besides *Self-regulation* (see R^2 in Table 4 no 1 - 5). This suggests that either other socio-economic characteristics better explain households psychology or household's socio-economic characteristics are not enough to predict the complexity of pyscho-social characteristics (Lilje and Mosler, 2017). Another limitation is that we assumed causal relationships based on the correlation results, which is highly debatable (Bollen and Pearl, 2013; Zhang and Zhang, 2017; Contzen and Marks, 2018). Third, since the sub-district selection was based on discussions with the local partner, there is a potential for subjective bias. However, we tried to minimize this by doing a random sampling at the household level. Finally, the deletion of one-third of the total households from analysis due to missing values has some consequences: (a) The results do not fully represent the population in that area; (b) Even though the final sample size of 256 used for the analysis was lower than the one recommended by (Krejcie and Morgan, 1970), it still met the recommendation of (Wilson Van Voorhis and Morgan, 2007); (c) the socio-economic characteristics difference of the remained and deleted samples is marginally significant (Mann-Whitney U-test, U = 12920, p=0.06).

Conclusion

This study provides insights into the relationship between socio-economic characteristics, psychological factors, and one of the WASH behaviours: the use of water treatment at household level. The influence of household's characteristics on the use of HWT appears to be mediated by household psychology as represented by the psychological characteristics ($B = 0.252$; $p < 0.001$). This apparent causal mechanism to explain the use of HWT can be used in future studies, e.g., designing behavioural change campaigns. The results suggest that interventions that address critical psychological factors, such as *Attitude* in our case, are necessary since the latter strongly influence the use of HWT. We also confirmed that better socio-economic conditions of the household could facilitate higher adoption of HWT. Our PCA results suggest that multiple information sources (questions) should be combined to capture the true state of psychological factors and also HWT behaviour. Combining interview's answer with observations is also recommended to reduce the risk of getting imprecise information about the behaviour in the data collection process in the field.

Chapter 4

Analysis of the household water treatment adoption using Bayesian belief networks: A study case of rural Nepal

- Village mapping before household visit in rural Nepal -

This chapter is based on:

Daniel, D., Diener, A., Pande, S., Jansen, S., Marks, S., Meierhofer, R., Bhatta, M., & Rietveld, L. (2019). Understanding the effect of socio-economic characteristics and psychosocial factors on household water treatment practices in rural Nepal using Bayesian Belief Networks. *International Journal of Hygiene and Environmental Health*, *222*(5), 847–855. https://doi.org/10.1016/j.ijheh.2019.04.005

Abstract

About 20 Million (73%) people in Nepal still do not have access to safely managed drinking water service and 22 million (79%) do not treat their drinking water before consumption. Few studies have addressed the combination of socio-economic characteristics and psychological factors that explain such behaviour in a probabilistic manner. In this chapter, we present a novel approach to assess the usage of household water treatment (HWT), using data from 451 households in mid and far-western rural Nepal. We developed a Bayesian belief network model that integrates socio-economic characteristics and five psychological factors. The socio-economic characteristics of households include presence of young children, having been exposed to HWT promotion in the past, level of education, type of water source used, access to technology and wealth level. The five psychological factors capture households' perceptions of incidence and severity of water-borne infections, attitudes towards the impact of poor water quality on health, water treatment norms and the knowledge level for performing HWT. We found that the adoption of technology was influenced by the psychological factors norms, followed by the knowledge level for operating the technology. Education, wealth level, and being exposed to the promotion of HWT were the most influential socio-economic characteristics. Moreover, households who were connected to a piped water scheme have a higher probability of HWT adoption compared to other types of water sources. The scenario analysis revealed that interventions that only target single socio-economic characteristic do not effectively increase the probability of HWT practice. However, interventions addressing several socio-economic characteristics increase the probability of HWT adoption among the target groups.

Keywords: Bayesian belief networks, Household water treatment, behavioural modelling

Introduction

Access to potable water is still a global challenge (WHO & UNICEF, 2017b). About 2.1 billion people, mostly in low and middle income countries (LMICs), are still without "improved drinking water source that is located on premises, available when needed, and free from faecal and priority chemical contamination" (WHO & UNICEF, 2017a). These unsafe conditions cause a high number of water-related diseases that have contributed to 9.1% of the global disease burden and have been responsible for the deaths of 1.3 million people in 2015. Most of whom are children below the age of 5 and located in LMICs (Collaborators, 2017).

Household water treatment (HWT), which treats water at the point of use, is one possible means to tackle the challenge of non-potable water at household level (WHO, 2009). Examples of HWT are boiling, solar disinfection, and ceramic filtration. However, studies have shown that households do not regularly use HWT (Brown and Clasen, 2012). This reduces its potential health benefits (Hunter et al., 2009).

Psychological concepts or frameworks have been used to understand why people use or do not use HWT, for example Risk – Attitude – Norm – Ability – Self-regulation (RANAS) model (Mosler, 2012), the health belief model (Rainey and Harding, 2005), or Integrated Behavioural Model for WASH (IBM-WASH) (Dreibelbis et al., 2013). In this chapter, we used the RANAS to model this behaviour due to its high capability of explaining WASH-related behaviour and the convenience to adapt the RANAS structure to a simple causal structure. RANAS, as also revealed by other behavioural studies, argues that the socio-economic characteristics of people (called contextual factors in RANAS) influence behaviour in two ways: directly (Ball et al., 2009; Businelle et al., 2010; Contzen & Mosler, 2015) and indirectly through the behavioural determinants (i.e., psychological factors) (Gecková et al., 2005; Martinez et al., 2018; Rodriguez et al., 2014).

Previous studies have included socio-economic characteristics and psychological factors in their analysis of explaining the use of HWT. A study in Sri Lanka, e.g., showed that socio-economic factors, such as education, WASH promotion, and type of water source drove the households' perception of risk, and higher perception of risk led to a higher likelihood of households treating water (Nauges and Berg, 2009). However, they only used one psychological factor: perceived risk; though we know there are other psychological factors that also play a role in shaping human behaviour, such as *norm* or *ability*. Recent RANAS studies have further analysed the combination of socio-economic and psychological factors, using hierarchical regression analysis to predict handwashing behaviour (Seimetz et al., 2016) and the cleaning of water storage containers (Stocker and Mosler, 2015).

However, in spite of the clear need for a systems-level approach that considers the influence of socio-economic characteristics on adoption of HWT via psychological factors, this perspective has often been ignored and remains to be explored (Dreibelbis et al., 2013; Daniel et al., 2018). Therefore, the motivation of this study is to analyse the interactions between socio-economic and psychological factors, to visualize these interactions in a conceptually causal manner, and accordingly, to model them in order to quantitatively predict the adoption of HWT.

Bayesian belief networks (BBN) can model the interaction between variables that are causally linked (or theorized to be so) in a probabilistic manner. A BBN contains a directed acyclic graph (DAG), showing the dependencies between variables (called "nodes" in BBN) based on conditional probability tables (CPTs). CPTs represent the strength of relationships between the parent nodes (i.e., where the arrow originates or *the cause*) and child node (i.e., where the arrow ends or *the effect*) (Pearl, 1988). For example, a Bayesian network could represent the probabilistic relationships between diseases, such as diarrhea or common flu, and a symptom, such as vomiting. Given data, the network can be used to impute the probabilities of the vomiting caused by diarrhea and flu independently, which are then documented in the CPT corresponding to the node of vomiting.

BBN offers advantages over other methods, such as regression analysis or agent-based modelling, for example, by 1) visualising a causal interpretation of a complex system, 2) stimulating stakeholder participation, 3) integrating expert judgement to tackle uncertainties and unknown data, 4) integrating quantitative and qualitative information, and 5) performing both predictive and diagnostic inference (Cain, 2001; Barton et al., 2012). Despite its many advantages, very few studies related to WASH have used BBN models. Examples of WASH studies that use BBN are the studies of hand pump functionality in Africa (Fisher et al., 2015; Cronk and Bartram, 2017). Two reviews of BBN applications in water science and management also indicate that BBN is still not widely used in understanding WASH-related behaviour (e.g., HWT or handwashing) (Landuyt et al., 2013; Phan et al., 2016).

We present a WASH related cross-sectional survey of rural communities in the mid and far-western regions of Nepal. We analysed the interactions between socio-economic characteristics and psychological factors and the impact of these interactions on the adoption of HWT through the lens of the simplified RANAS model. BBN was used to estimate the probability of HWT adoption, while considering the combinations of socio-economic and psychological variables.

Methods

Study setting and data source

A cross-sectional study was conducted in October 2014. 512 households were surveyed within five Village Development Committees (VDCs), which are the smallest administrative unit in Nepal. The five VDCs were located in different districts in two provinces: (1) Province Karnali Pradesh: Jarbuta VDC in Surkhet district, Nepa VDC in Dailekh district, and Sima VDC in

Jajarkot district; and (2) Province Sudurpashchim Pradesh: Birpath VDC in Achham district and Pahalmanpur VDC in Kailali district (Figure 1).

Figure 1. Location of the study area in mid and far-western Nepal, drawn using ArcGIS (ESRI, 2011).

Helvetas Swiss Intercooperation, a non-profit organization based in Switzerland, initiated this research collaboration to rigorously investigate WASH practices within its service area in the five districts described above. For the study of WASH practices, data collection involved semi-structured face-to-face household interviews. The questionnaires were translated into Nepali, back-translated into English, and reviewed for accuracy. A pilot test was conducted before the field research. Informed consent was obtained from all participants prior to the interview. This baseline study was part of a WASH project led by Helvetas Swiss Intercooperation which was approved by Department of Water supply and Sewerage Nepal.

Study households were randomly selected for enrolment in a two-step randomization process: first, within each VDC, wards (sub-level of VDC) were randomly selected after a participatory social mapping of the VDC with community members based on the population of the wards. Second, households were randomly selected within the selected wards through a transect-walk and enrolment of every two or three houses. The target participants were women who are the primary caregivers in the households. The questionnaire covers household information, information on water access, WASH knowledge (questions on sanitation and hygiene specifically), perception, water related behaviour, health status, and market information. A five-item *Likert scale* was used to measure each behavioural determinant factor (Table 1). Socio-economic characteristics were measured on a nominal scale (Table S3 in (Daniel et al., 2019)). The respondent's answer to this question was used as the outcome variable: "'Do you use any method to treat your drinking water?".

A conceptual model of HWT adoption

RANAS psychological factors

The RANAS model consists of five psychological factors: *risk*, *attitude*, *norm*, *ability*, and *self-regulation* (Figure 2) as described in Mosler (2012). *Risk* factors indicate an individual's understanding and perception of health risk. *Attitude* factors represent a person's belief towards the behaviour, such as positive or negative opinions about the costs and benefits. *Norm* factors represent which behaviours are perceived to be normal and abnormal. *Ability* factors relate to an individual's perception in his or her ability to execute the behaviour. Finally, *self-regulation* represents factors that are responsible for the continuation and maintenance of certain behaviour, such as commitment.

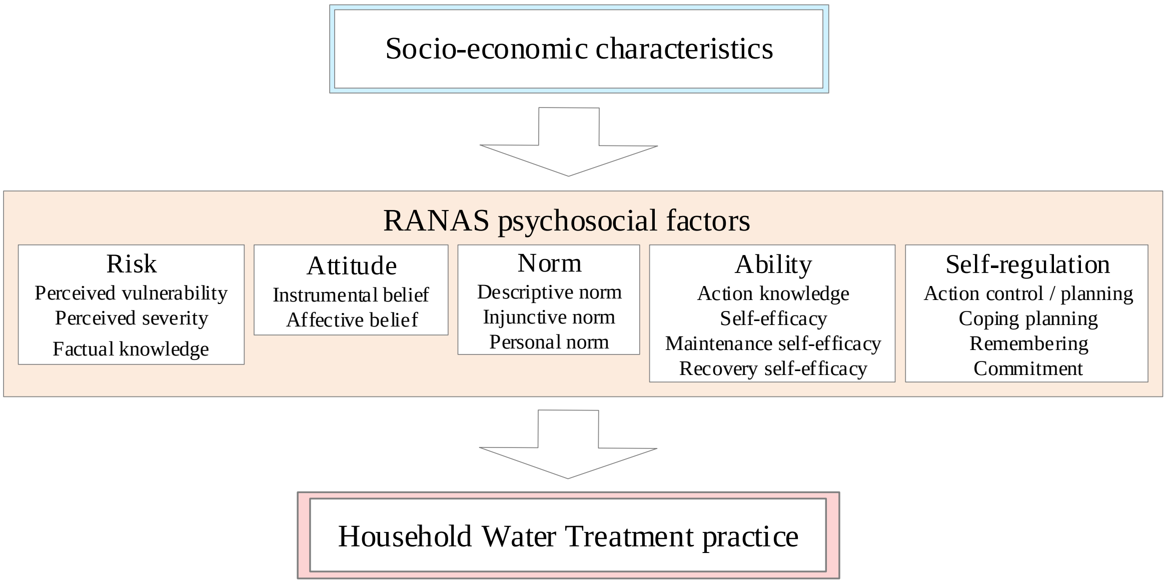


Figure 2. Conceptual model adapted from Risk – Attitude – Norm – Ability – Self-regulation (RANAS) model (Mosler, 2012) for constructing the BBN structure.

Since RANAS requests the information at the sub-factor level of psychological factors (Figure 2), Principal Component Analysis (PCA) on the sub-factors was performed to simplify the BBN structure. The first principle component, where possible, was used to represent each RANAS factor. The data were analysed in IBM SPSS 23. PCA was conducted only on the two psychological factors: *risk* and *norm*. The PCA on factor *risk* yielded two dominant components: Component 1, named *perceived severity*, was mostly influenced by variables *perceived severity on life* and *perceived severity on a child under five years*, and Component 2, named *perceived infection probability*, was mostly influenced by *perceived vulnerability* and *health knowledge*. The PCA on the sub-factors *norm* yielded one dominant component. The component scores were then divided into three levels based on the score: one-third of the lowest score as "low", the next one-third as "moderate", and the rest as "high". The "new" psychological factors obtained from PCA were then used in the BBN analysis.

We lost information on the sub-factors of *attitude, ability* and *self-regulation* due to coding error. Therefore PCA was not be conducted on these variables. The psychological factor *attitude* was represented by its sub-factor "beliefs about health benefits" and the factor *ability* was represented by the sub-factor "how-to-perform knowledge" (action knowledge). We scaled these factors into the three categories: "low", "moderate" and "high", in order to keep the CPTs of the BBN model parsimonious and understandable. We had to further simplify the model by removing the RANAS factor *self-regulation* from the analysis because only about 30% of the total cases had answered to the corresponding question. Such simplification does not undermine the conclusion that are drawn later. That is because self-regulation is hard to measure in households who do not perform the behaviour, i.e., we had only 22% respondents who practiced HWT (Lilje and Mosler, 2018).

Socio-economic characteristics

Eight socio-economic characteristics were identified from literature that may influence the psychological factors: 1) *level of education* (Fotue Totouomet et al. 2012, Nauges & Berg, 2009), 2) *WASH* (i.e., water, sanitation, and hygiene in general) or 3) HWT (i.e., HWT knowledge and practice specifically) *promotion activities* (George et al., 2016; Mosler et al., 2013), 4) *type of water source* (Casanova at al., 2012; DuBois et al., 2010), 5) *Wealth level* (Luby et al., 2004; Opryszko et al., 2010), 6) *logistic access* (DuBois et al., 2010; Goldman et al., 2001), 7) *presence of sick children* and 8) *presence of children under the age of 5* (Christen et al., 2011; Freeman et al., 2012).

We performed PCA to create *relative wealth level* using information on household assets. The first component of PCA was assumed to measure the wealth level of the respondents (Houweling et al., 2003). The respondents were then divided into three groups: poor (40%), middle income (40%), and rich (20%); according to their scores (Vyas and Kumaranayake, 2006).

For the analysis, we removed 61 data cases that did not contain information on the current practice of treating water. Thus, a total of 451 cases from 512 households were analysed. The answer "do not know" was coded as an empty value to simplify the categories in the analysis. Furthermore, we categorized the study locations in our study into *easy logistic access* (Surkhet and Kailali) and *difficult logistic access* (Accham, Jajarkot, and Dailekh).

Performing the BBN model

Four aspects were considered when building the BBN structure: statistical relationship between the socio-economic factors and psychological factors, the complexity of the model (i.e., number of variables and categories/states), conformity of inferred relationships with what are reported in literature, and model performance (Bae & Chang, 2012; Cain, 2001; Chen & Pollino, 2010; Marcot et al., 2006).

The one-to-one relationships (nonparametric Chi-square) tests between each households' socio-economic characteristics and 'principal' psychological factors were performed to assess potential causal relationships between them. However, connecting all significantly associated variables may result in a more complex model, in which case even a statistically significant relationship may not represent a true causal relationship. Therefore, more nodes should only be added and connected thereby increasing the sizes of CPTs, when it result in a significant improvements in the BBN model performance (Marcot et al., 2006). Thus, in this study, we considered the model performance (i.e., the comparison of the results of validation test) as the main consideration. In order to simplify the BBN structure, we only considered the indirect pathways of socio-economic characteristics influencing the adoption of HWT via psychological factors, using an assumption that socio-economic factors rarely influence behaviour directly.

We used the *Genie 2.2* (www.bayesfusion.com) software package to implement the BBN analysis. The expectation maximization (EM) algorithm within the software was used to estimate and populate the CPTs (i.e. calibrated) in a BBN based on the collected survey data set (Druzdzel and Sowinski, 1995). This algorithm is considered to be effective, especially when data sets are incomplete (Do and Batzoglou, 2008).

The ten-fold cross-validation was used, using the same software, to judge how robust calibrated CPTs are, by first calibrating them on a subset of data and using the calibrated model in prediction mode on the remaining data (not used in model calibration) to judge model's performance. In our case, 90% of the dataset was randomly selected to impute the CPT and the remaining 10% was then used to 'validate' the performance of the calibrated model. Since the calibration and validation subsets were randomly selected, the process was repeated 10 times and the average of validation performances was taken as the cross ten-fold cross validation score. Another performance that was considered was Receiver Operating Characteristics (ROC). The ROC graph plots the 'sensitivity' on the *Y* axis and *false positive* on the *X* axis. The value of the area under the ROC curve (AUC – Areas Under Curve) is used to assess model performance. The closer the AUC value is to 1, the better is its performance (higher sensitivity and lower false positives) (Greiner et al., 2000).

Parameter sensitivity analysis of the input node was performed to identify the nodes that most influence the output node. We utilized the algorithm within the Genie software which calculates the effect of small changes in the CPT of each node on the output node.

Finally, we simulated the interventions (scenario analysis) by exploiting the predictive strength of BBN, i.e., Bayesian inference. Updating the beliefs of socio-economic nodes (outer layer) updates, first, the likelihood values of psychological nodes (intermediate layer), and thereafter the outcome node. For example, updating *HWT promotion* to 100% "yes", increased the probability of four psychological nodes being "high" that were connected to it: *severity*, *infection probability*, *attitude*, and *ability*, then increased the probability of using HWT from 18% to 20%.

Results

Descriptive analysis of the study area

The questionnaire results show that only 22% of all the respondents treated their water. About 57% of the respondents obtained water from piped community taps and 27% from a tube well. About half of the respondents (51%) had at least one child below the age of 5. Only 10 cases of a household having a family member experiencing diarrhea in the last two days were reported during the survey. Forty-five percent of the respondents reported having no education. Means and standard deviations of the psychological sub-factors are provided in Table 1.

Table 1. Descriptive statistics of behavioural determinant factors, i.e. psychological factors. M = mean, SD = standard deviation

Determinant factors		Example questions	Scales	M(SD)
Risk	Vulnerability	How high do you feel is the risk that you will get diarrhea if you drink untreated water?	1-5	2.51 (1.07)
	Health knowledge	What are the causes of diarrheal diseases?	1-5*	1.32 (0.77)
	Severity on life	Imagine you have diarrhea, how severe would be the impact on your daily life?	1-5	4.16 (0.63)
	Severity on a child under 5 years	Imagine your child below 5 years has diarrhea, how severe would be the impact on his life and development?	1-5	4.15 (0.54)
Attitude	Health benefit	How certain are you that always treating your water will prevent you from getting diarrhea?	1-5	2.98 (0.93)
Norm	Descriptive	How many of your neighbours treat their water?	1-5	1.44 (0.83)

	Injunctive	People who are important to you, how do they think you should always treat your water before consumption?	1-5	2.44 (1.07)
	Personal	How strongly do you feel an obligation to yourself to always treat your water before consumption?	1-5	3.03 (0.97)
Ability	Action knowledge	Can you explain to me the procedures of the different methods for water treatment?	1-5*	2.13 (1.22)

*For *health knowledge*, the scale is based on the correct causes mentioned by the respondents; and for *action knowledge*, the scale is based on the correct HWT procedures explained by the respondent. See table S4 for more information.

Bayesian belief network structure and model

Lay-out of the BBN model

Figure 3 showed the final structure that had the best model performance, while it kept the number of links between the socio-economic characteristics and psychological factors to a minimum. The BBN model predicted a use of HWT of 18% considering information in all nodes, which was slightly different from the real percentage of HWT use (22%). We did not include variable *diarrhea cases* in the model because it did not have a statistically significant relationship with any of the psychological factors and the proportion of diarrhea cases was only 2.4% in the dataset. Furthermore, we included HWT promotion rather than WASH promotion in the model since it had a more statistically significant relationship, i.e. the Chi-square test, with other psychological factors.

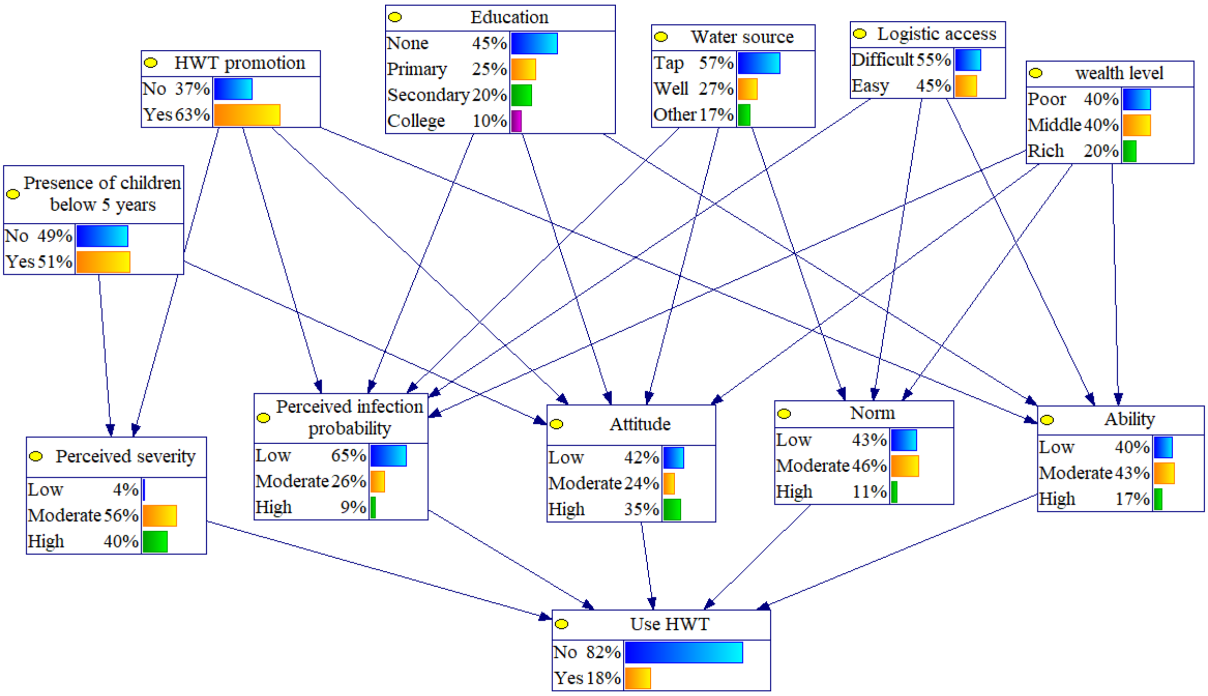


Figure 3. The compiled BBN model of household water treatment adoption in rural Nepal. The bars in each node show the probability that a node is in a certain state.

Validation test

The overall model accuracy to predict the output was 83.65% (STD = 0.35%). Its success in predicting the output "no" (true negative or 'specificity'), which means that a household did not treat its drinking water, was 93.33% (STD = 0.43%) and predicting the output "yes" (true positive or 'sensitivity') was 49.19% (STD = 1.51%). Moreover, the area under the ROC curve (AUC) was 0.85 (STD = 0.005). The closer the AUC value is to 1, the better is its performance (higher sensitivity and lower false positives). The result suggests that the model performance was *good* in predicting the output (Greiner et al., 2000), i.e., it could distinguish between the *adopters* and *non-adopters* of HWT sufficiently well.

Parameter sensitivity analysis

Figure 4 shows the maximum values of the derivatives of posterior probability distributions of the output node, taken in relation to the entries of the CPT of a node. For example, node *education* had a corresponding value of seven percent, which means that there was one entry in the prior probability table of education, which when perturbed by one percent of its current value caused a maximum seven percent change in the probability of HWT adoption. Changing other entries in that node gave derivative values lower than 0.07.

The sensitivity analysis shows that among socio-economic characteristics, *education* was the most sensitive node, followed by *wealth level*, and *received HWT promotion* in the past. The nodes *severity* and *norm* were the most sensitive nodes among psychological factors. However, from the sensitivity analysis, we considered that there were no single highly sensitive socio-economic or psychological nodes that highly affect the output node.

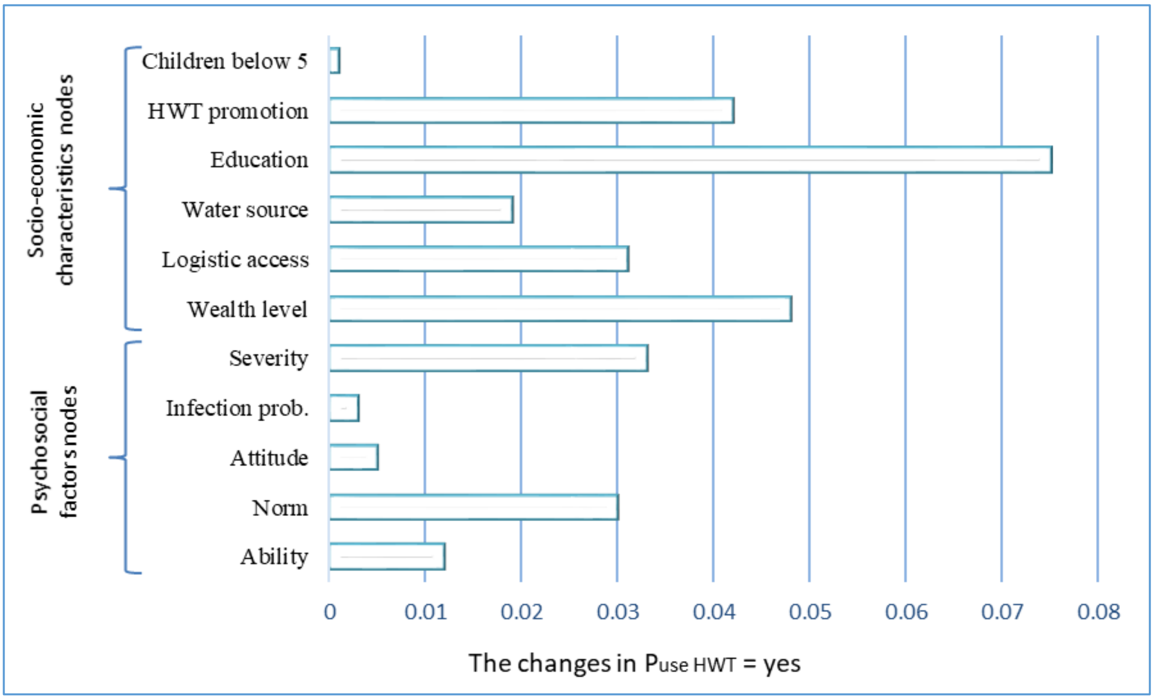


Figure 4. Sensitivity analysis of individual nodes on the output node.

Effect of updating single node on the output node

The effect of updating the belief (i.e., changing the value of input nodes) of a single node on the output node is presented in Table 2. For example, setting the type of water source to 100% = "Tap" to 100%, updates the probability of using HWT to 19% (from 18% in the baseline). No single factor, socio-economic or psychological, on its own increased the probability of HWT adoption to at least 50% (Updated $P_{use\ HWT}$ = yes; Table 2). Among the socio-economic characteristics, *education* was the most influential node, followed by *wealth level* and whether the respondents *received HWT promotion* or not, while the *presence of children under 5 years* did not change the likelihood of HWT adoption (see the change $\Delta P_{use\ HWT}$ = yes in Table 2). Another observation is that easily accessible areas such as Kailali, had a higher probability of using HWT.

Norm and *ability* were the most influential psychological factors in influencing the likelihood of using HWT. Moreover, the more households *perceived severity* and *infection probability*, the higher was their probability to use HWT. Additionally, the psychological factors realizing the *health benefits of doing HWT*, *social pressure*, and *know how-to-perform HWT* all significantly influenced the adoption of HWT.

Table 2. Changes in posterior probability of positive outcome (using HWT) by individual nodes.

Nodes	Updated P $_{\text{use HWT}}$ = yes (%) [a]	$\Delta P_{(HWT=yes)}$ (%) [b]
Socio-economic characteristics		
Type of water source	Tap 19 Tube well 17 Other 16	3
Presence of children under 5 years	No 18 Yes 18	0
Receive HWT promotion	No 15 Yes 20	5
Education	None 15 Primary 19 Secondary 20 Higher 24	9
Logistic access	Easy 20 Difficult 16	4
Wealth level	Poor 19 Middle 16 Rich 21	7
Psychological factors		
Perceived severity	Low 8 Moderate 20 High 16	12
Perceived infection probability	Low 17 Moderate 19 High 22	5
Attitude (certainty about health impact)	Low 11 Moderate 23 High 23	12
Norm	Low 10 Moderate 23 High 31	21
Ability (action knowledge)	Low 9 Moderate 22 High 29	20

[a] The value under each category is the updated probability of the output node given the belief of that node. The baseline probability was 18% (Figure 3). [b] ΔP is the difference between the lowest and highest value of the updated probability of HWT adoption being “yes” in %.

Scenarios analysis to increase the probability of HWT adoption

Bayesian inference was used not only to simulate potential interventions but also to understand how the system works, for example in the case of updating node *education*. Bayesian inference shows that the more educated the person is, the higher level of *ability* and *attitude* obtained. However, the analysis showed that *education level* had an inverse effect on *perceived infection* probability, with more education resulting in a lower level of *perceived infection*. Nevertheless, *education* still had an overall positive effect on HWT adoption (Table 2).

Because HWT adoption can mainly indirectly be influenced by socio-economic characteristics, we investigated combinations of socio-economic characteristics that gave the highest probability of HWT adoption. Furthermore, since *HWT promotion* alone could only increase the HWT adoption by five percent, compared to situation without promotion activities (Table 2), combinations with other socio-economic factors were tested (Table 3).

Table 3 showed how different categories in socio-economic characteristics nodes yielded different probabilities of HWT use. Table 3 also showed that, when promotion activities were done in areas with more educated households, the probability of adoption was higher than in areas with lower education (number 1-2). In addition, households who have a piped connection have a higher chance of HWT adoption compared to households that use other types of water sources (number 3-4). Further, even if a household is located in easily accessible parts of rural Nepal, a higher rate of HWT adoption was only possible when such households were able to afford HWT technology and had received promotion activities (numbers 9-10).

Finally, we found that households with a toddler, consisting of educated and relatively wealthy persons, who were aware of and have easy access to HWT products, and with piped water connections are most likely to adopt HWT, with 57% likelihood compared to 18% in the baseline, (Table 3, number 15). Figure 5 illustrates this causal interpretation and how the value in the all psychological nodes being *high* increased compared to the baseline (Figure 3).

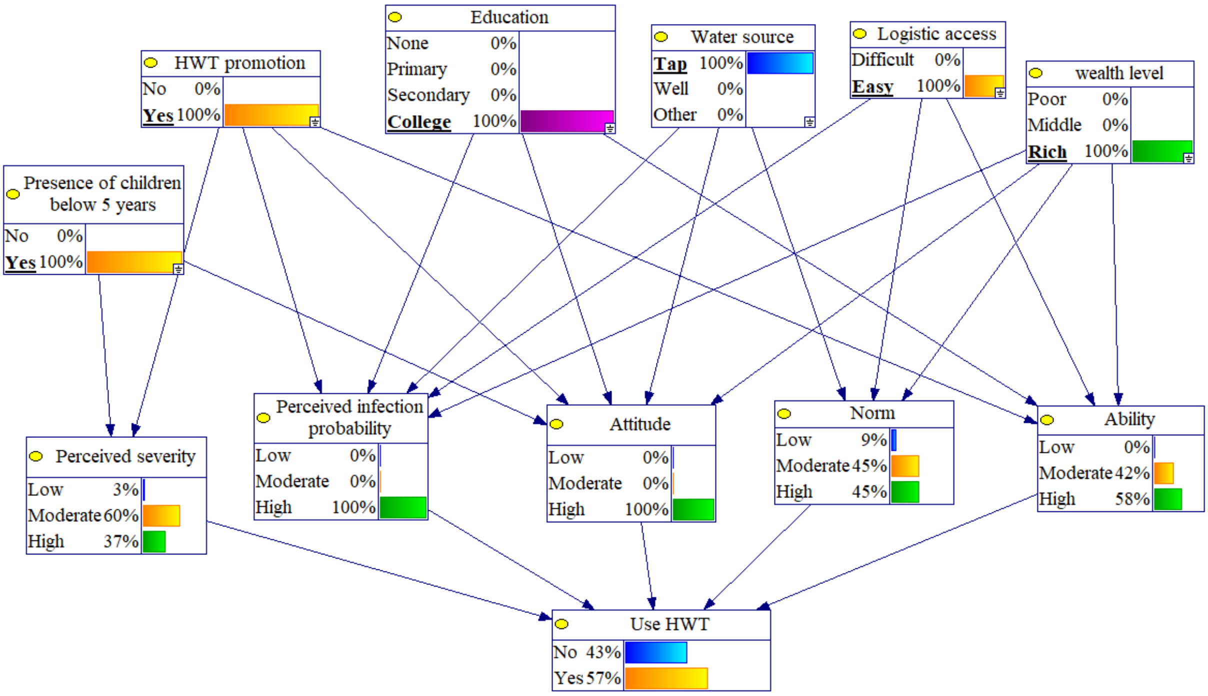


Figure 5. The best scenario of intervention (i.e., changing *belief*) in socio-economic factors on the outcome node *practicing HWT*.

Table 3. Effect of updating socio-economic characteristics on HWT adoption.

No	State for socio-economic characteristics*						$P_{\text{use HWT}}$ = yes (%)
	HWT promotion	Has children under 5 yrs.	Education	Water source	Logistic access	Wealth level	
1	Yes		None				17
2	Yes		College				29
3	Yes			Tap			20
4	Yes			Other			18
5	Yes				Easy		22
6	Yes				Difficult		18
7	Yes					Poor	21
8	Yes					Rich	22
9	Yes				Easy	Rich	29
10	No				Easy	Rich	22
11	Yes	No			Easy	Rich	30
12	Yes	No		Tap	Easy	Rich	34
13	Yes		College	Tap	Easy	Rich	52
14	Yes	No	College	Tap	Easy	Rich	46
15	Yes	Yes	College	Tap	Easy	Rich	57

*Empty boxes means that the value of that node did not change or was similar to the baseline condition.

Discussion

The presented model illustrates the causal linkages between socio-economic characteristics, psychological factors, and adoption of HWT. Furthermore, due to its graphical representation of BBN models, it “facilitates the communication of information to people without technical abilities so they can participate better in the decision making process” (Cain, 2001).

The BBNs presented in this chapter combined both quantitative and qualitative approaches to facilitate the design of interventions in the WASH domain. By analysing the interactions between combinations of variables in a probabilistic manner, the BBN model predicted the likelihood of different scenarios on the adoption of HWT in the study area. However, this has not been done in previous WASH-related *behavioural* studies that mainly used approaches different from BBN, e.g., logistic regression (Altherr et al., 2009; Casanova et al., 2012; Inauen et al., 2013; Stocker & Mosler, 2015).

Our model was able to predict 83.65% of the output, even though it predicted the correct adoption output being “yes” only 50% of the time. One possible reason is that the ratio between *adopters* and *non-adopters* is quite high (1:3.5), which might make the model “more familiar” with *non-adopters*. Death et al (2015) suggested using AUC to evaluate the model’s performance in this unbalanced situation. Our AUC was 0.85 (STD = 0.005) which suggests “good” model performance (Greiner et al., 2000).

The maximum predicted probability of practicing HWT by updating the belief in socio-economic characteristics layer was 57%. This is because the parent nodes (i.e., socio-economic characteristics) of each psychological factor could not fully explain the observed level of the psychological factors. This implies that there are probably more socio-economic characteristics that also could influence or explain the levels of the psychological factors besides those that we have used in our model. Nodes *education*, household's *wealth level*, and *receiving HWT promotion* were the most sensitive nodes (Table 2), as found also in other studies (e.g., Fotue Totouom et al., 2012; Gamma et al., 2017; George et al., 2016; Nauges & Berg, 2009; Opryszko et al., 2010).

Looking at the effect of updating the belief of *individual* psychological factors, *norm* and *ability* (action knowledge) are the most influential psychological factors behind the adoption of HWT (Table 2). The probability of HWT adoption greatly increased when these psychological factors were high. This finding is consistent with other reports mentioning that *norm* is the most influential factor for sustained positive behaviour related to WASH (Gerwel-Jensen et al., 2015; Inauen et al., 2013; Mosler & Kraemer, 2012) On the other hand, *ability*, which in this case is represented by how-to-perform knowledge, has also been found to be one of the important predictors of regular usage of HWT (Altherr et al., 2009). This was supported by the *diffusion of innovations* theory, which stated that individuals should have enough how-to-perform knowledge before they are expected to try the innovations (Rogers, 2003).

Although previous studies have also found specific psychological factors responsible for the adoption of HWT, a major result of our study is that the change of one psychological factor is not enough to boost the adoption of HWT to greater than 50%. It suggests that targeting multiple psychological factors is necessary to significanly change the behaviour in water treatment.

Node education has a different effect on various psychological nodes. In the case of our study, education positively influenced the HWT adoption via *attitude* and *ability*, but not via *perceived infection probability,* i.e., education has negative influence. Cross-tabulation of the sub-factors separately showed that households with higher education perceived slightly lower *vulnerability* and *factual knowledge*. This perhaps is because of implicit bias that educated households perceive that they know more than they actually do. This advantage, i.e., to visualize the effect of changes one variable on all related variables at once, is one unique aspect of the BBN model that sets it apart from other approaches, such as logistic regression. We could simulate and learn the pattern of how socio-economic characteristics influence people's perceptions which then drive the behaviour.

Implications

Our research revealed critical combinations of certain socio-economic characteristics that facilitated the adoption of HWT through corresponding psychological factors (Table 3). These findings can be used for targeting specific groups when designing HWT interventions (Table 3 and Figure 5). The households with socio-economic characteristics that correspond to high probability of adopting HWT might then be categorized as "earlier adopters" (a la *diffusion of innovations theory,* Rogers (2003)). The WASH program can target this group because rapid adoption among them might trigger others households to do so, i.e., 'snowball' effect.

This does not mean that we want to "change" people's characteristics by making them rich or attend college as a way to influence the practice of HWT. However, such socio-economic characteristics in the BBN model can be used as proxies to simulate potential interventions. For example, Table 2 shows that the availability of tap water resulted in a higher probability of adoption of HWT, compared to other types of water sources. The results suggest that water supplier agencies are one of the potential promoters of HWT products. They could combine their piped water scheme project with other activities to increase the probability of HWT adoption, for example, (1) designing HWT promotion to target the most educated person in each household (i.e., using nodes HWT promotion and education as a proxies), (2) integrating HWT promotional activities within an antenatal program (represented by having children), (3) establishing a distribution network to ensure easier access to HWT products and information for key target groups (represented by a node logistic access), and (4) ensure that households are willing and able to pay for cleaner water prior to procurement of HWT products. Figure 5 shows the “ultimate” intervention which addresses all the socio-economic characteristics nodes.

Furthermore, our model showed that the combination of the provision of products plus effective promotion activities were better than the provision of products or promotion alone. Some interventions gave the HWT products away for free or at a subsidized price because HWT are marginally expensive for poor households. This ‘economic’ effect was simulated by our model through node *wealth level* being “rich” and *logistic access* being “easy”. However, as suggested by a previous study on the use of toilet in Terai area, Nepal, the subsidies have to reach poor households. If a non-subsidised program is chosen, the implementers should think about right strategies for self-financed HWT products, e.g., by providing microloans (Gerwel-Jensen et al., 2015).

This study underlines some limitations and remarks for the future work. First, this study did not distinguish between different types of HWT promotion activities that respondents received in the past. Previous longitudinal studies revealed that different types of HWT promotion activities resulted in different levels of HWT adoption (Kraemer & Mosler, 2012; Mosler et al., 2013). This is worth modelling in the next study using BBN. Second, we also suggest validating the model in other locations to examine how generalizable the CPTs are, especially CPTs corresponding to psychological factors node conditional on socio-economic characteristics. By doing this, we could understand how the CPTs might change across contexts or locations. RANAS suggests that psychological factors can have different influence on behaviour depending on the situation or location (Mosler, 2012). Third, due to missing values on certain sub-factors in our datasets, the representative psychological factors used in this model may not fully reflect the complete meaning of each RANAS factor. Future studies should incorporate all RANAS factors and see how it can better explain the HWT adoption and improve the model's performance. However, we argue that targeting multiple psychological factors is still the key to increase the adoption rate of HWT. This might be true especially when the adoption rate in that area is very low. Fourth, we did not explore attitudes of households towards different HWT methods because the scope of the study was to explore general attitudes towards HWT practice and not to compare different HWT methods. Further, such an assessment would also not have been reliable because most of the respondents only used boiling as a HWT method. Fifth, future studies should investigate our assumption that socio-economic characteristics indirectly influence the use of HWT via psychological factors. Lastly, the data of the HWT use was respondent's self-reported HWT practice, which might have been over-reported and could have been subject to bias.

Conclusion

The causal relationship between socio-economic factors, psychological factors, and WASH-related behaviour have not been investigated in-depth in previous studies. In this chapter, we showed how socio-economic characteristics influence the psychological factors of people in rural Nepal and how those psychological factors collectively determine households' adoption of HWT. We visualized and quantified their interactions through a BBN model. The findings presented here highlight the complex system underlying HWT adoption. The most influential socio-economic characteristics that drive the HWT adoption were education, wealth level, and HWT promotion. Social norm and ability to perform the behaviour were the most influential psychological factors. The presented method is also helpful in setting priorities in behavioural change interventions in the WASH domain. It can be done by observing the socio-economic characteristics of HWT adopter and then targeting the combinations of psychological factors that can increase the probability of HWT adoption. The results also suggest that the piped water supply project in LMICs is a potential entry point for the high likelihood of HWT adoption, if it is accompanied by other activities as described in this study.

Chapter 5

Analysis of the household water treatment adoption using Bayesian belief networks: A study case of rural Indonesia


- Firewood and kerosene stove to boil water in East Sumba, Indonesia -

This chapter is based on:

Daniel, D., Pande, S., & Rietveld, L. (2020b). *Socio-economic and Psychological Determinants for Household Water Treatment Practices in Indigenous - Rural Indonesia*. Manuscript submitted for publication.

Abstract

Household water treatment (HWT) is one of the possible technologies to improve the quality of potable water in low-middle income countries. However, many people still drink untreated water which leads to negative health consequences. This study explores the role of socio-economic characteristics (SEC) and psychological factors on the practices of HWT, using a combination of statistical analyses and a Bayesian Belief Network (BBN). We present our findings from 377 household interviews in East Sumba, Indonesia; an area where indigenous belief is still common. We combined self-reported answers and observed practices of HWT. 51% of the respondents were categorised as regular users of HWT. Further, we showed that favourable socio-economic conditions, e.g. wealthier or more educated parents, result in positive psychological factors and then lead to regular use of HWT. The adoption of HWT was positively influenced by mother's education and people who followed indigenous belief tended not to use HWT on a regular basis. Moreover, easy access to water positively influenced household's ability to operate a HWT technology. Attitude towards the HWT practice, especially the perception of treated water's taste, was the most significant psychological factor that influence HWT adoption. An interpretation of complex interlinkages between socio-economic conditions and psychological factors that are behind the practice of HWT was offered. This study also provides recommendations for long-term and conservative interventions that may change household's behaviour in a culturally unique area with difficult access to water. Finally, our findings suggest the significance of reducing SEC inequalities to improve the HWT adoption.

Keywords: Household Water Treatment, indigenous belief, Bayesian Belief Networks, socio-economic characteristics, psychological factors, behavioural model

Introduction

Billions of people in low-middle income countries (LMICs) have inadequate water, sanitation, and hygiene (WASH) services. It was estimated that 2.1 billion people had no access to safely managed drinking water services in 2015 (WHO; UNICEF, 2017a). Lack of access to safe drinking water leads to adverse health conditions and inhibits productive activities (Hutton et al., 2007). Children below the age of five suffer the most from these water-related diseases, such as diarrhoea, stunting, and even mortality (Black et al., 2011; Collaborators, 2017).

WASH interventions have been conducted intensively in LMICs. Such interventions have included household water treatment (HWT), such as boiling, solar disinfection, adding chlorine, or water filtration (Sobsey et al., 2008). HWT has been effective in reducing water-related diseases in many LMICs (Wolf et al., 2018). However, previous studies have found that many households in LMICs, especially in Africa and rural areas in Asia and Latin America, have not adopted or practiced it regularly which can reduce the positive health effect of HWT (Zimmer et al., 2006; Enger et al., 2013).

Understanding the reasons behind adoption of HWT is essential in order to develop better WASH intervention strategies that sustain appropriate WASH behaviour. RANAS, which stands for *Risk*, *Attitude*, *Norm*, *Ability*, and *Self-regulation*, is one of the psychological frameworks which has been used to understand the behavioural determinants of diverse water use practices (Mosler, 2012b). It was able to in explaining the use of HWT in developing countries such as Bangladesh (Inauen et al., 2013), Chad (Lilje et al., 2015) and Ethiopia (Sonego et al., 2013).

Dreibelbis, et al. (2013) argue that combining the socio-economic characteristics (SEC) and psychological factors can provide better systems level understanding of WASH related behaviour. On the other hand, Lilje and Mosler (2017) argue that SEC is “less important” to measure because it explains only a small portion of the behaviour and SEC is nested within psychological factors. Other WASH studies have similarly suggested that the strength of the influence of SEC is much smaller than psychological factors, once it is combined with psychological factors as independent variables at the same level of regression analysis (Stocker and Mosler, 2015; Seimetz et al., 2016).

However, Daniel et al. (2020c) used mediation analysis and found statistically significant evidence for the hypothesis that the influence of SEC on HWT adoption is mediated by psychological variables. Daniel et al. (2019) introduced and implemented the hierarchical causal framework using Bayesian Belief Network (BBN) which combined SEC and psychological factors to analyse the use of HWT in Nepal. They used RANAS psychological framework to guide their analysis, but with some limitations, such as they did not completely utilise the RANAS factors, a potential bias of self-reported answers existed, and limited SEC were used in the BBN model. Therefore, this chapter aims to improve the previous work of Daniel et al. (2019) and “completed” the model with more SEC and complete RANAS psychological factors. We also studied the influence of SEC on the psychological factors which was not explored much in the previous HWT or WASH studies, i.e., they ruled out their inter-relationship; see for example (Stocker and Mosler, 2015; Seimetz et al., 2016).

The current study takes up the, above mentioned, hierarchical causal framework to understand the complex interlinkages between SEC and psychological factors behind the practice of HWT in a rural area in East Sumba, Indonesia. This area is known as one of the poorest in Indonesia, where open defecation is common, access to clean water is difficult, the prevalence of malnutrition among children is one of the highest in Indonesia, and many people still follow an indigenous belief, known as "Marapu" (Fowler, 2003; Picauly and Toy, 2013; Sungkar et al., 2015). Using the combination of BBN and statistical analysis, we were not only able to understand the complex system behind the practice of HWT, but also potentially enabling local stakeholders to design relevant behavioural interventions.

Methods

Study setting

We conducted a cross-sectional study in July-August 2018 in the district of East Sumba, Province Nusa Tenggara Timur, Indonesia. A total of 377 households were randomly visited within nine villages (Figure 1). The data collection was conducted in the dry period. We developed a structured household interview containing household's socio-demographic information, WASH knowledge and perceptions, and observations by hired local enumerators. The SEC were encoded in categorical variables, while most of the answers related to psychological factors questions were measured in a five Likert-scale. We targeted a mother as a respondent on behalf of the household, wherever possible, because they are mainly responsible for the water management in the house. We used the Open Data Kit (ODK) platform on a smartphone for the interview and the data were transferred to the computer for analysis. The Human Research Ethics Committee of Delft University of Technology and the Agency for Promotion, Investment and One-Stop Licensing Service at the province (East Nusa Tenggara) and district (East Sumba) level approved the study setting. Participation was voluntary and written informed consents were obtained from all respondents; as well as the consent from the village's head prior to the data collection.

2012).

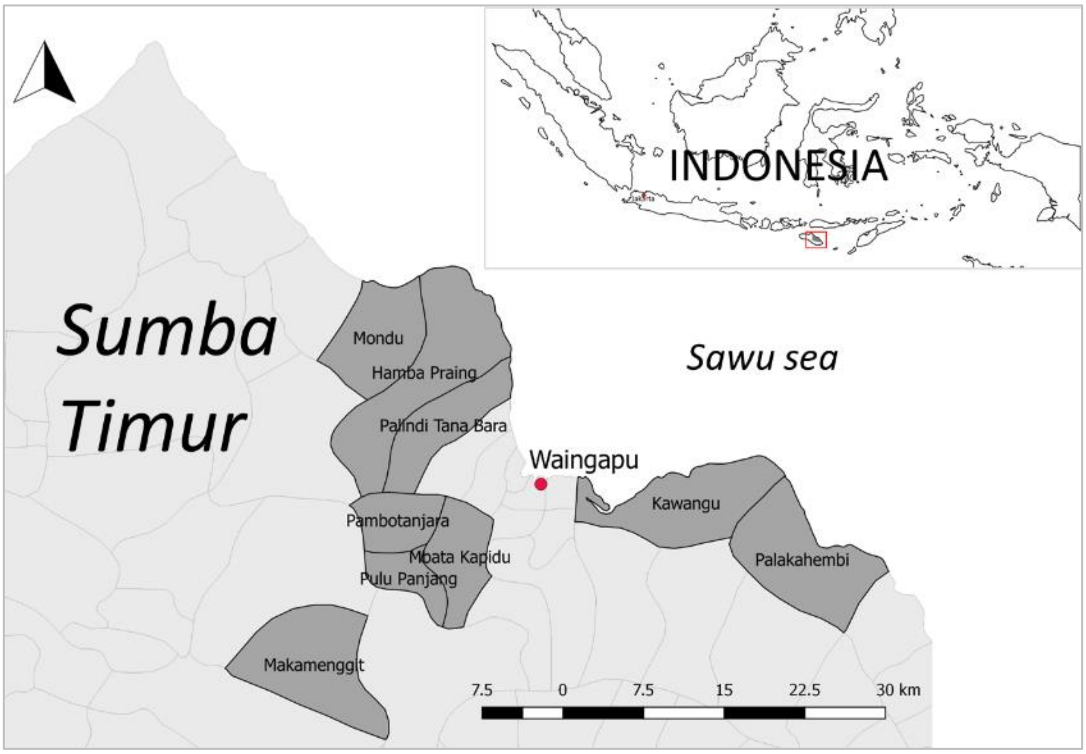


Figure 1. Location of nine villages visited in district East Sumba, Indonesia; drawn using QGIS (QGIS Development Team, 2017).

Bayesian Belief Network

A BBN is a directed acyclic graph showing a hypothetical causal relationship between "causal" variables (called "parent nodes" in BBN) and an "affected" variable (child node) (Pearl, 1988). The strength of a probabilistic relationship between parents and a child node is depicted by the values in the corresponding Conditional Probability Tables (CPT). An introduction on BBN can be found in Cain (2001). BBN offers advantages compared to other statistical methods, for example, by allowing for the possibility to combine expert judgement (qualitative) with actual data to tackle data's uncertainties or unavailability, better visualization of a complex system by multiple stakeholders, and allowing for both predictive and diagnostic inference (Barton et al., 2012).

A BBN structure can be inspired through statistical inference between variables, but it is more common to create a structure which is inspired either by theory or by consensus between experts (Nadkarni and Shenoy, 2004). In our case, we built a three-level hierarchical model depicting how SEC influence the use of HWT via psychological factors.

Socio-economic characteristics

We used eight SEC, which were expected to influence the practice of HWT or other WASH behaviour based on peer-reviewed literature: *Wealth* (Opryszko et al., 2010; Roma et al., 2014; Munamati et al., 2016), *Indigenous belief* (Kley and Reijerkerk, 2009; Waterworth et al., 2015; Behailu et al., 2016), *Access to market* (Goldman et al., 2001; Dubois et al., 2010), *Water-related health problem* (Christen et al., 2011; Freeman et al., 2012), *Information access* (George et al., 2016), *Mother's education* (Nauges and Van Den Berg, 2009; Fotue Totouom et al., 2012; Freeman et al., 2012; Munamati et al., 2016), *Father's education* (Dubois et al., 2010; Figueroa and Kincaid, 2010), and *Access to water* (Figueroa and Kincaid, 2010). We used a respondent's answer to "frequency of watching TV" as the proxy for variable *Information access*. Occurrence of diarrhoea in the preceding two weeks at the time of visit among children below the age of 5 in the house was used for the variable *Water-related health problem.*

RANAS psychological factors

As mentioned in the introduction, RANAS consists of 5 main factors (Mosler, 2012b). *Risk* is related to the individual's awareness and understanding of HWT-related issues. *Attitude* represents a person's positive or negative feeling towards HWT. *Norm* represents the social pressure towards HWT. *Ability* represents a personal confidence in his or her ability to execute HWT. Finally, *Self-regulation* reflects personal attempts to self-monitor and plan HWT and deal with conflicting goals. RANAS framework inquires psychological-related information at sub-factor level (Contzen and Mosler, 2015); see also Table 1.

Outcome variable: *HWT practice*

To assess the practice of HWT among the respondents, we combined respondent's answers to four questions related to the use of HWT and observation of the HWT practice by the enumerators at the time of visit,. The four questions corresponded to: percentage of water treated daily, frequency of drinking raw water daily, habit to perform HWT, and intention to treat water. The intention behind combining multiple answers is to diminish the bias of self-reported behaviour, which may overestimate the practice of HWT (Schmidt and Cairncross, 2009a).

Data analyses

We performed two sequential analyses: (1) statistical analysis: regression of the RANAS psychological sub-factors on HWT practice, reduction of RANAS sub-factors to five dominant factors, and correlation tests between each SEC and the five RANAS factors, and (2) hierarchical BBN modelling to assess the effect of SEC, via RANAS psycho-social characteristics, on *HWT practice*. The regression results were used to identify the significant RANAS sub-factors. Furthermore, we performed BBN using SEC and *reduced* RANAS psychological factors to predict the use of HWT.

Statistical analyses

We performed Principal Component Analysis (PCA) to create some "latent" variables and reduce dimensionality (i.e. number of variables used in the analysis) before building the BBN model, as conducted also by (Daniel et al., 2019). The "latent" variables obtained from PCA were: *wealth* and the five RANAS factors: *Risk*, *Attitude*, *Norm*, *Ability*, and *Self-regulation*, and finally *HWT practice*. *Wealth* was created from the first principal component of variables linked to household's assets. PCA was also conducted to create *HWT practice* using the four self-reported variables and observations made by enumerators as described before.

Using all RANAS sub-factors will make a BBN structure too complex and should be avoided (Marcot et al., 2006). Thus, we also performed PCA to combine the sub-factor information into one representative variable for each RANAS factor. For example, we combined the data of all *Norm* sub-factors *descriptive*, *injunctive*, and *personal norm* (see Table 1) using PCA and obtained the first principal component as the representative variable *Norm*. The reliability of performing PCA to represent RANAS main factors and *HWT practice* have been discussed in (Daniel et al., 2020c).

Before performing BBN analysis, we first performed forced-entry multivariate regression analysis using all RANAS sub-factors (Table 1) as independent variables with *HWT practice* as the dependent variable. We also conducted one-to-one Pearson's correlation test between each SEC and each of the five factors of RANAS (the representative variable obtained from PCA) to identify potential relationships between them. The results were used to build the final hierarchical BBN structure. All statistical analyses were conducted using IBM SPSS Statistics 24.

Bayesian Belief Network (BBN) analysis

BBN requires categorical or discrete information as model inputs. Thus, continuous variables, such as the output of PCA, were discretized into several categories. We then categorised the psychological factors into: low (lowest one-third of PCA scores, e.g., low *Norm*), moderate (one-third to two-third of the lowest PCA scores, e.g., moderate *Norm*), and high (the remaining data). For the *HWT practice,* three categories were created using the same approach for categorisation of psychological factors: “non-user”, “irregular user”, and “regular user”.

We also discretized and “reduced” the data on *wealth, access to water,* and *information access* for the BBN analysis. For variable *wealth* in the BBN, we categorized the respondents into three categories based on their first principal component’s score: poor (the lowest 40%), middle (the next 40%), and rich (the last 20%), as suggested by other authors (Houweling et al., 2003; Vyas and Kumaranayake, 2006). For *access to water*, respondent’s answer “below 5 min” was coded “close”, “5-30 min” was “medium”, and “above 30 min was “far”. The minutes estimate the time needed for respondent to walk to the main water source, wait in the line if there is a queue, collect the water, and come back. For *information access*, we coded “difficult” *information access* if the respondent answered “almost never” and “seldom” in the question related to the frequency to watch TV daily. If they answered “sometimes” and “quite often”, then *information access* was coded “medium”, and very often was coded as “easy” *information access*.

We performed BBN using Genie 2.2 (http://www.bayesfusion.com). The software uses the Expectation Maximization (EM) algorithm to estimate the entries of CPT depicting the strenghth of relationship between a child node and all its parent nodes (Druzdzel and Sowinski, 1995; Do and Batzoglou, 2008). We also conducted ten-fold cross-validation using the same software to assess model’s performance as indicated by the Area Under the Curve (AUC) value of the Receiver Operating Characteristics (ROC) curve. A value close to one indicates perfect prediction of the output variable (higher sensitivity and lower false positives) (Greiner et al., 2000). We also conducted sensitivity analysis, to find the most influential variable for the output node, and performed both predictive (forward) and diagnostic (backward) inference.

During the sensitivity analysis, the effect of a small change in the model parameters or CPT of each node on the output node was calculated. This sometimes called “global sensitivity analysis” (Dai et al., 2019). The predictive (Bayesian) inference was intended to simulate the influence of specific SEC and psychological nodes, i.e. model’s input, on the HWT practice. This sometimes called “local sensitivity analysis”. For example, by updating the node *Indigenous belief* to 100% “yes”, the probability value in the psychological node connected to it could change and will thereafter change the probability value in output node *HWT practice*. In addition, we performed diagnostic inference, which is the opposite of predictive inference. In diagnostic inference, we set a desired distribution of states in the output node and infer the distribution of states in its parent nodes that could lead to the desired outcome (Zabinski et al., 2018). For example, diagnostic inference of *HWT practice* at 100% “regular” will identify distribution of states in all SEC and psychological nodes that lead to such output, i.e. it will identify most probable causes of 100% of households to practice HWT.

Table 1. Descriptive statistics of psychological factors. M = mean, SD = standard deviation

Psychological factors		Example question	Scale	M(SD)	Cronbach's α
Risk	Perceived vulnerability	How high do you feel is the risk that you will get diarrhea if you drink untreated water?	1-5	2.9 (1.0)	0.846
	Health knowledge	What are the causes of diarrheal diseases?	1-5*	1.9 (0.9)	
	Perceived severity (on life)	Imagine you have diarrhea, how severe would be the impact on your daily life?	1-5	3.2 (1.1)	
	Perceived severity (on a child)	Imagine your child below 5 years has diarrhea, how severe would be the impact on his life and development?	1-5	3.6 (1.2)	
Attitude	Health benefit	How certain are you that always treating your water will prevent you from getting diarrhea?	1-5	3.4 (1.1)	0.780
	Affective belief (taste)	How much do you like the taste of treated water?	1-5	3.9 (1.1)	
	Affective belief (enjoy)	How much do you enjoy the moment when you treat your water?	1-5	3.9 (0.9)	
Norm	Descriptive	How many of your neighbours treat their water?	1-5	3.0 (1.1)	0.734
	Injunctive	People who are important to you, how do they think you should always treat your water before consumption?	1-5	3.5 (0.8)	

	Personal	How strongly do you feel an obligation to yourself to always treat your water before consumption?	1-5	3.8 (1.2)	
Ability	Confidence in performance	How certain are you that you will always be able to treat your drinking water before drinking?	1-5	3.3 (1.0)	0.905
	Confidence in recovering	Imagine that you have stopped treating your water for several days, how confident are you that you would restart treating your drinking water again)?	1-5	3.3 (1.1)	
	Confidence in continuation	Imagine that you have much work to do. How confident are you that you can always treat your water?	1-5	3.3 (1.0)	
Self-regulation	Action control	How much do you pay attention to the resources needed to treat the water?	1-5	3.6 (0.9)	0.535
	Remembering	Within the last 24 hours: How often did it happen that you intended to treat your water and then forgot to do so?	1-5	3.8 (1.2)	
	Commitment	How important is it for you to treat the water?	1-5	3.8 (1.0)	
	Barrier planning	Could you tell me how do you deal with the obstacles that hinder you to treat water?	1-0*	0.5 (0.5)	

*For *health knowledge*, the scale is based on the correct causes mentioned by the respondents; for *coping* planning, 1 = has clear solution, 0 = no clear solution. The Cronbach's α is for PCA.

Results

Socio-demographic characteristics of the respondents

In terms of schooling, 33% of the respondents attended at least secondary school, while only 29% among the household's head (male). The majority of the respondents (87%) had non-permanent housing walls, i.e. wood or bamboo; 7.4% a non-permanent roof, i.e. straw; and 69% a non-permanent floor, i.e. compacted soil. 26% of the respondents followed the indigenous belief "Marapu". Around half of the respondents mentioned that they almost never watched TV (56%). Furthermore, 52% of respondents were living in relatively difficult market access.

Additionally, 29% of the respondents said that they still practiced open defecation, while 50% of the respondents had their own toilet. 34% of the respondents had access to a piped water scheme, while 58% still relied on river or well, and 8% bought water from commercial entities, e.g. water truck or refill water station. 51% of the respondents had a water source nearby or in the house, i.e. below 5 min per trip to get water, while 29% of the respondents needed at least 15 min per trip to fetch water. 101 respondents (27%) claimed, i.e. self-reported answer, that almost all of their drinking water was treated. However, after using PCA to create the variable *HWT practice*, 51% of the respondents were categorized as "regularly" practicing HWT, 26% as irregular user, and 23% as non-users. Moreover, 85% of the respondents answered boiling as the HWT method that they often practiced. Diarrhoea incidence among children below the age of 5 was 32% in the preceding two weeks at the time of visit.

Statistical analyses

Table 2 shows the results of regression analyses using all RANAS sub-factors as predictors of the use of HWT. According to our results, *perceived severity - on life* (risk), *affective belief –*

taste (attitude), *descriptive* and *personal norm*, *confidence in performance* and *in continuation* (ability), and *barrier planning* (self-regulation) were significant psychological sub-factors. The *affective belief – taste* (attitude) was the most significant psychological sub-factor (see β value in Table 2).

Table 2. Regression analysis of all RANAS sub-factors psychological factors on HWT practice.

Variables	**B**	**SE B**	**β**
Risk			
Perceived vulnerability	0.061	0.034	0.069
Health knowledge	0.037	0.040	0.033
Perceived severity (on life)	-0.077	0.036	-0.090*
Perceived severity (on a child)	0.019	0.032	0.023
Attitude			
Health benefit	0.002	0.038	0.002
Affective belief (taste)	0.246	0.034	0.277***
Affective belief (enjoy)	0.052	0.043	0.046
Norm			
Descriptive	0.058	0.029	0.065*
Injunctive	0.027	0.041	0.024
Personal norm	0.190	0.035	0.233***
Ability			
Confidence in performance	0.122	0.040	0.118**
Confidence in recovering	0.043	0.045	0.044
Confidence in continuation	0.159	0.049	0.158**
Self-regulation			
Action control	-0.028	0.037	-0.027
Remembering	0.012	0.024	0.016
Commitment	0.017	0.028	0.018
Barrier planning	0.406	0.067	0.209***

*$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$. Adjusted $R^2 = 0.842$, n = 257.

Further, we performed Pearson's correlation analyses between each SEC and the five RANAS main factors (Figure 2). *Indigenous belief, access to market, information access, father's education, and wealth* were correlated with all RANAS factors. Almost all SEC had positive correlations with the RANAS factors, e.g. the higher the education level of mother and father, the higher is the perception level of the RANAS factors. Exceptions were *Indigenous belief* and *access to water* which had negative correlations with psychological variables. Households who followed indigenous belief and need longer time to get water were inclined to have lower levels of psychological factors, e.g. have lower level of ability perception.

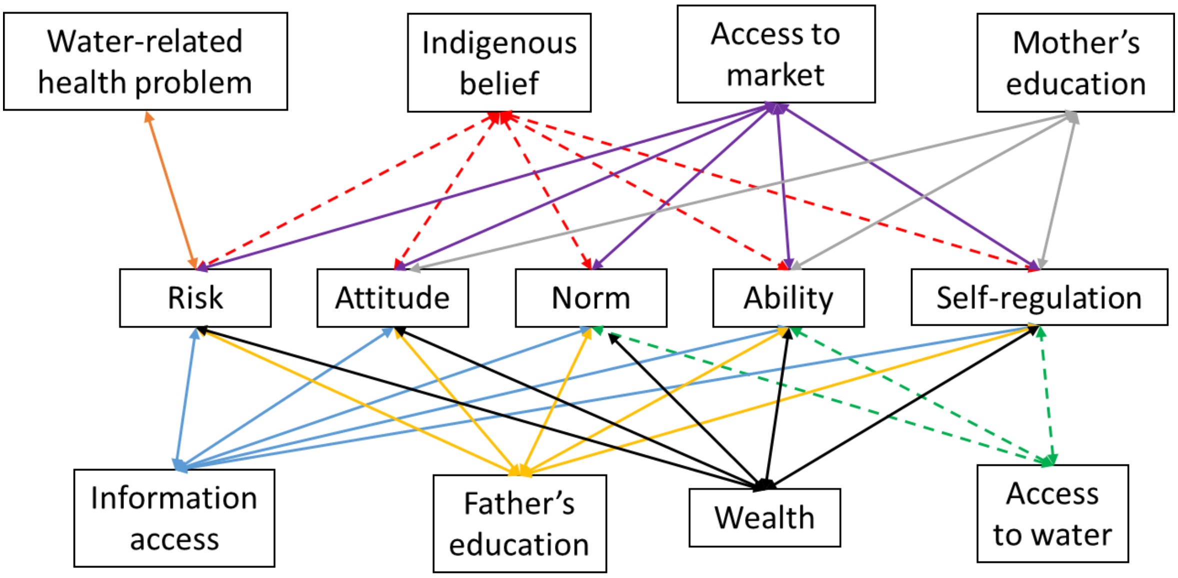


Figure 2. Correlation relationship between SEC and RANAS psychological factors. Solid lines indicate positive correlation and dashed lines indicate negative correlation (Pearson correlation, $p \leq 0.05$).

BBN analyses

Figure 3 shows the complete BBN model. This is the "status-quo" condition where 42% of the respondents were categorised as regularly practicing HWT. The average model accuracy to predict the *HWT practice* was 79%. Further, the accuracy to predict the three categories, non-user, irregular user, and regular user was 79%, 54%, and 90%, respectively. The area under the ROC curve (AUC) was 0.94, which is categorised as "highly accurate" (Greiner et al., 2000). It means that the model can distinguish between the three categories in the output node *HWT practice* based on the SEC and RANAS psychological data.

The sensitivity analysis shows that *mother's education*, *indigenous belief*, and *information access* were the three most influential nodes (Figure 4). Moreover, *attitude* followed by *risk* were the most influential psychological variables.

The effect of updating individual nodes on *HWT practice*, i.e. predictive inference, is shown in Table 3. Overall, the better the socio-economics conditions of households, the more favourable were the psychological factors, i.e. the "level" of psychological factors that facilitate the desired behaviour. This then led to higher probability of regularly practicing HWT. The predictive inference found *ability* as the most influential node. If a respondent perceived his/her ability to practice HWT to be low, his/her probability of practicing HWT regularly was only 22%. However, if households were confident then the probability of treating water regularly jumped to 53%.

Diagnostic inference shows that a higher probability of regularly practicing HWT required higher levels of all five psychological factors. For example, Figure 5 shows that if we set the level of regularly practicing HWT to 100%, then the probability values in the psychological nodes being "high" changed by 5% to 13%. However, the values in all socio-economic nodes did not change much compared to the status quo in Figure 3. Diagnostic inference also shows that *attitude* was a key psychological factor to change non-user to an irregular user, while the *ability* was a key factor to change irregular to a regular user of HWT. This re-affirms the previous findings of predictive inference.

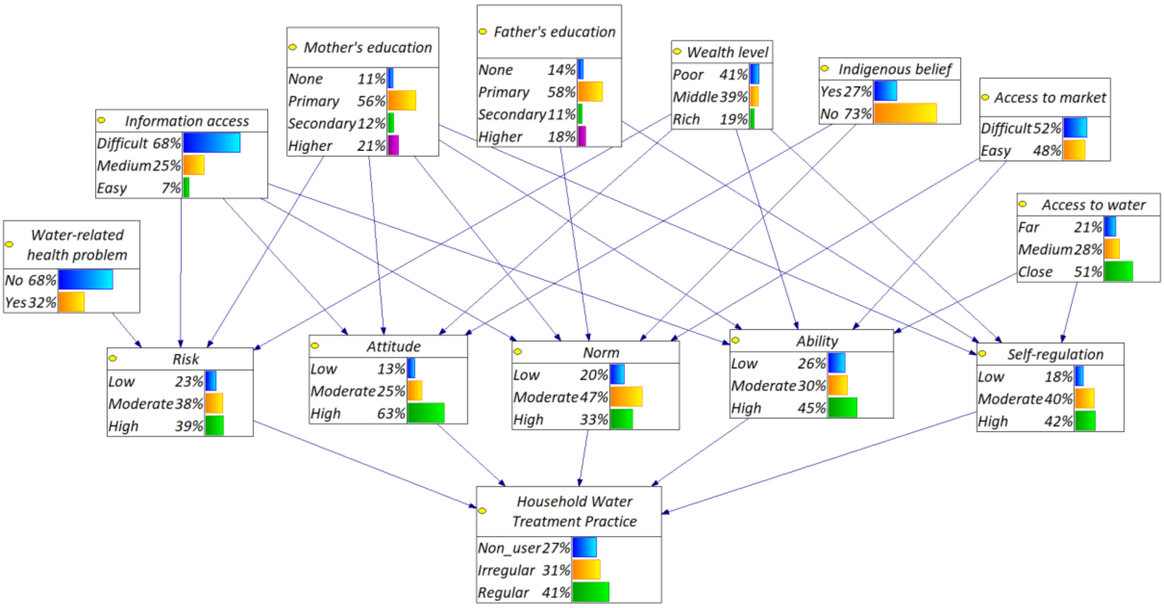


Figure 3. The BBN model showing the hypothetical causal relationship between socio-economic characteristics (SEC), RANAS psychological factors, and HWT practice in rural Indonesia. The bars in each node show the probability that a node is in a certain state (status quo or existing condition).

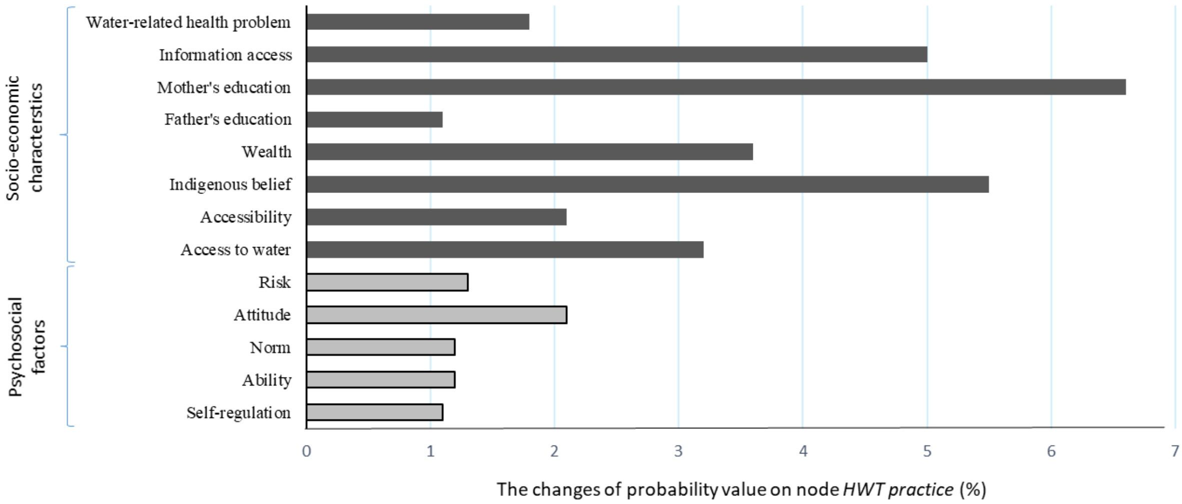


Figure 4. Sensitivity analysis of individual nodes on the output node *HWT practice*.

Table 3. Predictive inference that measures the effect of each state in each node on *HWT practice*. The value under each category corresponding to a node as displayed in the first column is the updated probability of the output node being "regular" given that all households maintain this state. The baseline probability was 41% (Figure 3).

<table>
<tr><th colspan="2">Nodes</th><th colspan="4">Updated $P_{\text{HWT practice}}$ = regular (%)</th><th>$\Delta P_{\text{HWT practice}}$ = regular (%)[1]</th></tr>
<tr><td rowspan="16">Socio-economic characteristics</td><td rowspan="2">Water-related health problem</td><td colspan="2">No</td><td colspan="2">Yes</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">41</td><td colspan="2">43</td></tr>
<tr><td rowspan="2">Information access</td><td>Difficult</td><td colspan="2">Medium</td><td>Easy</td><td rowspan="2">4</td></tr>
<tr><td>41</td><td colspan="2">43</td><td>37</td></tr>
<tr><td rowspan="2">Mother's education</td><td>None</td><td>Primary</td><td>Secondary</td><td>Higher</td><td rowspan="2">8</td></tr>
<tr><td>36</td><td>42</td><td>37</td><td>44</td></tr>
<tr><td rowspan="2">Father's education</td><td>None</td><td>Primary</td><td>Secondary</td><td>Higher</td><td rowspan="2">1</td></tr>
<tr><td>41</td><td>42</td><td>42</td><td>41</td></tr>
<tr><td rowspan="2">Wealth</td><td>Poor</td><td colspan="2">Middle</td><td>Rich</td><td rowspan="2">4</td></tr>
<tr><td>40</td><td colspan="2">41</td><td>44</td></tr>
<tr><td rowspan="2">Indigenous belief</td><td colspan="2">Yes</td><td colspan="2">No</td><td rowspan="2">6</td></tr>
<tr><td colspan="2">37</td><td colspan="2">43</td></tr>
<tr><td rowspan="2">Access to market</td><td colspan="2">Difficult</td><td colspan="2">Easy</td><td rowspan="2">3</td></tr>
<tr><td colspan="2">40</td><td colspan="2">43</td></tr>
<tr><td rowspan="2">Access water</td><td>Far</td><td colspan="2">Medium</td><td>Close</td><td rowspan="2">4</td></tr>
<tr><td>39</td><td colspan="2">40</td><td>43</td></tr>
<tr><td rowspan="10">Psychological factors</td><td rowspan="2">Risk</td><td>Low</td><td colspan="2">Moderate</td><td>High</td><td rowspan="2">16</td></tr>
<tr><td>32</td><td colspan="2">40</td><td>48</td></tr>
<tr><td rowspan="2">Attitude</td><td>Low</td><td colspan="2">Moderate</td><td>High</td><td rowspan="2">18</td></tr>
<tr><td>30</td><td colspan="2">32</td><td>48</td></tr>
<tr><td rowspan="2">Norm</td><td>Low</td><td colspan="2">Moderate</td><td>High</td><td rowspan="2">17</td></tr>
<tr><td>30</td><td colspan="2">42</td><td>47</td></tr>
<tr><td rowspan="2">Ability</td><td>Low</td><td colspan="2">Moderate</td><td>High</td><td rowspan="2">33</td></tr>
<tr><td>21</td><td colspan="2">40</td><td>54</td></tr>
<tr><td rowspan="2">Self-regulation</td><td>Low</td><td colspan="2">Moderate</td><td>High</td><td rowspan="2">21</td></tr>
<tr><td>29</td><td colspan="2">38</td><td>50</td></tr>
</table>

[1]The difference between the lowest and highest value of the updated probability of output node, HWT practice being "regular", in %

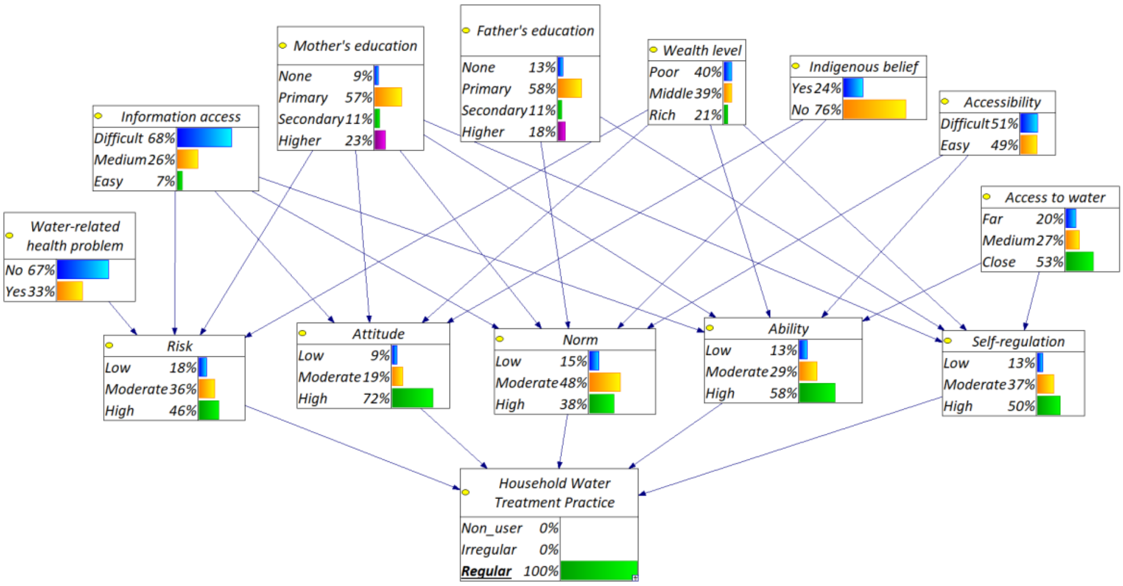


Figure 5. Diagnostic inference: most probable states of all SEC and psychological factors that will lead to the probability of regularly practice HWT to 100%.

Further we studied in more detail the effect of specific SECs on psychological factors connected to it using the BBN's predictive inference. Households that followed indigenous belief had a lower probability of psychological nodes connected to it being "high", e.g. *attitude* and *norm* (46% and 31% respectively), compared to a households that did not follow the belief (69% and 34% respectively). Another example is that if someone needed to walk more than half hour to fetch water, then the probability of *ability* and *self-regulation* being "high" was only 42% and 36%, respectively, compared to 47% and 46% if they needed to less than 5 min. The effect of other SEC on psychological factors were in a "positive direction": higher parent's education level, easier information access, wealthier, having water-related health problem, and more accessible location all had a positive influence on the psychological factors.

Discussion

Explaining water-related behaviour, such as the practice of HWT, is very complex, particularly because there are many factors involved (Peters, 2014). Using a system-based approach which combines socio-economic characteristics and psychological factors, we found that that locally rooted belief and access to water highly influence people's perceptions (psychological factors) and further the adoption of HWT. Moreover, the model's performance was better than the one in Daniel et al. (2019), as showed by the AUC value of 0.94. It could be because we used complete RANAS variables in the analyses and included more relevant socio-economic characteristics that may influence the people's psychological situation. We also minimized the bias from respondent's self-reported answers by combining multiple answers to give a true state of the behaviour.

The results of the sensitivity analysis and predictive (Bayesian) inference show the same pattern. For example, a more educated mother perceived a higher level of the psychological factors, i.e. a positive correlation (Figure 2). This is in line with the (Figueroa and Kincaid, 2010) who mentioned that a more educated mother may have better understanding of the health risk of untreated water and could manage and plan better about the practice of HWT. In addition, since the mother is the primary adult caretaker and usually responsible for home WASH management, the new mindset obtained from the promotional activities or school are probably translated into a sustained behaviour and followed by other household members (Allen et al., 2018).

The effects of other individual socio-economic characteristics and psychological factors on HWT practice are also consistent with literature, i.e. a positive influence or correlation. For example, easier information access, may facilitate the spread of knowledge and understanding of health risks from untreated drinking water (George et al., 2016; Daniel et al., 2019). Easier access to market also stimulates more confidence in getting the resources needed to adopt HWT, while wealth represents their ability to purchase the resources (Opryszko et al., 2010; Roma et al., 2014). This supports the idea that "context matters" and that SEC of households play a significant role in context of health-related behaviour. Previous studies said that SEC is the fundamental causes of health-related behaviour (Adler and Newman, 2002; Braveman and Gottlieb, 2002; Manstead, 2018; Winter et al., 2018). We argue that including SEC in the analysis is essential if we use the system thinking approach to explain HWT practice or want to find "the causes of the causes" of the water-related behaviour (Braveman and Gottlieb, 2002; Dreibelbis et al., 2013). Furthermore, since our results show that better SEC lead to more regular HWT practices, reducing SEC disparities is essential to improve a healthier behaviour (Adler and Newman, 2002).

Indigenous belief played a significant role in our study. We found it to be negatively correlated with both psychological factors and the behaviour with respect to practicing HWT. Previous WASH-related behavioural studies have also highlighted that indigenous belief play a critical role. For example, rainwater is considered to be blessed by God in some areas of Kenya. Therefore, HWT is deemed unnecessary and not practiced (Harris, 2005). Water from rivers such as River Ganga is considered pure by many people in India for the same reason and often consumed without treatment (Kley and Reijerkerk, 2009). Being a Christian or not has been found to be a significant predictor of using private latrine (Winter et al., 2018). In addition, indigenous belief has facilitated a high sanitation coverage in Uganda (Okurut et al., 2015), but has led to distrust in filtered water in Bangladesh (Johnston et al., 2010). Other studies have also mentioned indigenous belief as key drivers of HWT practice in Pakistan (Mahmood et al., 2011) and Nepal (Rainey and Harding, 2005).

By understanding more about the role of belief, behavioural change interventions could be better designed without changing their unique cultural belief and practices. For example, religious leaders could be involved in the WASH promotion activities (Dwipayanti et al., 2019). This might also work in East Sumba since we found that the religious leader is highly respected.

Households who need more time to collect water perceived lower levels of ability and self-regulation to operate HWT technologies. That is probably because the time to treat water, e.g. to boil and cool water, competes with the time needed to fetch water (Clasen et al., 2008). Access to water supply is a challenge in East Sumba where the area faces drought throughout the year (Messakh et al., 2018). This finding underlines the need for easier access to the water supply to facilitate a behavioural change towards the adoption of HWT. This is because ability and self-regulation are the main two factors which related to the continuation of the behaviour (Mosler, 2012b).

From the BBN sensitivity analysis, the psychological factor *attitude* of households towards HWT was found to be most influential variable (Figure 4). If we also consider the regression analysis, *affective belief (taste)*, i.e., one of *attitude* sub-factors, was the most influential variable. This suggests that if households in the area like the taste (or temperature) of the treated water, they are highly likely to regularly practice HWT. We could relate this finding to another study in Pakistan where households preferred to have fresh and cold water in hot weather (Luby et al., 2001). We suspect that similar interpretation applies to our study area since Sumba island is quite hot and humid area, i.e., people prefer to have raw-fresh water which taken directly from tap, river, or well. Moreover, since the perception of *risk* appears as the second critical psychological factor in BBN, we suggest that inform the households about the water quality of the fresh - but untreated - water is necessary to change the behaviour. However extra effort would be needed to ensure that households perceive treated water more positively, e.g. by finding opportunities where households experience the taste (freshness) of treated water. Boiling, which is common in the study area, will release the dissolved oxygen in the water and make the water taste less fresh, and may not be the preferred option. Therefore, other HWT that does not change the taste of water could be a preferred option, such as SODIS (Luzi et al., 2016).

Conclusion

In this study, the role of socio-economic characteristics (SEC) of people in the indigenous Sumba area in Indonesia on the water-related perceptions and the practice of household water treatment were analysed. We combined statistical analyses and Bayesian Belief Network models to analyse the data. We found that SEC influenced water-related perceptions (psychological factors), resulting in higher or lower adoption of HWT. We found that indigenous belief played a significant role in influencing household perceptions. Access to water was the precondition for households to develop the ability to practice HWT. To increase the adoption of HWT, attitude towards the HWT, especially the taste of treated water, also needs to be addressed. Finally, we argue that, based on the multi-factor analyses, improving socio-economic conditions of the respondents is critical to ensure the sustainability of HWT practice.

Chapter 6

Endogeneity in the household water treatment adoption in developing countries

- Interviews with water-related stakeholders / institutions in East Sumba -

This chapter is based on:

Daniel, D., Pande, S., & Rietveld, L. (2020a). *Endogeneity in water-related behavioural analysis: a meta-analysis of household water treatment adoption in developing countries*. Manuscript submitted for publication.

Abstract

Reverse causality or endogeneity in regression analysis results in biased estimation of the effects of independent variables on the dependent variable and leads to inaccurate interpretations. However, the biased estimation in the water–related behavioural study is rarely discussed. Therefore, this study focussed on the endogeneity of psychological factors in water-related behaviour using an instrument variable (IV) approach. Data from eight household water treatment (HWT) studies in Asia, Africa, and South America were utilized. A combination of several socio-economic characteristics, such as education and accessibility, as a control variable and three psychological factors, i.e. perception of risk, attitude towards HWT, and social norms, as predictors of the adoption of HWT were used. Variables related to institutional quality of the countries, based on the World Governance Indicators of the World Bank as the IVs, were used as IV to predict psychological factors. These variables were called institutions in this study. The results suggest that endogeneity exists in water-related behavioural studies. Institutions were found to be valid instruments for psychological factors attitude and norms, but not for the perception of risk. This suggests that the institutional quality "heavily" influences households' attitude and norms regarding behaviour. Moreover, the endogeneity of the psychological factors should be controlled when estimating the effect of psychological factors on water-related behaviour. If the feedback effect of actual behaviour on the psychological factors were not considered or ignored in the analysis, the effects of attitude and norms on HWT adoption were underestimated by 59% and 40%, respectively.

Keywords: Endogeneity, instrument variable, water-related behaviour, institutions, household water treatment

Introduction

Accelerating the provision of water, sanitation, and hygiene (WASH) services are necessary to achieving 100% safely managed WASH services by 2030. In 2017, there were still about 2.2 and 4.2 billion people without safely managed drinking water and sanitation services worldwide, respectively (UNICEF and WHO, 2019). One of the challenges of achieving this goal is the water-related behaviour of a target group (Ginja et al., 2019). Therefore, behavioural change interventions, sometimes called “soft interventions”, become essential elements beside infrastructure or technology interventions, or “hard interventions”, in WASH projects in developing countries (Peal et al., 2010).

Human behaviour, including WASH-related behaviour, is determined by an individual’s psychology and perceptions (Aunger and Curtis, 2016). “Positive and supportive” psychological factors, e.g. the knowledge of the importance of enacting a behaviour, stimulate individuals to do the behaviour (Mosler, 2012a). Hence, understanding the drivers of behaviour is the first step in developing effective behavioural change interventions.

Several psychological theories can be utilised to explain WASH-related behaviour, such as the RANAS model (Mosler, 2012a), the Health Belief Model (Rainey and Harding, 2005), the Theory of Planned Behaviour (Ajzen, 1991; White et al., 2015), and the IBM-WASH model (Dreibelbis et al., 2013). Household interviews or cross-sectional studies among the target groups, i.e. quantitative analyses, are often used (Kesmodel, 2018), in addition to qualitative approaches to identify the behavioural drivers (Wasonga et al., 2016; Shiras et al., 2018). Afterwards, a WASH implementer can target critical behavioural drivers to accelerate the behavioural change. It is believed that theory-based interventions will result in more effective behavioural change interventions (Davis et al., 2015). There are several success stories of using theory-based interventions in the WASH sector (Sonego et al., 2013; Lilje and Mosler, 2018; Tidwell et al., 2019).

The effects of behavioural determinants on WASH behaviour are often analysed by regressing household psychological variables, as predictors or independent variables, on the behaviour variable, as the output or dependent target variable. Previous studies often used, for example, ordinary least squares (OLS) or logistic regression on data obtained from interviews and surveys (Blanca et al., 2018). They often assumes that errors in the dependent variable are uncorrelated with the independent variable in the regression analysis (Verbeek, 2017).

However, this assumption might not always hold in behavioural analysis. That is because there is a possibility of a correlation between the independent variable and the error terms resulting from the “endogeneity” of independent variables (Roberts and Whited, 2012). Endogeneity can emerge as a result of reverse causality or feedback effect from a dependent target variable to the independent variables (Foster and McLanahan, 1996; Abdallah et al., 2015). For example, when the psychological factor *social norms* is used as a predictor variable to predict the use of water filtration in a community, it is assumed that there is a one-way influence from *social norms* to the behaviour of using water filtration. However, one can suspect that households who already use water filtration in a community influence back the *social norms* of that community. This exemplifies a two-way (or bi-directional) feedback between the psychology and the behaviour of households (Figure 1).

Ignoring the bi-directional feedbacks can lead to biased and inconsistent estimations of the effects and inaccurate inferences of psychological factors, e.g., how social norms influence the adoption of water filtration technology (Abdallah et al., 2015). Therefore, the need to analyse it is evident. That is especially because if the feedback effect is significant, the conventional regression analysis that ignores reverse causality may not be sufficient. A two-stage regression or instrumental variable approach is often used to assess this reverse causality (Bascle, 2008).

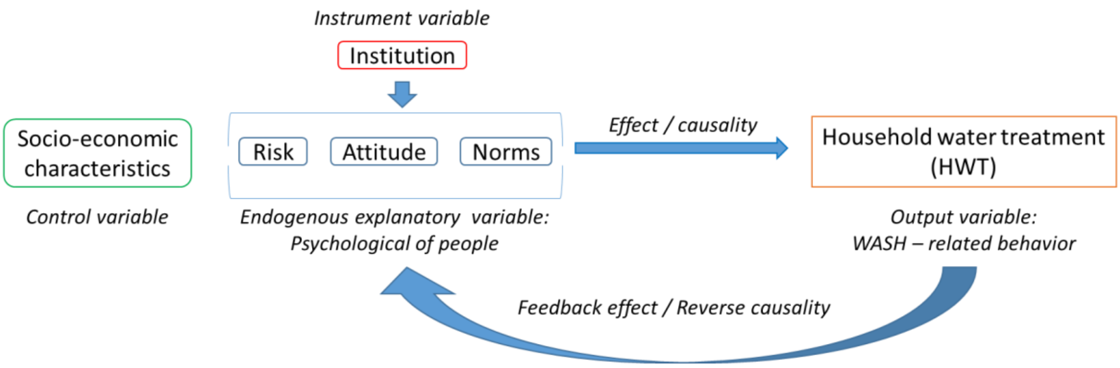


Figure 1. An illustration of the feedback effect or reverse causality in the WASH-related behaviour analysis.

This study focuses on household water treatment (HWT) adoption, i.e. one of the water or WASH-related behaviours. HWT is a method to treat drinking water at home, such as boiling, water filtration, solar disinfection, or adding chlorine (Sobsey et al., 2008). HWT could reduce water-related diseases in many settings in developing countries (Wolf et al., 2018). In order to remedy the potential endogeneity of psychological factors and de-bias its influence on HWT adoption, an *instrument variable* (IV) is used. IV can "breaks" the reverse causality of the effect of the behaviour on the psychology of households (Figure 1). The psychological factors do not act as predictor variables *alone*, but as endogenous explanatory variables, i.e., predictor variables whose values are determined by other variables or IV. The IV should be *directly* related to the psychological factors and only *indirectly* to the behaviour (Foster and McLanahan, 1996). Indirectly means that the influence of IV on the behaviour is "mediated" by the psychological factors. The instrument variables are used to first predict the psychological factors. The predicted factors of the psychological factors are then used in the second stage regression to predict HWT adoption, which result in unbiased estimates of the effects of household psychology factors on the behaviour (Bascle, 2008).

This two-stage regression approach is widely used in econometrics studies to remedy the effects of endogeneity (Roberts and Whited, 2012), but is relatively not used in the field of psychology (Bollmann et al., 2019) and water systems and sociohydrology (Troy et al., 2015; Müller and Levy, 2019),. Some WASH studies consider endogeneity in their analyses, e.g. the studies on WASH-related health issues (Pande et al., 2008; Díaz and Andrade, 2015; Garn et al., 2016; Augsburg and Rodríguez-Lesmes, 2018; Usman et al., 2019), water quality (El Khanji and Hudson, 2016), WASH-related economic studies (Ahmad et al., 2017), WASH program (Bennett, 2012; Wayland, 2018), and perceptions of tap water quality and its relation to the type of drinking water source or the economic value of water (Vásquez et al., 2015; Appiah et al., 2019). However, only Vásquez et al. (2015) have used instrument variables in WASH-related behavioural studies, based on a study case in urban Nicaragua. In addition, they only used one variable related to the psychological factor, i.e., perception regarding the quality of tap water, and focused more on the context of tap water. To the best of our knowledge, there is no study that particularly discuss the endogeneity effect of the HWT adoption in developing countries using more psychological factors, such as perception of risk, attitude, or norm.

The first objective of the study was to investigate the existence of endogeneity of household psychology in the context of HWT adoption. Three psychological factors were used in the analysis: perception of *risk*, *attitude*, and social *norms* toward the behaviour. The second objective was to test the validity of institutional quality, or institutions, as instrument variables for the endogenous psychological variables. This is based on our hypothesis that the institutions is correlated with the psychological factors. The chapter aims to highlight and contribute to the investigation of endogeneity in WASH-related behavioural studies. A meta-analysis of eight HWT studies from seven countries in Asia, Africa, and South America was conducted.

Methods

Datasets

Household survey data from eight HWT studies were utilized. The period of data collection varied from 2005 to 2018. In total, there were 4311 respondents interviewed (Table 1). However, due to incomplete data, 1575 respondents were excluded from the analysis and only 2736 respondents were analysed. Examples of the incomplete data were missing information of the HWT adoption, education level, or information related to wealth. Among the remaining respondents, 814 (29.8%) respondents used HWT, such as solar disinfection, boiling, or water filter. The number of questions asked in the interviews varied. For example, there were 18 questions related to *attitude* in Ethiopia's datasets, but only four questions in Burundi's datasets, and only one in Nepal's dataset. More information about specific datasets can be found in original articles (see the references in Table 1).

Table 1. Information of the datasets and respondent characteristics.

Country	Indonesia (1)	Indonesia (2)	Nepal	Chad	Ethiopia	Burundi	Zimbabwe	Bolivia
Authors	(Daniel et al., 2020c)	(Daniel et al., 2020d)	(Daniel et al., 2019)	(Lilje et al., 2015)	(Sonego et al., 2013)	(Sonego and Mosler, 2016)	(Mosler et al., 2013)	(Tamas, 2009)
Year of data collection	2018	2018	2014	2014	2010	2012	2007	2005
Total samples	369	202	451	1000	159	760	834	536
Total samples after excluding incomplete data	282	164	351	473	92	700	480	194
Use HWT	177 (62.8%)	118 (72.0%)	72 (20.5%)	134 (28.3%)	84 (91.3%)	63 (9.0%)	110 (22.9%)	56 (28.9%)

*if the percentage does not reach 100%, it means there is a missing data in that variable;

Psychological factors: *Risk*, *Attitude*, and *Norms*

Three psychological factors inspired from RANAS psychological framework were available across all eight datasets: *Risk, Attitude,* and *Norms* (RAN) (Mosler, 2012a). *Risk* represents a person's understanding and awareness of the health risk in relation to drinking water. *Attitude* indicates a person's positive or negative stance towards the HWT adoption. *Norms* denote the perceived social pressure towards the HWT adoption. There are several sub-factors within each main factor. *Risk* consists of health knowledge, perception of vulnerability, and perception of severity. *Attitude* consists of feelings towards the behaviour and beliefs about benefits and costs. *Norms* comprise descriptive, injunctive, and personal norms. There is usually one question or information relevant for each sub-factor. Example questions can be found in Mosler & Contzen (2016).

Control Variable: Socio-economic characteristics

Socio-economic characteristics (SEC) of households were used as control variables, i.e. variables that are hold constant (Figure 1). There are four SEC variables which have been linked to the HWT adoption and were available across all datasets: wealth (Opryszko et al., 2010; Roma et al., 2014; Munamati et al., 2016), education level (Nauges and Van Den Berg, 2009; Fotue Totouom et al., 2012; Freeman et al., 2012; Munamati et al., 2016), accessibility (Goldman et al., 2001; Dubois et al., 2010), and whether any children or household members get water-related diseases, e.g., diarrhoea or fluorosis (Christen et al., 2011; Freeman et al., 2012). Education level was recorded as years of education or standard education level, i.e. "no education", "primary school", "secondary school", etc., in the datasets. Those 8 surveys also asked about the case of water-related disease in the household. All datasets relied on household's assets or income to measure the relative wealth index. These four characteristics are often measured in national demographic surveys, such as the Demographic Health Survey (Croft et al., 2018).

Instrument variable (IV): institutional quality

Finding an IV that is statistically correlated with all RAN psychological factors and influences the outcome variable *only* indirectly via RAN is challenging (Foster and McLanahan, 1996). One of the potential instruments for RAN is institutional quality. An institution is defined as "a system of social factors that conjointly generates a regularity of behaviour" (Greif, 2006). Alesina and Giuliano (2015) argue that institutions are endogenous variables, which may be influenced by history, political system, or geographical situation, reflecting emergent local culture and could influence the psychology of people that are responsible for household's behaviour in general.

In the IBM-WASH model, five aggregate levels of WASH behaviour has been identified (from top to bottom): societal/structural, community, interpersonal/household, individual, and habitual (Dreibelbis et al., 2013). The top level *societal/structural level* points to institutional, organisational, policy, and cultural factors that influence the WASH behaviour. The psychological factors, RAN, are located in lower levels: interpersonal/household, individual, and habitual. It is assumed that institutional quality is a potential instrumental variable for RAN, in which strong institutions facilitate appropriate WASH behaviour (Chatterley et al., 2014; Jiménez et al., 2014; Tilley et al., 2014; Barstow et al., 2016; Curtis, 2019). Strong institutions or good governance are characterised by, for example, the existence of a legal framework, clear short and long term strategies, and full compliance with the regulations (Hamer et al., 2020).

"Many sociologists treat all institutions as social norms" (Dequech, (2006), which is because the latter are influenced by the former (Legros and Cislaghi, 2020). The institutions may also be correlated with the perception of *risk* and *attitude*. For example, trust in governmental agencies of water supply could influence the perception of the quality of distributed water (Doria, 2010). There could also be an interplay between institutions, the perception of risk, and attitude that influences a household's decision to treat water, for example regarding smell, taste, colour, and turbidity aspects of distributed water (Jain et al., 2014; Crampton and Ragusa, 2016). Thus while there is strong literature evidence to support that the quality of institutions is correlated with RAN, it remains to be tested whether the quality of institutions is a "valid" instrument.

One of the ways to measure the "quality" of institutions is in terms of governance indicators. Governance is defined as "the traditions and institutions by which authority in a country is exercised" (Kaufmann et al., 2010). Kaufmann et al. (2010) define six dimensions of governance: (1) Voice and Accountability, (2) Political Stability and Absence of

Violence/Terrorism, (3) Government Effectiveness, (4) Regulatory Quality, (5) Rule of Law, and (6) Control of Corruption. Together with the World Bank, Kauffman et al. (2010) published a score that estimates the governance performance of all countries worldwide every year since 1996 based on surveys of companies, households, and assessment of a variety of national or international agencies. The scores, called the Worldwide Governance Indicators (WGI), represent general perceptions of the respondents on countries' performance with regards to the six dimensions and vary from -2 to +2. The scores are constructed in a way that allows meaningful comparison across countries. Low scores mean that a country is weak with regard to the specific indicator and vice versa. Detailed information and definition can be found in Kaufmann et al. (2010). The data can be downloaded from https://info.worldbank.org/governance/wgi/.

Two-stage regression procedure

If the data on socio-economic characteristics of people (*SEC*) and the level of people's perceptions of *risk*, *attitude*, and *norms* with regard to the HWT adoption is available then the standard regression equation to predict *HWT adoption* is shown in equation 1 (Schneider et al., 2010). The SEC of households act as a control variable. SEC is treated as a single variable to simplify the equation 1. The parameters b_2 *to* b_4 quantify the corresponding effects of the independent variables on HWT adoption and ε_i is the error term. Here *i* represents a household. Equation (1) and (2) could be called standard or non-instrumentalised regression equations.

$$HWT\ adoption = b_0 + b_1\ SEC + b_2\ Risk + b_3\ Attitude + b_4\ Norms + \varepsilon_i \quad (1)$$

If *HWT adoption* is coded as a binary variable, i.e., "yes" or "no", the standard logistic regression equation is:

$$P\ (HWT\ adoption = yes) = \frac{e^{(b_0 + b_1\ SEC + b_2\ Risk + b_3\ Attitude + b_4\ Norms + \varepsilon_i)}}{1 + e^{(b_0 + b_1\ SEC + b_2\ Risk + b_3\ Attitude + b_4\ Norms + \varepsilon_i)}} \quad (2)$$

If there is reverse causality from *HWT adoption* to all psychological factors, the error in equation (1) or (2) will be correlated with psychological factors, leading to biased and inconsistent estimation of parameters b_2 *to* b_4. In this situation, the variables *risk*, *attitude*, and *norms* are called endogenous explanatory variables.

In order to remove this effect of reverse causality, appropriate instrument variables are identified and two-stage regression is performed. A valid instrument variable is one that only indirectly influences the dependent variable via the endogenous variables. The correlation between errors and the endogenous variables is broken by regressing the instrument variables on the endogenous variables in the first stage. Afterwards, the "predicted" endogenous variables are used as independent variables in the second stage to predict the dependent or outcome variable. For example, if *norms* is an endogenous explanatory variable and at least one instrument variable is used to predict *norms* using a standard regression analysis (equation 3). This is the first-stage regression, where γ is i.i.d. variable and a_0 and a_1 are first stage regression parameters.

$$Norms = a_0 + a_1\, IV + \gamma_i \quad (3)$$

In the second-stage regression, the predicted *norms* ($\widehat{norms}$) is then used. This is obtained based on regression in equation (3) and used to explain the variance of the dependent variables, instead of using the *norms* obtained directly from the respondent interview. Hence, the equation (1) is then updated to a new regression equation (equation 4 for linear regression and equation (5) for logistic regression), i.e. the second-stage regression.

$$HWT\ behavior = b_0 + b_1\, SEC + b_2\, Risk + b_3\, Attitude + b_4\, \widehat{Norms} + \varepsilon_i \quad (4)$$

$$P\ (HWT\ behaviour = yes) = \frac{e^{(b_0 + b_1\, SEC + b_2\, Risk + b_3\, Attitude + b_4\, \widehat{Norm} + \varepsilon_i)}}{1 + e^{(b_0 + b_1\, SEC + b_2\, Risk + b_3\, Attitude + b_4\, \widehat{Norm} + \varepsilon_i)}} \ (5)$$

Weak instrument variable will result in a poor prediction of the endogenous explanatory variable in the first-stage regression. Consequently, the model performance in the second-stage is also determined by the performance of the first-stage regression. Thus, it is necessary to select a highly correlated instrument for the analysis.

Data analysis

Since there was more than one question related to each RAN psychological factor (Mosler and Contzen, 2016), Principal Component Analysis (PCA) was performed to capture the dominant axes of variations linked to *risk*, *attitude*, and *norms* respectively. For example, there were three questions related to *norms*: personal, descriptive, and injunctive norms. Assuming that responses to these questions might be correlated, PCA was used to obtain their principal component, called *norms*. The same approach was used to reduce the dimensionality of *risk* and *attitude* related factors; see the same approach used by (Daniel et al., 2019, 2020c). The exception was for datasets where only one question related to a psychological factor was available. For example, there was only one question related to *attitude* in dataset for Nepal study. In this case, we used directly the data without performing PCA.

Before analysing the SEC of the respondents, the respondents' years of education was converted into "no education", "primary school", "secondary school", and "high school and higher" in some datasets which measured the education level by years of education to allow dataset inter-comparison. For accessibility, urban area was coded as "easy access" (1) and rural area as "difficult access" (0). Furthermore, households with water-related diseases were coded 1 and 0 otherwise. For datasets that collected household's assets, we used PCA to create the relative wealth index (Houweling et al., 2003); but for datasets which collected household's income, it was used directly to measure the relative wealth index.

To capture the general SEC of the respondents, we combined four SECs using PCA: wealth, education, accessibility, and presence of water-related disease. The first principal component scores were used in the analysis as a control variable (see Figure 1).

For the instrument variables, the values of six governance indicators of those countries in the year of data collection were used. For example, for the case of Zimbabwe where the households survey was conducted in 2007, the WGI scores of Zimbabwe for 2007 was used. Exception was the case for Indonesia where the scores of 2017 were used even though the households survey was conducted in 2018. That was because 2017 was the last year for which WGI scores were available.

An OLS regression in the first-stage regression, i.e., three regressions with *institutions* as the independent variables for *risk*, *attitud*e and *norms* respectively, was conducted. The HWT adoption was coded as a binary variable in all eight datasets, either "yes" (practice HWT) and "no" (do not practice HWT)". Therefore, logistic regression was used in the second-stage regression (Kraemer and Mosler, 2010; Friedrich et al., 2017). All eight datasets were pooled into one and unweighted logistic regression was performed in the second stage.

A valid IV should meet two basic conditions. The first condition is "relevance" or it should be (strongly) correlated with the endogenous explanatory variable, i.e., RAN. The second condition is exogeneity or it should not be correlated with the output variable HWT adoption, after controlling for the endogenous explanatory variable and the control variable in the output equation (Tabellini, 2010; Becker, 2016).

The first assumption was tested empirically by OLS regression of instrument variables, i.e. WGI scores, on each psychological factor, i.e. *risk*, *attitude* and *norms*. We assessed the relevance of instruments by looking at: (1) the R^2 value (strength of correlation), and (2) an *F*-test of all the regressions (Bound et al., 1995). As a rule of thumb, the *F*-stats above 10 suggesting that the assumption of weak instruments are not violated (French and Popovici, 2011). Furthermore, even though there is no formal agreement on the R^2 value, we used R^2 value above 0.25 as a threshold for “good” or “accepted” correlation. Only instruments that pass both conditions were used in the analysis.

In contrast with the first assumption that can be tested empirically, Appiah et al. (2019) argue that the exogeneity assumption cannot be empirically tested. This can be the reason why the WASH-related studies have not tested this second assumption (Pande et al., 2008; Bennett, 2012; Díaz and Andrade, 2015; Vásquez et al., 2015; El Khanji and Hudson, 2016; Garn et al., 2016; Ahmad et al., 2017; Wayland, 2018; Augsburg and Rodríguez-Lesmes, 2018; Appiah et al., 2019; Usman et al., 2019). However, we followed the approach of Tabellini (2010) to test the exogeneity assumption. This was done by regressing the control variable, predicted psychological variables (obtained from the first stage), the remaining psychological factor (the psychological factor that is not treated as endogenous), and the used instrument variables on *HWT adoption*. The validity of the instruments was verified if the regression coefficients of the instrument variables become insignificant.

Moreover, to avoid multi-collinearity, different combinations of governance indicators for each of the psychological factors were considered in the first-stage regression. For example, if the indicator *political stability* was used as IV for *attitude*, it was not used as the IV for *norms*. Various possible combinations of WGI indicators were then sought and potential combinations were selected using three criteria: (1) the R^2 must be above 0.25, i.e., to indicate good prediction, (2) meet the second assumption of a valid instrument, i.e., exogeneity, plus (3) the predicted endogenous psychological factors must be significant in the second stage regression. Wald tests were conducted for exogeneity assumption, i.e., whether the “suspected” psychological variables were indeed endogenous.

Afterwards, the second-stage logistic regression was performed (equation (5)). The results were compared with the “non-instrumentalised” logistic regression (equation (2)), i.e. logistic regression of *HWT adoption* without removing the endogeneity effect of psychological factors.

Results

The Wald tests show that *attitude* and *norms* were endogenous, giving χ^2 values of 49.04 and 126.80, respectively (both significant at p value <0.001). The validity of the IVs was then first tested before performing the two-stage regression. The results of the first assumption, i.e. IVs are strongly correlated with the endogenous variable, are shown in Table 2 and 3. When all six indicators were inserted at once as predictors to predict RAN in multiple linear regressions , the R^2 was relatively low for *risk*, but quite high for *attitude*, and *norms* (Table 2). Furthermore, one-to-one linear regressions between each WGI indicators and RAN were investigated. The results show that a single WGI indicator was weakly correlated with *risk* and *attitude*, but reasonably correlated with *norms*, giving an average R^2 of 0.179 (Table 3). The results of Table 2 and 3 indicate that: (1) WGI indicators were weak instruments for *risk* and (2) multiple WGI indicators needed to be used to predict *attitude* and *norms* in order to increase the R^2 value between respective observed and predicted psychological variables. Therefore, *risk* was treated as an exogenous variable in the second stage regression. Moreover, all six indicators were found to be significant predictors of *norms* in multiple linear regressions (Table 2) where the average R^2 for *norms* was the highest (Table 3), indicating that governance indicators were more related to the social norm, compared to *risk* and *attitude*.

Table 2. Unweighted multiple linear regression of *all* six governance indicators on Risk, Attitude, and Norm[a].

Governance indicators	Risk	Attitude	Norms
Voice and accountability	1.333 (0.672)*	-0.033 (-0.015)	1.831 (0.175)*
Political stability and absence of violence or terrorism	-1.936 (-0.748)*	-3.211 (-1.130)*	-5.128 (0.301)*
Government effectiveness	-0.358 (-0.160)	-3.304 (-1.349)*	-1.966 (-0.862)*
Regulatory quality	3.190 (1.672)*	4.219 (2.015)*	2.076 (1.064)*
Rule of law	-6.837 (-2.647)*	-11.025 (-3.888)*	-7.372 (-10.425)*
Control of corruption	3.269 (1.265)*	12.016 (4.237)*	9.944 (3.765)*
R^2	0.163	0.441	0.344

*significant at 0.001 level; **significant at 0.05 level; the value inside the parentheses is the standardised coefficient (β); [a] all six indicators were inserted at once in the analysis; All F statistics > 10.

Table 3. Unweighted linear regression of *each* six governance indicator on Risk, Attitude, and Norm[b].

Governance indicators	Risk		Attitude		Norms	
	B	R^2	B	R^2	B	R^2
Voice and accountability	0.346*	0.030	-0.298*	0.019	0.814*	0.161
Political stability and absence of violence or terrorism	-0.029	0.001	0.941*	0.110	0.798*	0.091
Government effectiveness	0.291*	0.017	0.397*	0.026	1.119*	0.241
Regulatory quality	0.333*	0.030	-0.551*	0.069	0.771*	0.156
Rule of law	0.256*	0.010	-0.451*	0.025	1.168*	0.196
Control of corruption	0.059	0.001	0.631*	0.050	1.264*	0.229
Average R^2		0.015		0.050		0.179

*significant at 0.01 level; [b] the indicator was inserted one-by-one in the analysis; All significant coefficients have F statistics > 10.

The one-to-one regression between each WGI indicator and each RAN gave positive correlations for 13 out of 16 significant relationships (Table 3). This indicates that good institutions' performance, i.e. higher scores of WGI indicators, positively stimulated the household psychology regarding HWT adoption.

To avoid multi-collinearity, combinations of WGI indicators were investigated that could predict *attitude* and *norms* using the three criteria that have been mention previously (section data analysis). Two combinations were found that met those three assumptions: (1) *Voice & accountability* and *Government effectiveness* to predict *attitude* ($R^2 = 0.252$), and (2) *Political stability and absence of violence or terrorism* and *Control of corruption* to predict *norms* ($R^2 = 0.295$). The predicted *attitude* and *norms* were also significant in the second stage regression (Table 4, column 2). Furthermore, the second assumption of a valid instrument was also fulfilled (Table 4 column 3-5). These instruments were not significant at p value <0.001, when included in the logistic equation with other predictors, i.e. SEC, *risk*, and predicted *attitude* and *norms*.

Table 4. Testing the second assumption of instrument validity: Unweighted logistic regression of selected governance indicators as instruments, socio-economic characteristics of respondents (*SEC*), exogenous psychological factor, and predicted endogenous psychological factors on HWT adoption.

Predictor variables	**Coefficients (B) in the logistic regression**			
SEC	0.483 (1.621)*	0.479*	0.504*	0.495*
Risk	0.197 (1.218)*	0.200*	0.198*	0.229*
$\boldsymbol{\widehat{Attitude}}$	1.203 (3.331)*	1.191*	1.152*	0.927*
$\boldsymbol{\widehat{Norm}}$	1.104 (3.018)*	1.148*	0.991*	1.329*
Voice & accountability		-0.051		-0.587***
Political stability and absence of violence or terrorism			0.258	0.617**
Government effectiveness		n.a.		n.a.
Control of corruption			n.a.	n.a.
Pseudo R^2	0.210	0.210	0.211	0.213

*significant <0.001; **significant <0.01; ***significant <0.05; the value inside the parentheses is the standardised coefficient (β); n.a. variable is omitted from the analysis due to redundancy. $\widehat{attitude}$ is predicted by *Voice & accountability* and *Government effectiveness*; $\widehat{norms}$ is predicted by *Political stability and absence of violence or terrorism* and *Control of corruption*.

We further performed the standard logistic regression using *SEC* and RAN as predictors of *HWT adoption* to compare its results with the two-stage regression. The coefficient (B) of the endogenous variables *attitude*, and *norm* were 0.758, and 0.790, respectively. The equation explained 30% of the variance in the output variable *HWT adoption*, and *norms* appeared to be the most significant predictor (highest β).

Table 5. Unweighted logistic regression of socio-economic characteristics of respondents (*SEC*), *Risk*, *Attitude,* and *Norm* on HWT adoption.

Variables	**B**	**SE B**	**β**
SEC	0.489*	0.053	1.631
Risk	0.124**	0.045	1.132
Attitude	0.758*	0.050	2.134
Norms	0.790*	0.047	2.203

*$p \leq 0.001$, ** $p \leq 0.01$ Pseudo $R^2 = 0.300$, n = 2736.

Table 4 column 2 shows the results of the second stage regression. The coefficients of the endogenous variables *attitude* and *norms* were 1.203 and 1.104, respectively, and the R^2 was 0.210, being lower than the standard logistic regression (0.300) (Table 5). The reduction in explained variance can be attributed to the low variance in the first stage regression of endogenous variables *attitude* and *norms*. However, the effect of *attitude* and *norms* on HWT adoption was underestimated by the standard logistic regression. The coefficients (B) of *attitude* and *norms* are 0.758 and 0.790, respectively, (Table 5) in standard logistic regression, compared to B = 1.203 (59% higher) and 1.104 (40% higher), respectively, (Table 4 column 2) in the second-stage regression or when *attitude* and *norms* were treated as endogenous variables . Additionally, *norms* was the most significant psychological factor in the standard regression (highest β, Table 5), but *attitude* became the most significant psychological factor in the two-stage regression approach (Table 4 column 2). The variable *risk* remained the least significant factor in both approaches.

Discussion

This chapter found that psychological factors are endogenous in water-related behaviour. The endogeneity of *attitude* and *norm* led to a biased estimation of the corresponding effect by 59% and 40%, respectively. All predictors, i.e., SEC and psychological factors, positively influenced the HWT adoption, as showed by the positive coefficients. This findings indicate that households that have favourable, i.e., better conditions of, SEC and psychological factors are more likely to treat their drinking water.

The analysis shows that the most significant psychological factor changes from *norms* in the standard logistic regression to *attitude* in the two stage regression. Another observation is that the psychological factor *risk* seems to be less significant when compared to attitude and norm in influencing the HWT adoption. A person's awareness of risk is not enough to sustain the water-related behaviour, as also suggested by the previous multi-country review of HWT adoption (Lilje and Mosler, 2017). Apparently, the personal feeling or satisfaction after using the water-related technology and external nudges from outside or society are more important to drive the behaviour. This idea is also proposed by the theory of planned behaviour (Ajzen, 1991).

The existence of endogeneity in water-related behaviour suggests the need to analyse the feedback effect from behaviour to psychological factors. This feedback effect will lead to a total effect in the system that is "reinforcing" itself, i.e. the psychological factors and the behaviour are mutually reinforcing (Latkin et al., 2013; Huber et al., 2017) (Figure 2). It means that the accumulation of positive norms and attitude perceptions in a community could increase the use of HWT, both in terms of regularity and quantity, i.e. from few number of users to more HWT users. For example, the more people use HWT, the higher the norms in the society to treat drinking water, and this will attract even more people to use HWT. The same situation may apply for perception of attitude, since people who use HWT are more likely to have a positive attitude towards treated water by HWT and then influence their peers to use HWT.

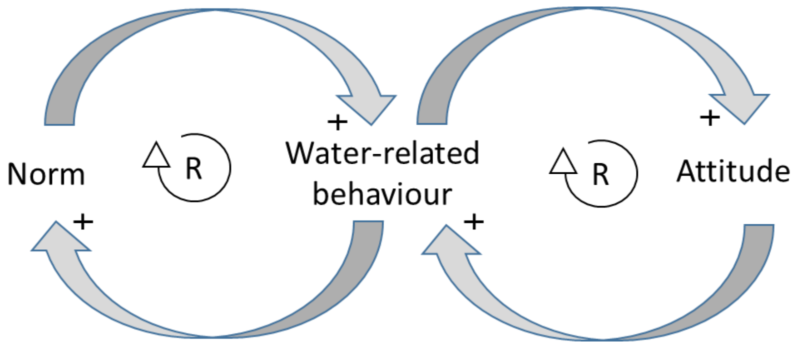


Figure 2. The psychological factors and the HWT adoption are mutually reinforcing.

This study confirms that *institutional quality*, as represented by the governance indicators, is one of the potential IVs for psychological factors. The results show that good institutions, showed by higher scores of the WGI indicators, lead to favourable psychological factors in the water sector. For example, a regulation by a municipality can lead a social norm to treat drinking water. Economic incentives by the municipality can also allow low-income people to afford water-related technology, i.e. influencing attitudes related to cost. This supports the argument that institutions can either catalyse or inhibit the adoption of water-related technologies or behaviours (Pande and Sivapalan, 2017; Bromley and Anderson, 2018; Pande et al., 2020).

The governance indicators are closely related to norms, as also suggested by others (Dequech, 2006; Legros and Cislaghi, 2020). One of the interpretations is that institutions are products of culture, and culture is closely linked to the social norms of a society (Tabellini, 2010; Alesina and Giuliano, 2015). Another study has mentioned that values, beliefs, and norms are part of the culture (Roobavannan et al., 2018). We then argue that institutional quality is *theoretically* an appropriate instrument for norms.

The perception of risk was not found to be endogenous in the analysis due to its low correlation with the IVs, even though previous studies show that the quality of institutions could influence the risk perception of people (Doria, 2010; Jain et al., 2014; Vásquez et al., 2015; Crampton and Ragusa, 2016). However, those studies also imply that perception of attitude may mediate the impact of institutions on risk and diminish the "direct effect" of institutions on risk perception. For example, unreliable treatment processes and services by a water supplier, i.e. one of the indicators of weak institutions, may result in bad taste and odour of the tap water, i.e. one of the attitude aspects. People may then perceive that the chance of getting sick due to drinking untreated water is high, i.e., perception of risk.

Vásquez et al. (2015) has used two instruments, (1) hours of water supply interruptions and (2) perception of receiving better water quality compared to their peers, to predict the perceptions of water quality, i.e. part of the *attitude* factor. However, they do not show the fit results of the model (R^2) which does not allow to the comparison with the instruments used here. Furthermore, this study confirmed that the perception of attitude is endogenous to institution's performance (Doria, 2010; Jain et al., 2014; Vásquez et al., 2015; Crampton and Ragusa, 2016).

The use of institutional quality as instruments has a major limitation. Institutional quality cannot be used as instruments for prevalent psychology if the case study is located in the same area, because all respondents then have the same institutional environment. Using institutional quality as instrument is mainly applicable for meta-analyses, where behaviour in different contexts or locations are studied, unless information on local institutional setting is obtained as well. Therefore, the IV approach is strongly suggested in analysing water-related behaviours if good instruments for psychological factors can be found, since institutional quality may not be applicable as instruments in all situations. Future studies need to come up with other choices for instrumental variables.

Conclusion

This study utilised data of eight HWT studies in low-middle income countries to investigate the endogeneity in HWT adoption. We confirmed that endogeneity exists in the water behavioural system. Institutions, which are represented by governance indicators, were used as instrument variables to tackle endogeneity in the psychological factors *attitude* and *norms.* Results demonstrated that institutional quality directly influence the attitude and social norms related to water technology or behaviour. In contrast, institutional quality was not a good instrument for *risk*, indicating that perception of *risk* is not directly influenced by institutions. The second-stage regressions showed that attitude towards water technology or behaviour is the most significant psychological factor to make households use HWT, followed by the social pressure from the community, i.e. social norms. The perception of risk had only half of the effect of *attitude* and *norms*. Moreover, the effect of *attitude* and *norms* were larger when we treated their endogeneity. This study underlines the need to treat psychological factors as endogenous variable in water or WASH-related behavioural analyses..

Chapter 7

Linking drinking water quality and sanitary inspection in a medium resource setting: A study case of rural Indonesia

- Water quality analysis using portable equipment in East Sumba, Indonesia -

This chapter is based on:

Daniel, D., Iswarani, W. P., Pande, S., & Rietveld, L. (2020). *A Bayesian Belief Network Model to Link Sanitary Inspection Data to Drinking Water Quality in a Medium Resource Setting in Rural Indonesia*. Manuscript accepted in *Scientific Reports*.

Abstract

Assessing water quality and identifying the potential source of contamination, by Sanitary inspections (SI), are essential to improve household drinking water quality. However, no study link the water quality at a point of use (POU), household level or point of collection (POC), and associated SI data in a medium resource setting using a Bayesian Belief Network (BBN) model. We collected water samples and applied an adapted SI forms at 328 POU and 265 related POC from a rural area in East Sumba, Indonesia. Fecal contamination was detected in 24.4 and 17.7% of 1 ml POC and POU samples, respectively. The BBN model showed that the effect of holistic - combined interventions to improve the water quality were larger compared to individual intervention. The water quality at the POU was strongly related to the water quality at the POC. The effect of household water treatment to improve the water quality was more prominent in the context of better sanitation and hygiene conditions. In addition, we found that the inclusion of extra "external" variable, besides the standard SI variables, could improve the model's performance in predicting the water quality at POU. In our case is a variable related to the fullness level of water at storage. Finally, the BBN approach proved to be able to illustrate the interdependencies between variables and to simulate the effect of the individual and combination of variables on the water quality.

Keywords: Water quality, sanitary inspection, bayesian belief network, risk assessment, system-level approach

Introduction

It has been recognised that unsafe drinking water is responsible for high numbers of diarrheal morbidity and mortality among children below the age of five (Prüss-Ustün et al., 2014). Water quality analysis becomes crucial because supplied water in low and middle-income countries (LMICs) is often contaminated, even though it is categorised as an improved water source (Bain et al., 2014b). Groundwater, which is considered safer than surface waters, is also found contaminated in many locations (Podgorski and Berg, 2020). In Addition, high levels of contamination has been found at the household level in LMICs and water quality often deteriorates after collection (Wright et al., 2004; Levy et al., 2008; Daniel et al., 2020a).

The World Health Organization (WHO) and International Water Association (IWA) launched a Water Safety Plan (WSP) concept to minimise the risk of contamination and provide safe drinking water to people. WSP is a comprehensive risk assessment and management covering all steps in water supply from catchment to consumers (WHO, 2012). Identifying potential sources of contamination is part of the risk assessment and one of the critical elements in WSP.

In order to assess potential sources of contamination in a water supply system, systematic observation called sanitary inspections (SI), are performed. SI variables record potential sources of contamination based on "on-site inspection and evaluation by qualified individuals of all conditions, devices, and practices in the water-supply system that pose an actual or potential danger to the health and well-being of the consumer" (WHO, 1997). SI have the advantage to be easy to implement, not expensive, can be adapted to the local context, and can give a quick snapshot of potential causes or pathways of contamination. However, SI are not a substitute for drinking water quality testing, but identify contamination source in the system, especially in the context of risk management. SI can be used to design appropriate actions to change the situation (Howard et al., 2007). Therefore, it has been recommended to accompany drinking water quality testing with SI (Misati et al., 2017).

Conducting drinking water quality testing in LMICs, however, can be challenging, especially because of limited resources such as laboratory facilities or infrastructure (Diener et al., 2017). Bain et al. (2012) summarised all available microbial water quality tests for low and medium resource settings and they classified the resource settings into low, medium, and high resource settings. A low resource setting has been characterised as having no laboratory equipment and 24 h electricity. The medium one has at least a basic laboratory or clean space with 24 h electricity, while the high resource setting is equipped with reliable 24 h electricity and a modern laboratory. Researchers are able to choose relevant water quality tests according to local context or situation.

Attempts have been made to link SI data to drinking water quality to judge the reliability of the system. The most common approach has been to analyse the SI and drinking water quality by using statistical analyses, e.g., bivariate correlation or regression analyses, especially in high resource settings (Dey et al., 2017; Ercumen et al., 2017a; Misati et al., 2017; Snoad et al., 2017; Robinson et al., 2018; Daniel et al., 2020a).

Bayesian Belief Network (BBN) is another alternative to analyse factors responsible for the water quality (Bertone et al., 2016; Tang et al., 2016). BBN offers benefits compared to other statistical methods, such as the ability to integrate quantitative and qualitative information in the model and an intuitive visualisation of the hypothetical causal relationships. These can aid stakeholders with less technical knowledge in understanding the system (Cain, 2001).

However, the application of BBN in analysing water quality at the household level (mentioned as a point of use (POU)) and at water source or point of collection (POC) is very limited. Hall & Le (2017) utilised BBN to predict the faecal contamination of drinking water by household's socio-economic characteristics as predictor variables, however not using SI variables. To the authors' knowledge, the present study is the first to link drinking water contamination at the POU with a *combination* of water quality at POC, the hygiene conditions in the household, water handling, and household water treatment (HWT) practices in a medium resource setting. This study aims to delineate the microbial water quality and general sanitary conditions in POC and POU in the district of East Sumba, Indonesia.

Methods

Study setting

A cross-sectional study was conducted in July – August 2019 in the district of East Sumba, Province East Nusa Tenggara, Indonesia (Figure 1). This study is the continuation of a previous household water treatment study conducted in the same area (Daniel et al., 2020c). A total of 328 households in 9 villages in four sub-districts were revisited during this study. This area is known as one of the poorest areas in Indonesia where open defecation is still common and there is high prevalence of children's malnutrition (Sungkar et al., 2015). The topography of the area is hilly. Furthermore, about 40% the total populations in East Sumba relied on wells as their main water source and only 18% had access to piped distribution system in 2017 (BPS Statistics of East Sumba Regency, 2018). No water treatment is conducted in the rural piped distribution systems in this area.

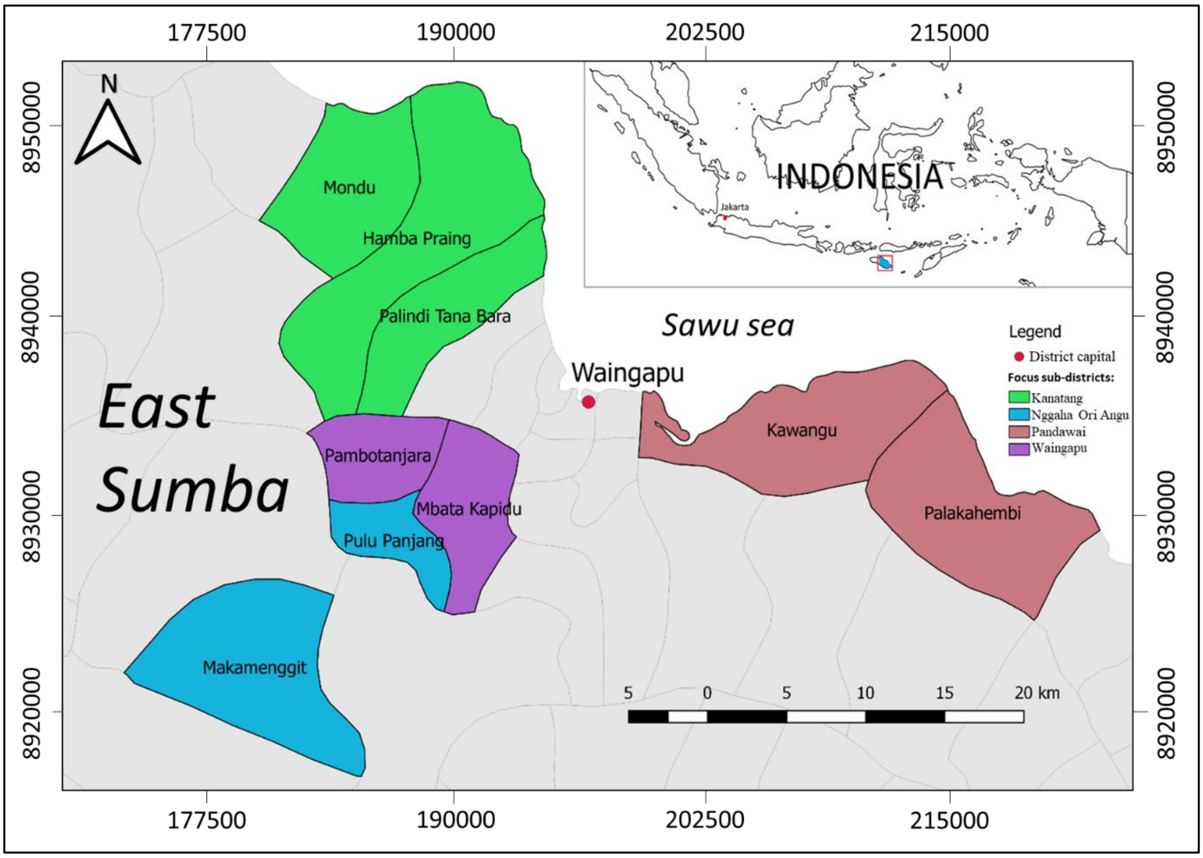


Figure 1. Map of the study location. There were 9 villages visited in four sub-districts. The map is drawn using QGIS (QGIS Development Team, 2017).

Approximately 100 mL of drinking water sample, i.e., from the drinking water storage container, was taken at each household. The households were asked to give water in the same way as for drinking water. The water samples were put in Nasco Whirl-Pak bags and kept inside a thermos during the transport to the field lab. All the samples were analysed within six hours after collection. We only analysed the microbial water quality and used *E. coli* as an indicator bacteria for fecal contamination in water (WHO, 2017). We took 1 mL of sample using a 1 mL sterile pipette and placed it on a Nissui Compact dry EC plate (CDP) and incubated for 24 hours at 35 ± 2º C (Nissui Pharmaceutical Co. Ltd). After incubation, we counted the colony forming units (CFU) of *E.coli* in the CDP and reported in concentration units (CFU/1 mL). The process was conducted as sterile as possible to prevent contamination from sample processing, e.g., using hand gloves and sterile pipette tips when processing the sample, avoid touching the inside of the whirl-pack bag when collecting and processing the sample, and working in a stable and clean space. The sample processing was conducted by two master students from Delft University of Technology who were familiar with microbial water quality analyses. According to the classification of Bain et al. (2012), our analysis was categorised as medium resource setting, e.g., there was neither distilled water and proper disinfection for laboratory equipment. Data were collected during the dry season with temperature in that area ranging from 25º - 26º C.

For the SI, we used the Open Data Kit (ODK) software on a smartphone, and the data were transferred to a computer for analysis. We did SI at POCs and POUs. Information taken at a POC and POU can be found in Table 1. Participation was voluntary and a written informed consent was obtained from all participants. The study was approved by the Human Research Ethic Committee of Delft University of Technology and the Agency for Promotion, Investment, and One-Stop Licensing Service at the district level. All experiments were conducted in accordance with relevant guidelines and regulations.

Table 1. Information used for the analysis.

Point of collection (POC)*	**Surrounding environment – hygiene condition**	**Water storage condition and HWT**
Type of POC [Which source do you use for drinking water purpose right now?]*	*Still practise open defecation* [What types of toilet do you have?]	*Storage covered* [Is the water storage being covered (at that time)?]
Livestock nearby [Is there livestock near the point of collection (POC), 10 m?]	*Livestock nearby* [Is there livestock around the house?]	*Storage cracked* [Is the container cracked ?]
Prone to erosion [Is the area uphill from the source visibly eroded or prone to erosion?]	*Floor cleanliness* [How is the cleanliness of the house floor?]	*Place of storage* [When not in use, is the storage container kept in a place where it may become contaminated? E.g., can be reached by animal

		easily; open space (risk by flies), etc.]
Excreta / garbage nearby [Is excreta or garbage found within 10 m of the tap stand/water source?]	*Faeces around* [Is there human or animal faeces in the yard (or even inside the house)?]	*fullness level of water at storage* [How full is the water storage?] **
Proper fencing [Is there proper fencing or a barrier around the well to prevent contact with animals?]	*Garbage around* [Is there garbage around the house?]	Household water treatment [Is the water in the storage treated?]
Latrine within 10 m [Distance to the nearest latrine (m)]	*Flies around* [Could you see flies around the water storage container?]	
Cracked structure [Are there any damages/cracks in the system/source?]		
*E.coli detected at POC / well**		

¶The sentence inside the [ ] were the questions in the sanitary inspection and the italic words were the variable / node name in the BBN. *based on water quality testing. ** External variable besides standard SI variables

Bayesian Belief Network (BBN)

BBN is a directed acyclic graph showing a hypothetical causal relationship between "causal" variables (where the arrow start; called "parent nodes" in BBN) and an "affected" variable (called "child node") (Pearl, 1988). The strength of the relationship between parent and child node is shown by the values in the Conditional Probability Tables (CPT) of the child node. The CPT values are showing the probability of a child node in a particular state or category, given all possible combination of the states of its parent nodes. The CPT values can be obtained from expert or stakeholder judgment or elicitation, the output of other models or calculations, or by direct measurement. Cain (2001) provides a clear explanation of using a BBN in the water sector.

Data analysis

A BBN's structure is often inspired by a conceptual theory or framework or by consensus between experts in that field (Nadkarni and Shenoy, 2004). There are some conceptual frameworks from previous water, sanitation, and hygiene (WASH) studies that can be adapted into a BBN's structure (Cohen et al., 2015; Navab-Daneshmand et al., 2018), including the well-known F-diagram (Wagner et al., 1958). According to those frameworks, there are four main clusters of determinants of water quality at POU: (1) Surrounding environment - hygiene condition, (2) HWT, (3) the water quality at POC, and (4) the water storage conditions (see Figure 2). All variables for these four cluster are often included in a standard SI form (WHO, 1997).

However, Navab-Daneshmand et al. (2018) argues that fecal contamination at the household level in LMICs is complex. This implies that there might be other variables, besides SI variables, that could correlate with the household drinking water quality. This includes container material, duration of storing water, inappropriate extraction water from storage, etc. (Brick et al., 2004; Elala et al., 2011; Boateng et al., 2013). However, all these "external" factors are not included in the standard SI form (WHO, 1997).

Based on the above mentioned literature, we created a conceptual model of potential factors that could influence the water quality at the household level (Figure 2). The conceptual model includes multiple contamination pathways in a system (Eisenberg et al., 2012), and was used to create the BBN's structure by clustering SI variables based on those five clusters.

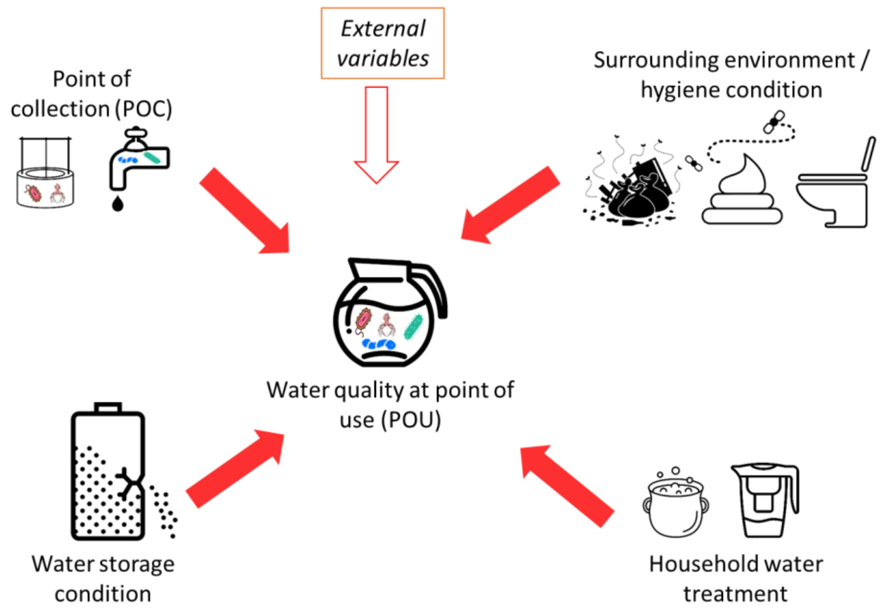


Figure 2. The conceptual model of five clusters of the determinants of water quality at a point of use (POU). Red arrows indicate that the variables are often included in a standard SI form and white arrow is not included in the standard SI form.

Because some houses used the same POC, we could make pairs of 271 POCs – POUs (Figure 3). 49 POU did not have POC samples. That is because POC samples were not taken, mostly due to long distance walk (>30 min return trip). However, these 49 POU samples were included in the BBN analysis, since the EM algorithm compensated for the missing information with the available data (Do and Batzoglou, 2008).

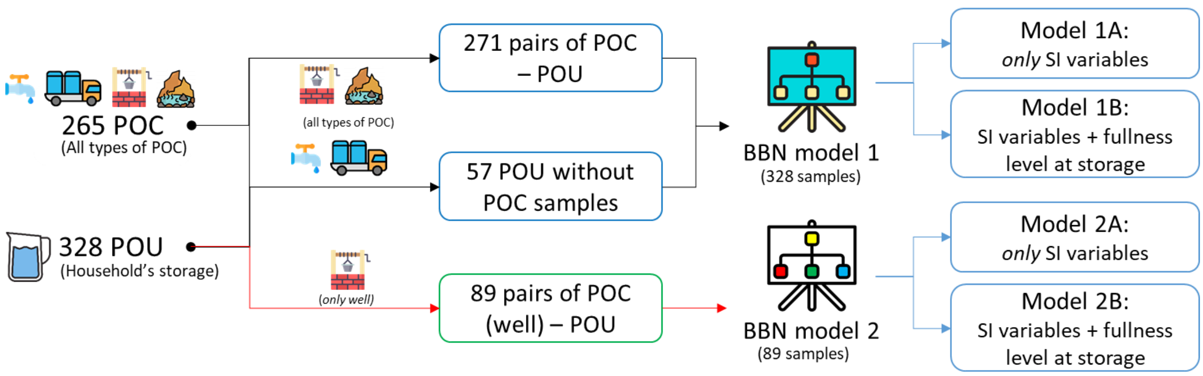


Figure 3. Overview of the datasets and analysis.

Four BBN models of the water quality at the POU were created (Figure 3). BBN model 1 (A and B) and 2 (A and B) differ in terms of the variables used in the cluster of POC. For BBN model 1 we added node *Type of POC* as a parent node for *E.coli detected at POC* (Figure 4-5). But for BBN model 2 we used information of the SI at the POC as parent nodes of *E.coli detected at POC*, but we modelled only one type of POC: well (Figure 6-7). That is because the SI information that we collected at POC were only relevant to the well's characteristics. For BNN model 1, we had in total of 328 samples and for BNN model 2 was only 89 well samples (Figure 3).

In addition, we added one extra variable, *fullness level of water at storage*, on top of both models and compared the model's performance, i.e., BBN model 1A vs 1B and model 2A vs 2B. This variable could indicate the duration of storing water, because water quality could deteriorate over time (Levy et al., 2008). Thus, BBN model 1A and 2A were the BBN models with SI variables *only* and BBN model 1B and 2B were the BBN models with SI variables plus variable *fullness level of water at storage*. The results of validation tests indicated the model's performance. The predictive inference tests were then conducted using BBN models with the best performance.

Moreover, Since it is not recommended to have many parent nodes in BBN (Cain, 2001), we needed to reduce the BBN structure as much as possible. Clustering the SI variables reduces the parent nodes of the outcome node, e.g water quality at the POC. All variables in the SI for POC were grouped as one cluster and the variables in the SI related to water storage were grouped as another cluster. In the latter case, e.g, three variables related to the condition of the water storage, *Storage covered*, *Storage cracked*, and *Place of storage*, were connected to an intermediate node *Chance of (re)contamination from water storage* (red node in Figure 4).

Since we did not have the information on intermediate nodes in our datasets, the CPT corresponding to this node was populated manually. First, we gave score 1 to the best situation in each variable, e.g., score 1 if "yes" in variable *storage covered* and score 1 if "no" in variable *storage cracked*. Then we created a simple index by summing all the scores of the three parent nodes. Finally, we categorised it as "low" if the total score was 0-1, "moderate" if the total score was 2, and "high" if the total score was 3. In the same way, another intermediate node *Chance of (re)contamination from environment* was created by six variables (six parent nodes of this variable, see Figure 4). We categorised it as "low" if the total score was 0-2, "moderate" if the total score was 3-4, and "high" if the total score was 5-6. Different from the other intermediate nodes, we used the results of water quality testing to fill the information of node *E.coli detected at POC* (see Figure 4; green nodes). BBN requires discrete or categorical information for the analysis. Therefore, we discretised and categorised the number of *E.coli* into *E.coli* detected or non-detected.

We used software GeNIe 2.2 (http://www.bayesfusion.com) to perform the BBN analysis. The software uses the Expectation Maximization (EM) algorithm to estimate the CPT values (Do and Batzoglou, 2008). We performed validation tests using the same software to assess the model's performance. We used the ten-fold cross-validation and the performance was reflected by the value of area under the ROC curve (AUC): AUC of 0.5 indicates poor model, AUC between 0.5 and 0.7 is a "less accurate" model, $0.7 < \text{AUC} \leq 0.9$ is a "moderately accurate", $0.9 < \text{AUC} < 1$ is a "highly accurate" model, and AUC = 1 is a perfect model (Greiner et al., 2000).

We also conducted a "predictive inference" in BBN to find influential nodes that help us to prioritise actions to improve the water quality of POU in that area. We performed that by setting the state of a specific node to 100% and observe the updated probability in the output node. For example, if we wanted to observe the influence of HWT on POU's water quality, we set the probability of node *Household water treatment* being "yes_treat" to 100% and observed the updated probability of *E.coli detected at POU* being "detected". We did that to all states in all nodes.

Finally, we simulated the "best scenario" by setting the best situation of all SI variables (outer nodes) at all clusters, including node *Household water treatment* being "yes_treat" and node *E.coli detected* *at POC* being “not_detected”. By setting node *E.coli detected at POC* being “not_detected”, we assumed that all types of water source that household use are safe.

Results

Socio-demographic characteristics of the respondents

When asked about the education of the household’s head, 12.5% of them had no formal education, and 57.3%, 11.9%, and 18.3% finished primary, secondary, and higher school, respectively. In terms of housing condition, 87.6% did not have permanent walls, e.g., wood or bamboo, 7.5% did not have a permanent roof, i.e., straw, and 71.4% still had a natural floor, i.e., compacted soil. Moreover, 45.3% of the respondents had no electricity. About 32.7% of the respondents practised open defecation. Based on observations, households either had simple pit latrines or pour-flush latrines, some were communal and some were in respective households. Tap water (from a small-scale distribution network) was used by 31.8% of the respondents, followed by wells 27.2%, water trucks 19.6%, and spring water 17.4%, respectively. Remaining respondents used river water, rainwater, or refill potable water stations. Boiling was used to treat the drinking water.

Description of the sanitary inspection and water quality results

The general hygiene situation of the respondents is depicted in the BBN model, i.e. the outer nodes in Figure 4 (in blue colour). For example, 23% of the respondents did not cover their drinking storage and only 30% of the respondent’s houses were free from flies. From the cluster of *surrounding environment – hygiene condition*, we found that 66.7% of the respondents kept their livestock near the house, resulting in 60% of the respondents had animal faeces around the house. In addition, 89% and 70% of the respondents had garbage and flies around the water storage or house, respectively. These conditions led to only 15% respondents had low chance of contamination from the surrounding environment and hygiene condition.

The general condition of the cluster *water storage condition* indicated that 37% of the respondents had a low chance of contamination from "bad condition of water storage". The low chance means that the respondents comply to all three criteria: storage with cover, without cracking, and proper - safe place. About 77% and 96% of the storages were found to be covered and without cracking, but 51% of the storages were put in a place that can be prone to (re)contamination, e.g. on the floor.

Of all the POU samples, 56.5% of the respondents claimed to treat water at the time of visit. 75% of households who abstracted water from river treated their drinking water, followed by 68.5% and 59.4% from households who used well and piped system, respectively.

Of all the POU samples, 56.3% of our respondents claimed to treat water at the time of the visit. For the water quality, we did not detect *E.coli* in the 1 mL samples in 195 (75.6%) of the POC samples and 270 (82.3%) of the POU samples. *E. coli* was not detected in almost 90% of the piped and spring samples. On the other hand, 42% and 83% of well and river samples, respectively, were detected with *E. coli*.

Comparison of the BBN models' performance

The four BBN models are shown in Figure 4 – 7. We first compared the performance of BBN models with SI variables *only* and SI variables plus extra variable *fullness level of water at storage*. The validation tests of these four BBN models gave AUC value: 0.55, 0.69, 0.71, and 0.84 for model 1A (Figure 4), 1B (Figure 5), 2A (Figure 6), and 2B (Figure 7), respectively. According to the classification of Greiner et al. (2000), model 1A and 1B were classified as "less accurate" and model 2A and 2B as "moderately accurate".

The addition of variable *fullness level of water at storage*, which is not part of "standard" SI variables, improved the model's performance. Therefore, we decided to use BBN model 1B (Figure 5) and 2B (figure 7) for further BBN analyses, because model 1 and 2 differ in structure (Figure 3).

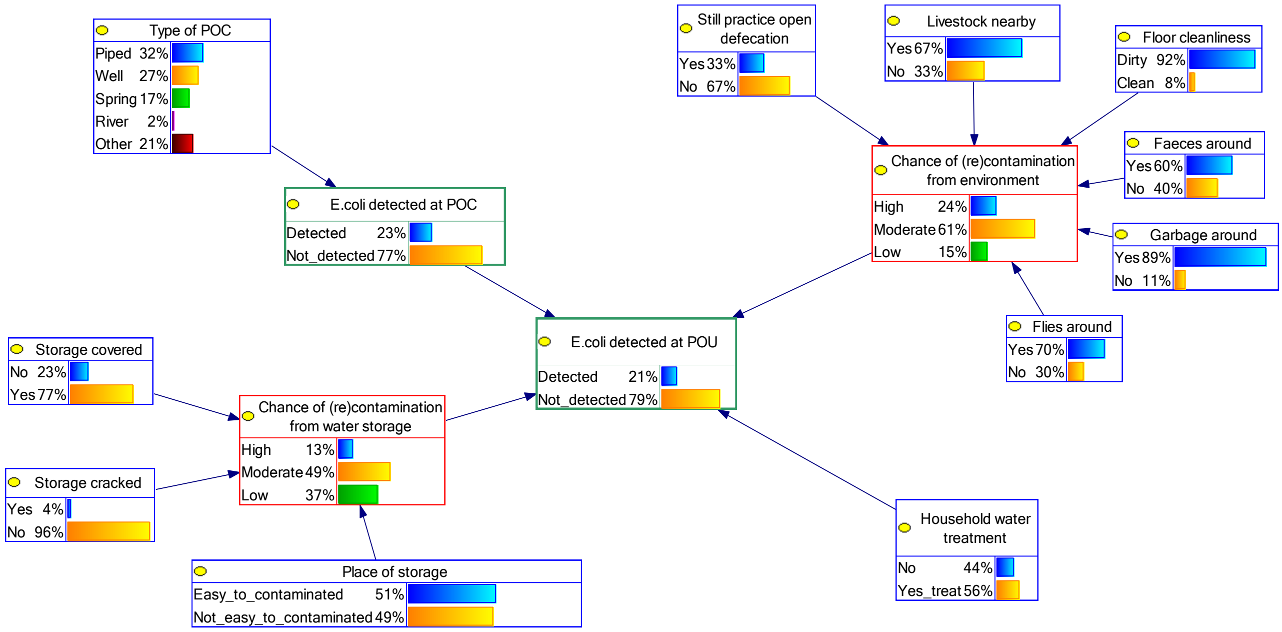


Figure 4. BBN model 1A (type of POC as a parent node of "*E. coli* detected at POC"). Blue nodes: data obtained from SI; Green nodes: data obtained from water quality testing; Red nodes: Intermediate nodes were obtained by summation of the value in the outer nodes. The percentages in each node indicate the probability of a node being in a certain state, e.g., 56% of the households perform household water treatment.

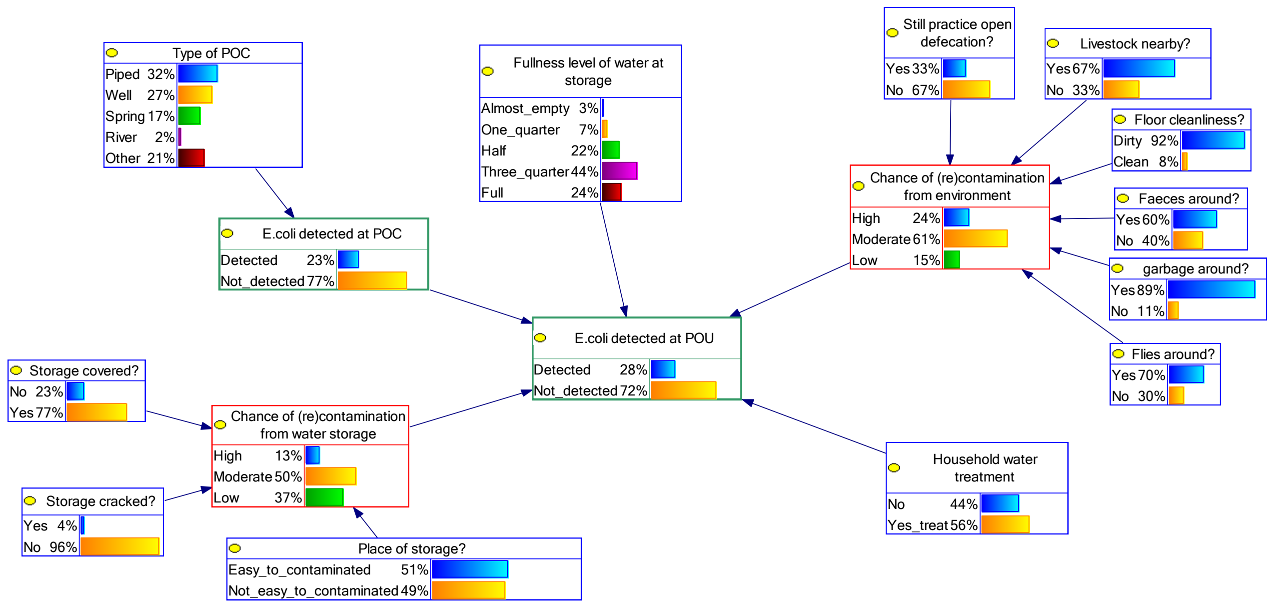


Figure 5. BBN model 1B (type of POC as a parent node of "*E. coli* detected at POC" and adding node "fullness of water at storage" as one of the parent nodes of "*E. coli* detected at POC").

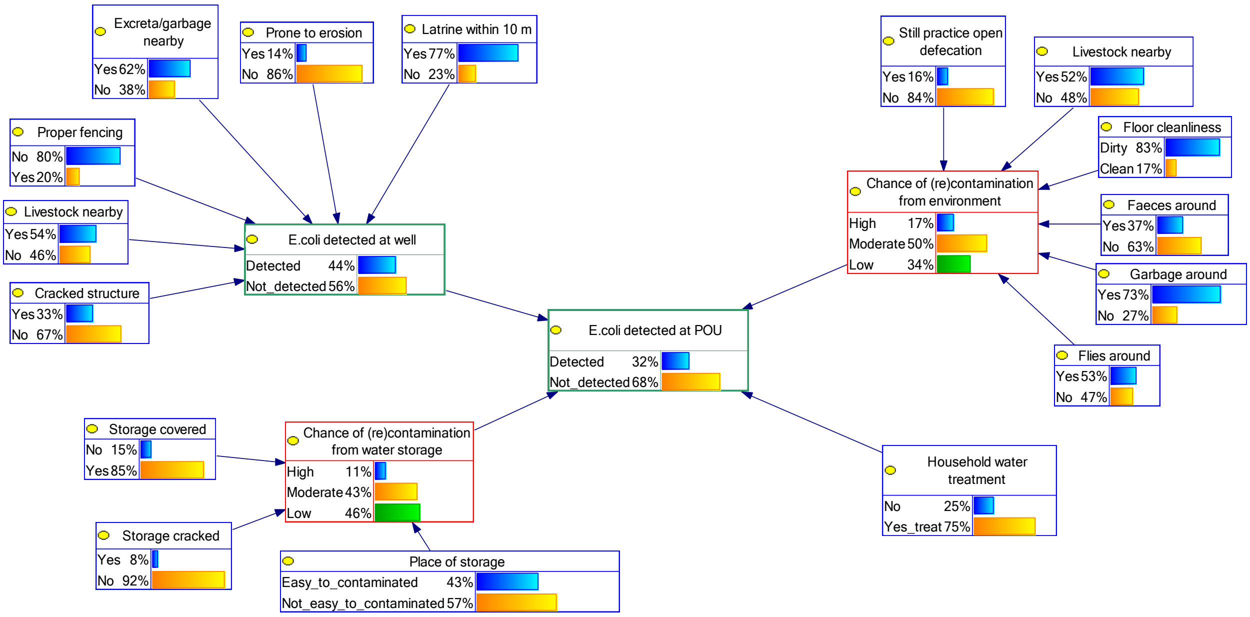


Figure 6. BBN model 2A (SI variables at well as parent nodes of "*E. coli* detected at POC").

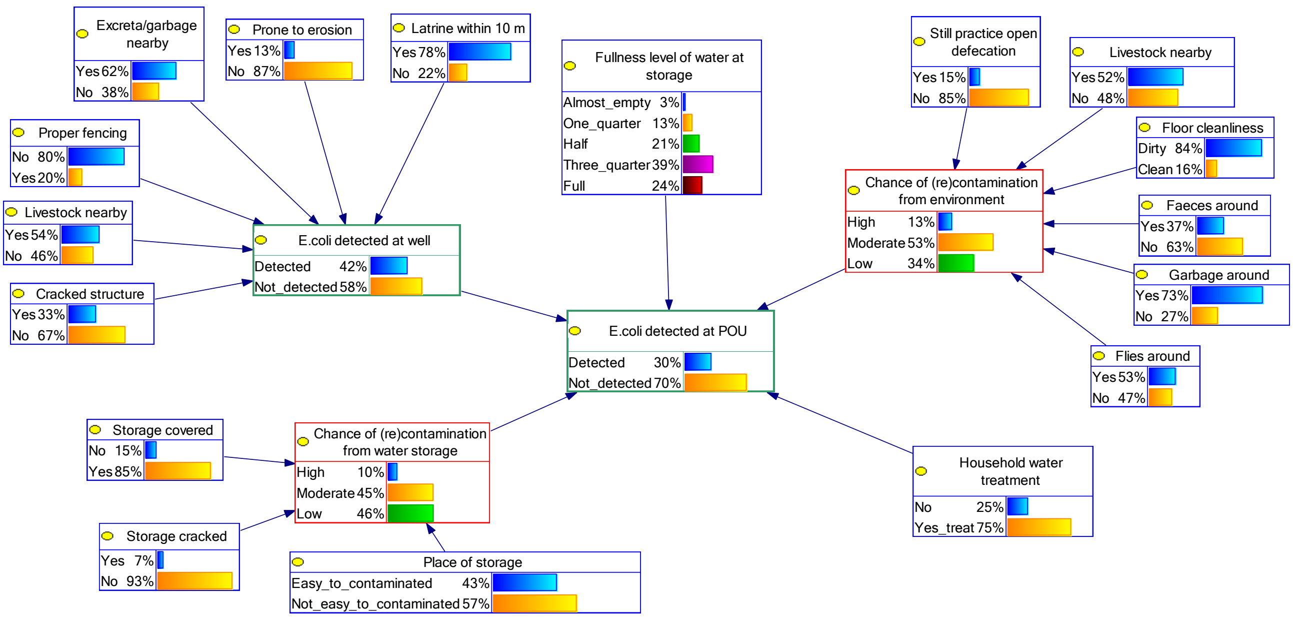


Figure 7. BBN model 2B (SI variables at well as parent nodes of "*E. coli* detected at POC" and adding node "fullness of water at storage" as one of the parent nodes of "*E. coli* detected at POC").

Table 2. Predictive inference, measuring the effect of changes in the states of each node on the output node of BNN models: *E.coli detected at POU* (drinking water storage). The value under each category corresponding to a node as displayed in the first column is the updated probability of the output node being “Not_detected” given that all households maintain this state. The left side of the table was for the BBN model 1A (Figure 5) and the right side was for BBN model 2B (Figure 7).

<table>
<tr><th colspan="7">BBN model 1B: with type of POC as one of the outer nodes</th></tr>
<tr><th>Variable</th><th colspan="5">Probability of E.coli not-detected at POU (%)</th><th>ΔP*</th></tr>
<tr><td colspan="6">Point of collection</td><td></td></tr>
<tr><td rowspan="2">Type of POC</td><td>Piped</td><td>Well</td><td>Spring</td><td>River</td><td>Other</td><td rowspan="2">17</td></tr>
<tr><td>75</td><td>69</td><td>75</td><td>58</td><td>72</td></tr>
<tr><td rowspan="2">E.coli detected at POC</td><td colspan="2">Yes</td><td colspan="3">No</td><td rowspan="2">21</td></tr>
<tr><td colspan="2">56</td><td colspan="3">77</td></tr>
<tr><td colspan="7">Household water treatment</td></tr>
<tr><td rowspan="2">Household Water treatment</td><td colspan="2">No</td><td colspan="3">Yes</td><td rowspan="2">6</td></tr>
<tr><td colspan="2">69</td><td colspan="3">75</td></tr>
<tr><td colspan="7">(re)contamination from environment – hygiene condition</td></tr>
<tr><td rowspan="2">Still practise open defecation</td><td colspan="2">Yes</td><td colspan="3">No</td><td rowspan="2">2</td></tr>
<tr><td colspan="2">71</td><td colspan="3">73</td></tr>
<tr><td rowspan="2">Livestock nearby</td><td colspan="2">Yes</td><td colspan="3">No</td><td rowspan="2">1</td></tr>
<tr><td colspan="2">72</td><td colspan="3">73</td></tr>
<tr><td rowspan="2">Floor cleanliness</td><td colspan="2">Dirty</td><td colspan="3">Clean</td><td rowspan="2">1</td></tr>
<tr><td colspan="2">72</td><td colspan="3">71</td></tr>
<tr><td rowspan="2">Faeces around</td><td colspan="2">Yes</td><td colspan="3">No</td><td rowspan="2">1</td></tr>
<tr><td colspan="2">72</td><td colspan="3">73</td></tr>
</table>

<table>
<tr><th colspan="4">BBN mode 2B: with SI at well as one of the outer nodes</th></tr>
<tr><th>Variable</th><th colspan="2">Probability of E.coli not-detected at POU (%)</th><th>ΔP</th></tr>
<tr><td colspan="4">Point of collection</td></tr>
<tr><td rowspan="2">Cracked structure</td><td>Yes</td><td>No</td><td rowspan="2">2</td></tr>
<tr><td>69</td><td>71</td></tr>
<tr><td rowspan="2">Livestock nearby</td><td>Yes</td><td>No</td><td rowspan="2">1</td></tr>
<tr><td>70</td><td>71</td></tr>
<tr><td rowspan="2">Proper fencing</td><td>Yes</td><td>No</td><td rowspan="2">0</td></tr>
<tr><td>70</td><td>70</td></tr>
<tr><td rowspan="2">Excreta / garbage nearby</td><td>Yes</td><td>No</td><td rowspan="2">0</td></tr>
<tr><td>70</td><td>70</td></tr>
<tr><td rowspan="2">Prone to erosion</td><td>Yes</td><td>No</td><td rowspan="2">1</td></tr>
<tr><td>71</td><td>70</td></tr>
<tr><td rowspan="2">Latrine within 10 m</td><td>Yes</td><td>No</td><td rowspan="2">0</td></tr>
<tr><td>70</td><td>70</td></tr>
<tr><td rowspan="2">E.coli detected at POC</td><td>Yes</td><td>No</td><td rowspan="2">19</td></tr>
<tr><td>59</td><td>78</td></tr>
<tr><td colspan="4">Household water treatment</td></tr>
<tr><td></td><td>No</td><td>Yes</td><td>13</td></tr>
</table>

Garbage around	Yes		No			0
	72		72			
Flies around	Yes		No			0
	72		72			
Chance of contamination from the environment	High	Moderate	Low			7
	68	75	70			
(re)contamination from water storage						
Storage covered	Yes		No			5
	74		69			
Storage cracked	Yes		No			4
	69		73			
Place of storage	Easy to contaminated		Not easy to contaminated			3
	71		74			
Chance of contamination from water storage	High	Moderate	Low			10
	64	74	74			
Fullness level of water at storage						
Fullness level of water at storage	Almost empty	One quarter	Half	Three quarter	Full	17
	58	64	70	75	74	

Household water treatment	60		73	
(re)contamination from environment – hygiene condition				
Still practise open defecation	Yes		No	4
	67		71	
Livestock nearby	Yes		No	5
	68		73	
Floor cleanliness	Yes		No	2
	70		72	
Faeces around	Yes		No	5
	67		72	
Garbage around	Yes		No	1
	70		71	
Flies around	Yes		No	1
	70		71	
Chance of contamination from the environment	High	Moderate	Low	22
	57	67	79	
(re)contamination from water storage				
Storage covered	Yes		No	0
	70		70	
Storage cracked	Yes		No	0
	70		70	
Place of storage	Easy to contaminated		Not easy to contaminated	2

		71		69			
	Chance of contamination from water storage	High		Moderate		Low	4
		68		72		68	
	Fullness level of water at storage						
	Fullness level of water at storage	Almost empty	One quarter	Half	Three quarter	Full	4
		70	73	69	70	71	

*ΔP = The difference between the lowest and highest value of the updated probability of output node: *E.coli detected at POU* being "Not_detected", in %. Examples of how to read the table: (a) row 4-5 *BBN model 1B*: if the type of POC is piped, the Probability of *E.coli* not-detected at POU (%) is 75%; (b) row 6-7 *BBN model 1B*: if *E.coli* is detected at POC ("yes"), the Probability of *E.coli* not-detected at POU (%) is 56%; (c) row 4-5 *BBN model 2B*: if there is a cracked in the structure, ("yes"), the Probability of *E.coli* not-detected at POU (%) is 69%.

Predictive inference of the BBN models

Node *E.coli detected at POC* was the most influential node (see ΔP = 21 in Table 2 – left) for the model 1B (type of POC as one of the outer nodes). This means that the better the water quality at POC, the better the water quality at the household level or POU. Node *Type of POC* and *Fullness level of water at storage* appeared as the second most influential nodes (ΔP = 17 in Table 2 – left). The intermediate node *Chance of (re)contamination from the water storage* was the third most influential node (ΔP = 10 in Table 2 – left).

The probability of not detected *E. coli* at POU was 75% for households who used both *Piped* and *Spring*. The fuller the level of water in the storage, the better the water quality at POU was. The probability of *E. coli* contamination at POU was 58% for *Almost empty* compared to 74% for *Full*. Among all three outer nodes in the cluster *(re)contamination from water storage*, node *storage covered* (ΔP = 5 in Table 2 – left) was the most influential node. The households who claimed to do HWT have a higher chance of not to be contaminated by *E.coli* than households who claimed not doing HWT, i.e., $P_{Not\_detected}$ = 75%, $P_{Not\_detected}$ = 69%, respectively.

In model 2B, intermediate node *Chance of (re)contamination from the environment* was the most influential node among households who used a well as their water source (ΔP = 22 in Table 2 – right). Node *E.coli detected at POC* was the second most influential nodes (ΔP = 19 in Table 2 – right), followed by node *Household water treatment* (ΔP = 13 in Table 2 – right). In addition, the influence of node *Fullness level of water at storage* and the intermediate node *Chance of (re)contamination from the water storage* were smaller compared to model 1B (both had ΔP = 4 in Table 2 – right).

The effect of HWT to improve the water quality was larger in model 2B (ΔP = 13 in Table 2 – right), compared to model 1B (all types of POC; ΔP = 6 in Table 2 – left). If we compare the situation of intermediate nodes *Chance of (re)contamination from the environment* and *Chance* *of (re)contamination from the environment* in model 1B (Figure 5) and 2B (Figure 7), the hygiene situation was better in model 2B. The probability of being “high” in both intermediate nodes in model 2B was lower than in model 1B, e.g., 24% in model 1B compared to 13% in model 2B for the intermediate node *Chance of (re)contamination from the environment*.

Furthermore, keeping the house free from livestock ($P_{Not\_detected}$ = 73%) and faeces ($P_{Not\_detected}$ = 72%) seemed critical to reduce the probability of fecal contamination at the household storage among households who used a well as their water source. Respondents who practiced open defecation had a larger probability of fecal contamination at the POU than they who did not, i.e., $P_{Not\_detected}$ = 67%, $P_{Not\_detected}$ = 71%, respectively ($\Delta P = 4$). The influence of HWT to reduce the chance of contamination was prominent in model 2B, i.e., $P_{Not\_detected}$ = 73% for households who treated their drinking water and $P_{Not\_detected}$ = 69% for not treating water.

The intermediate nodes were the sum of the values in outer nodes. We found that the ΔP of intermediate nodes in both model 1B and 2B were bigger than their outer (parent) nodes. For example, in model 2B, the ΔP of 6 outer nodes in the cluster of *surrounding environment – hygiene condition* had less variation (range ΔP= 1-5) compared to the intermediate node *Chance of (re)contamination from the environment* ($\Delta P = 22$).

Model 2B was used to simulate the best scenario of all respondents (Figure 8). The updated probability of outcome node *E. coli detected at POU* being “not_detected” was 91%, compared to the 70% in the baseline situation (Figure 7). Given the same scenario in model 1B, the updated probability of the outcome node was 92%, compared to the 72% in the baseline (Figure 5), which suggests the same pattern as model 2B.

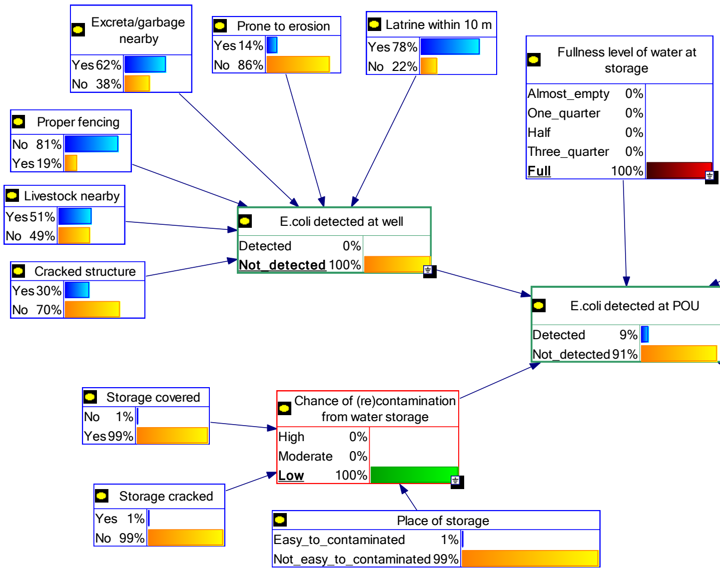


Figure 8. The best scenario of water and hygiene management at households level using BBN model 2B (SI at well as one of the outer nodes, SI variables, and *fullness of water at storage*).

Discussion

BBN model's performance

Since there is no BBN study which links SI and water quality data, we compared our models' performance with statistical analysis. Snoad et al. (2017) utilized logistic regression to predict the fecal contamination by SI and their AUC values were low (range 0.41 – 0.64). Other authors also used multiple statistical analyses and found that SI variables could not explain well the water quality (Ercumen et al., 2017; Misati et al., 2017; Robinson et al., 2018). This implies that our models (with AUC values of 0.69 and 0.84) were slightly better in predicting the water quality at POU using SI data.

Moreover, we found that an "external" factor, besides standard SI variables, increased the model's performance, in our case we used the level of water *fullness inside the storage*, as also found to be relevant in other studies (Brick et al., 2004; Elala et al., 2011; Boateng et al., 2013). Our findings suggest the need to extend the standard SI with external factors for better model performance. In addition, BBN models with SI variables at well (AUC for model 2A and 2B are 0.71 and 0.84, respectively) perform better than BBN models with different types of POC (AUC for model 1A and 1B are 0.55 and 0.69, respectively). Since the same type of POC can have varying conditions, detailed information of the POC conditions can better explain the water quality than the information on the type of POC itself. This may explain why BBN models with SI variables as explanatory variables perform better than BBN models with types of POCs as explanatory variables.

Sanitary inspection, water quality, and BBN predictive inferences

To the authors' knowledge, this is the first study that links SI data with water quality in a medium resource setting. The BBN approach allowed the inclusion of all factors influencing the water quality at POU and grouping them in relevant clusters and pathways, as implied by other conceptual frameworks (Wagner et al., 1958; Cohen et al., 2015; Navab-Daneshmand et al., 2018). Furthermore, we were able the analyse the water quality at POU by considering not only the water management and hygiene situation at home, but also the broader scope, such as the situation at the water source. Moreover, the conventional statistical analysis methods, e.g., bivariate correlation or regression analyses, often quantify the effect of the individual variable on water quality, but not a combination of variables or pathways (Daniel et al., 2020; Ercumen, et al., 2017; Misati et al., 2017). The BBN approach was able to simulate both the effects in one model and can then help to prioritise the interventions that improve the water quality at household level, i.e., either targeting one variable or combination of multiple variables.

The BBN approach also enabled the portrayal of interdependencies among variables. This interdependency have attracted the attention of WASH practitioners and experts over the past years (Eisenberg et al., 2012). For example, SI results revealed that there were some hygiene challenges related to livestock ownership. The majority of the respondents (67%) kept livestock in the surroundings of the house, which could be the reason why many flies (70%) and faeces (60%) were detected in our respondents' houses (see Figure 5 cluster *(re)contamination from environment – hygiene condition*). A study of Ercumen et al. (2017b) found that the presence of animals is related to fecal contamination, and the presence of animal faeces is associated with diarrhea and stunting (Penakalapati et al., 2017). This could be the reason why this area was reported as one of the locations with the highest stunting levels in Indonesia (Local Burden of Disease Child Growth Failure Collaborators, 2020). To solve tackle these problems are challenging since livestock is a symbol of social status in East Sumba (Bamualim, 2000).

Our BBN models (1B and 2B) showed that the water quality at POCs critically affected the water quality at the POU in the study area, which has also been found by others (Cronin et al., 2006; Daniel et al., 2020a). We also found that types of water source used by the households determine the drinking water quality that they have at home, similar to the findings in rural Honduras (Trevett et al., 2004). These data suggest that the fecal contamination at POU due to poor water quality at the water source, especially wells, is a serious problem in East Sumba, i.e., 40% the total populations in East Sumba used well as their main water source (BPS Statistics of East Sumba Regency, 2018).

Since we found that the effect of HWT to improve the water quality was larger in model 2B (POC = well only) compared to model 1B (all types of POC), we argue that the effect of HWT to improve the water quality is larger in the case of better sanitation and hygiene conditions. In our case, the overall condition in model 2B was "more hygienic" than in model 1B. This result has also been suggested by a previous study (Esrey and Habicht, 1986).

Model 1B showed that storage with full water had a better water quality than (almost) empty storage. The explanation could be that the water inside the empty storage was stored for a longer period than a fuller storage, resulting in larger risks for recontamination and permitting bacteria regrowth (Levy et al., 2008; Mellor et al., 2013).

Furthermore, we found that the ΔP (the difference between the lowest and highest value of the updated probability of output node: *E.coli detected at POU* being "Not_detected" given the specific condition of a specific node) of intermediate nodes are larger than the influence of their outer (parent) nodes. This implies that collective information of the specific cluster was more meaningful, i.e., more sensitive, to predict the water quality than individual information of specific node or variable. Additionally, it suggests that our simple index, by summing the scores of the parent nodes to populate the CPT in some intermediate nodes, was "acceptable".

A previous WASH study found that a combined HWT, sanitation, handwashing, and house's cleanliness intervention have the same effect as with HWT intervention alone in reducing fecal contamination in household drinking water (Pickering et al., 2019). In contrast to their study, we found that a combined improvement, targeting all potential contamination sources from the water source until house, had a larger effect in reducing the chance of fecal contamination in the water storage rather than the improvement of one single condition. This suggests that a holistic approach or multi-barrier prevention are needed to minimise drinking water contamination at the POU in rural households (Gundry et al., 2004; WHO, 2012). However, considering the costs and time constraint, we suggest to prioritize the improvement of the water quality at the water source. Afterwards, WASH behavioural change promotion, e.g., promoting the correct and sustained use of HWT and safe storage container, could be conducted.

Future water quality studies in that area should analyze and include other external factors that may influence the water quality at POC and POU, e.g., type and depth of the well and the types of water containers used by households. This can improve our understanding of water quality in this area.

Conclusion

This chapter introduces an application of BBN to analyse how water quality at the point of use is related to the water quality at the point of collection and associated sanitary inspection data in the medium resource settings in low-middle income countries. The model simulations showed that holistic - combined interventions improved the water quality considerably compared to individual interventions. Moreover, the results demonstrate that water quality at the POC was related to the water quality at the POU. Furthermore, household water treatment had a larger effect of improving the storage water quality in the case of better sanitation and hygiene conditions. We also found that the BBN model performance increased by adding an external variable besides standard SI variables, suggesting that the current SI form should accommodate more (relevant) variables. *E.coli* was detected in 24.4 and 17.7% of POC and POU samples, respectively. Additionally, there was a hygiene issue related to the ownership and presence of livestock surround the house in the study area. Based on the water quality analysis, tap and spring water are relatively cleaner than other types of water sources and should be prioritised by the households as main drinking water sources. In order to improve the drinking water quality in this area, reducing the contamination risk at the water source and promoting correct and regular household water treatment are suggested. From the study it can finally be concluded that the BBN approach could be considered as an alternative for conventional statistical methods to link sanitary inspection and water quality data in low-middle income countries.

Chapter 8

Factors influencing the sustainability of water supply, sanitation, and hygiene services in developing countries: A study case of rural Indonesia

- A woman from a low caste group carrying a jerry can of water in East Sumba -

This chapter is based on:

Daniel, D., Djohan, D., Machairas, I., Pande, S., Arifin, A., Djono, T. P. Al, & Rietveld, L. (2020). *Identifying factors that contribute to the sustainability of water supply, sanitation, and hygiene services in indigenous - rural Indonesia*. Manuscript submitted for publication.

Abstract

There is increasing recognition of the complexity behind the sustainability of water, sanitation, and hygiene (WASH) services in developing countries. That is mainly due to many factors at play and they are often interconnected to each other. This chapter explores this complexity to assess the vulnerability of a specific area to unsustainable WASH services using a qualitative approach. We present our findings from district East Sumba, Indonesia. This area is known as one of the poorest regions in Indonesia, poor WASH services, indigenous belief, and a high rate of children malnutrition. All factors that contribute to the WASH sustainability were discussed through the lens of Financial, Institutional, Environmental, Technological, and Social (FIETS) framework. We then summarised The factors and visualized the "system" using a conceptual map which shows how factors are interconnected and help to find the root causes of the unsustainable WASH services. There are three main challenges that can threaten the sustainability of WASH services in this area: institutional aspect, water scarcity, and poor socio-economic conditions. We found that a village leader is a key actor who influences the WASH services especially in that area. This study also shows how culture shapes people's daily lives and institutions performance, and further influence the current WASH situation in that area.

Keywords: water supply, sanitation, qualitative analysis, sustainability, system approach, culture

Introduction

Water supply, sanitation, and hygiene (WASH) are focal points in the Sustainable Development Goal (SDG) 6, which aims to "ensure availability and sustainable management of water and sanitation for all" (UN General Assembly, 2015). The latest report showed the progress of the WASH situation in 2017: 71% Safely managed drinking water services, 45% safely managed sanitation services, and 60% of the global population had basic handwashing facilities with soap and water available at home (UNICEF and WHO, 2019). This indicates that billions of people, especially in low-middle income countries (LIMCs), still lack such WASH services. Moreover, lack of adequate WASH services contributes to disease and death cases, especially among children under five in LMICs (Wolf et al., 2018).

Only 89% of Indonesia's population benefited from "basic" drinking water services, despite significant progress in reducing open defecation from 33% in 2000 to 10% in 2017 (UNICEF and WHO, 2019). The prevalence of child stunting was still high, 30.8% in 2018 (Tim Riskesdas, 2019). Among all 34 provinces in Indonesia, East Nusa Tenggara had the highest prevalence (42.6%) of child stunting (Tim Riskesdas, 2019). In 2018, the access to the improved drinking water source in East Nusa Tenggara was 72%, increased from 63% in 2015, and access to improved sanitation was increased sharply from 23% in 2015 to 51% in 2018 (Badan Pusat Statistik, 2019b, 2019a).

East Sumba, one of the districts of East Nusa Tenggara, is located on Sumba Island and characterised by poor economic conditions, high prevalence of open defecation, and Indigenous belief, called "Marapu", is commonly practiced by the locals (Fowler, 2003; Sungkar et al., 2015). In 2018, the level of dropout from school at the age of 7-24 years was 29%, and the ratio of poor people in East Sumba was also high (30%). Moreover, people regularly face severe droughts, which usually occur in April until October (Messakh et al., 2018).

Dreilbelbis et al. (2013) argue that previous WASH-related behavioral studies were more focused on factors related to individual level and little attention was given to other factors, such as technological, environmental, and institutional aspects. In order to extend the traditional evaluation of WASH services, the objective of this chapter is to identify the factors that positively contribute to the sustainability of WASH services, by considering *financial*, *institutional*, *environmental*, *technological*, and *social* (FIETS) aspects. East Sumba was used as a study area. A previous study in this area focussed on the adoption of household water treatment (HWT) in a quantitative way (Daniel et al., 2020b). In this study, we used some of the Daniel et al.' (2020b) results to support our analysis. We adopted a qualitative approach to explore factors that influence the sustainability of WASH services and understand how and why such a condition exists. Figure 1 show examples of unsustainable WASH services in that area (Sutton and Austin, 2015).

Figure 1. Examples of unsustainable WASH services in East Sumba. Left: A not functioning water tank; Right: An unfinished latrine construction. Pictures were taken by the first author.

Since WASH is a complex system, which consists of many interconnecting factors, we adopted a system approach in this chapter (Valcourt et al., 2020). The system approach requires an illustration of the interconnecting or interacting factors which are contributed to the specific phenomena or behavior of the system (Arnold and Wade, 2015). This approach can be used to understand the roots of the phenomena. We applied this by visualizing the results in a conceptual map to show how these factors, under the FIETS aspects, are interconnected and find potential root causes of the problems in WASH services.

Methods

Guiding theoretical framework: FIETS

We followed the FIETS framework to explore aspects that contribute to the current WASH situation in East Sumba. FIETS was introduced by the Dutch WASH Alliance (DWA) as a tool to evaluate or monitor the sustainability of their WASH programs in developing countries (Dutch WASH Alliance). FIETS consists of five main aspects, namely (1) *Financial*, (2) *Institutional*, (3) *Environmental*, (4) *Technological*, and (5) *Social*.

Financial covers aspects related to economics, such as government or local financing, project financing, community contribution, tariffs, and household's economic situation. *Institutional* aspects cover stakeholder's performance, such as government effectiveness, regulation, or corruption. *Environmental* considers aspects related to natural environment and resources that support the sustainability of a WASH program. *Technological* aspects are related to hardware or technology used by the target group, such as technical maintenance. *Social* aspects focus on appropriate social conditions to sustain the WASH program or behaviour, like psychological factors that influence a person's behavior.

Study setting

The study took place in a rural area in the district of East Sumba, East Nusa Tenggara, Indonesia (Figure 2). The study was divided into two phases: the first phase was from July – August 2018 and the second one was from July – August 2019. During the first phase, a quantitative analysis of HWT perceptions and adoption was performed. A total of 377 households in four sub-districts in East Sumba were interviewed. More details on this study can be found in (Daniel et al., 2020b). During the second phase of the study, we implemented a qualitative analysis to understand the influencing factors related to WASH. More specifically, we conducted semi-structured in-depth interviews with relevant stakeholders, such as District Agency for Regional Development, Health Agency, Public Works Agency, Sub-district Board, Community Based Rural Water Supply and Sanitation Program (PAMSIMAS) officer, health post, and water driller. At the village level, we interviewed the village's head, village council, water board, religious leader, and at least five random households in each selected village. Nine villages in four sub-districts were the focus of our research, see (Daniel et al., 2020b) for more information about the village selection. During the time of the interview, there was not an NGO actively executing a WASH program in East Sumba. However, we interviewed five local NGOs that had been active in that area for more than five years to gain more insight into the situation from the NGO's perspective. The interviews were conducted by the first three authors.

We obtained informed consent from participants and the village head. The study was also approved by the Human Research Ethics Committee at the first author university and the Agency for Promotion, Investment and One-Stop Licensing Service at the district level.

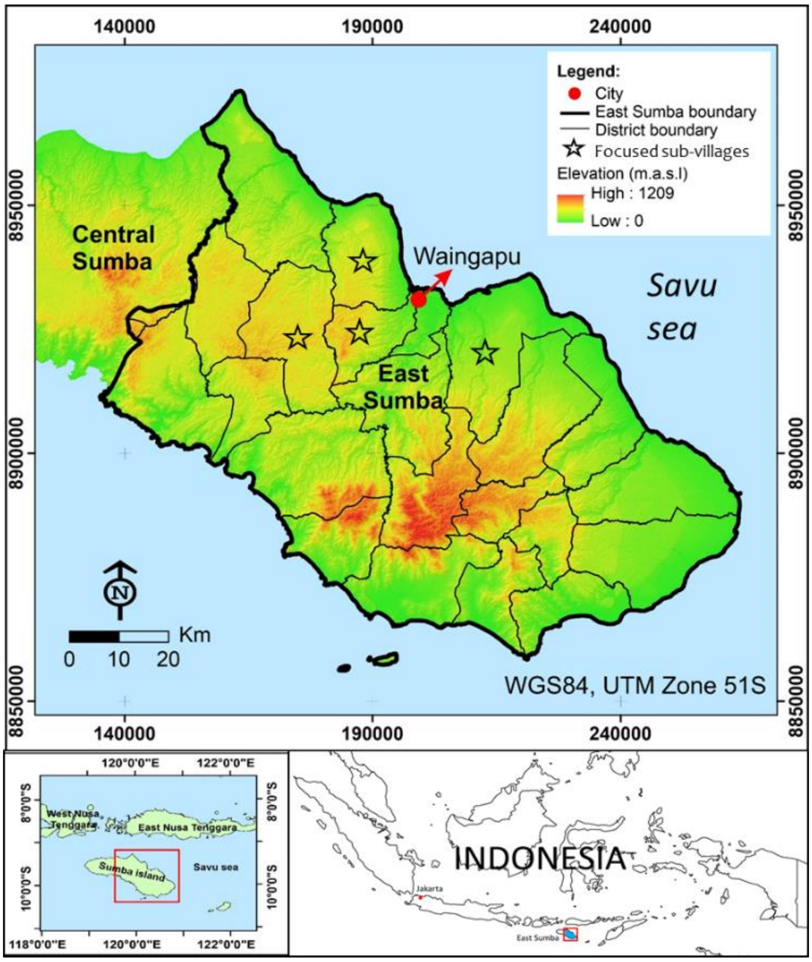


Figure 2. The map of the study area and the focused sub-villages. The map was generated using ArcGIS 10.5 (ESRI, Redlands, CA, USA).

Data analyses

During the in-depth interviews, key points were noted and discussed at the end of the day by the interviewers to match information and understanding. We also strengthened the analysis with extra information from literature, related data from government agencies, Geographic Information System (GIS) modelling, and previous household surveys in 2018 (Daniel et al., 2020b). For example, the issue of a severe drought in East Sumba was strengthened by the results of GIS modelling, using ArcGIS 10.5 (ESRI, Redlands, CA, USA). All findings were then grouped and discussed within the scope of the FIETS aspects. There is some information which is related to several aspects and we placed them in the most relevant aspect.

We then created conceptual maps to summarise key factors in all FIETS aspects. We mainly used factors which either were often mentioned by the respondents or factors which were mentioned as critical even though only mentioned by one-two respondents. The arrows in the conceptual map do not always indicate hypothetical causality but also the relationship between factors. In this chapter, factor refers to elements of the system, e.g., local culture, sense of ownership, climate, norms, etc., while aspect refers or points out to *Financial, Institutional, Environmental*, *Technological,* and *Social*.

For the factors related to *social* aspect, we followed RANAS psychological framework (Mosler, 2012b). RANAS stands for *Risk* (perceptions regarding health risk related to behavior), *Attitude* (positive or negative views toward a behaviour), *Norms* (social pressure related to behavior), *Ability* (personal confidence to perform the behavior), and *Self-regulation* (self-management or attempts to plan and monitor the behaviour) which are the psychological aspects responsible for people's behavior. The factors in the *social* aspect are discussed under these five psychological factors in the conceptual map.

Lastly, we performed a stakeholder analysis and created an importance-influence matrix to identify key actors and the "most-affected" actors of the current situation. "Importance" means the priority given to satisfying stakeholder's needs and interests, while "influence" means the stakeholders' power to affect the project (Dearden et al., 2003). We first made a list of WASH-related stakeholders in that area. To assess the level of importance and influence, we assigned a score from 1 to 5 to each stakeholder and created the importance-influence matrix. The matrix was divided equally into four quadrants A – D, e.g., quadrant A (top-right left) consists of stakeholders who have an importance score between 2.5 – 5 and influence score between 0 – 2.5. In addition, we discussed potential WASH promoters in that area.

Results and discussion

Applying the FIETS framework to identify factors related to WASH services

Financial aspect

Respondents from district agencies and/or village boards often mentioned lack of funds as an obstacle for sustainable WASH in East Sumba. However, one of our respondents said that there are actually many funding sources for WASH. For example, village or related agencies can ask for *dana alokasi khusus* (DAK, special allocation fund) from the national government to build or repair WASH infrastructure. Further, we found that the priority of village boards to improve the WASH situation was often low, as can be observed from the village budget in 2018. In our focused villages, the average village fund allocated for WASH was 2.1% in which we consider that the number is low considering the emergency WASH situation in that area, e.g., the average level of open defecation in 2019 was 27.4%, based on the quantitative survey (Daniel et al., 2020b).

In most villages, there was a subsidy from the village office to construct a latrine. Households can get the materials and they have to construct the latrine themselves, although it was given in turns and reached only a few selected poor houses per year. However, there were beneficiaries who did not construct the latrine, due to laziness or lack of water for proper use.

Since the final decision of the beneficiaries was made by the village head, there was a chance for bribery, or arbitrary favouritism by the village’s head, e.g., village head’s relatives or supporters. For the latter, nepotism was quite often mentioned by our respondents.

The community was expected to contribute financially to WASH services, especially communal tap water. However, there was a tendency that beneficiaries do not want to contribute anymore after they use the service for some time. Most common reasons by the beneficiaries were "the water does not flow anymore", a suspicion that the water board misused the collected money, or "I saw people from outside the village, who do not pay for the tap, came and took the water from our tap ". In addition, the village water boards said that a low sense of ownership and a lack of understanding of the importance of a financial contribution by the community were also the reason for that.

It was further found that people in East Sumba tended to spend large amounts of money for cultural events, e.g. funeral and marriage ceremonies. They frequently feel rejected if they do not financially contribute to the cultural event. Therefore, local NGOs argued that people in East Sumba are actually not poor but they do not understand how to manage their money well.

Institutional aspect

One of the indicators of a strong institution that was mentioned by Hamer et al. (2020) is whether there is a district policy regarding WASH. At the district level, we found that there were policies and instructions to reduce the amount of malnutrition in children and to improve the WASH services. These policies require relevant stakeholders to cooperate, e.g., district health agency and public work agency. However, from the interviews with the stakeholders, we found that communication lines were not well developed and the stakeholders rarely met or communicated. In addition, one of the respondents said that function rotation, i.e. staff movement within an institution, is one of the obstacles for effective collaboration between agencies. That is because new officers would need some time to reach the level of understanding of the previous officer.

At the village level, we found that many village leaders were not aware of the importance of WASH. Only two villages out of the nine villages that we visited had a village policy regarding WASH. These two villages also formed a village water board and allocated a budget for WASH, e.g. for maintaining and repairing the water distribution system.

All water boards of the focused villages said that they are reluctant to penalize households who do not regularly pay for the water service. It was said to be a dilemma because most people in the same village are relatives. Therefore, rule enforcement was hard to be conducted by the water or village board.

We also found the influence of local culture on the institutional aspects. The local belief, *Marapu*, practice a caste system which affects daily life. A leader in the village or other government agencies has to be from a high-level caste, i.e. royalty, while people who are from a low caste are considered to be a "servant" by the high caste people. This makes the voice of a high caste person more powerful than that of the low caste people, making the latter group more vulnerable.

Another output of this social system was the (political) competition between some high caste groups or families. The effect on WASH was apparent, particularly after the period of village or district election. According to our respondents, there were some cases in East Sumba in which the village's aid mainly targeted the supporters or families of the elected leader.

However, there were also some examples mentioned of good or strong leadership. We found in one village that people who received a subsidy to build a latrine had to sign an agreement with the village board in which it was stated that they should finish the construction of the latrine within a predetermined time, otherwise the village would withdraw all the materials. Another example came from the only sub-district in East Sumba that was declared as open defecation free. The sub-district head had been able to persuade all village heads under him to perform *sumpah adat* (custom vow) to eliminate the open defecation. The custom vow was highly appreciated by the indigenous East Sumba people and it worked effectively as a stimulus. Moreover, we found some stories of successfully applying the “reward and punishment” approach, especially by the district social agency. In some villages the “threat” of not receiving social aid by the district social agency was effective to force poor people to construct a latrine.

Environmental aspect

From the quantitative interviews, it was concluded that most of the households (86%) chose water supply as the most critical and urgent in the village which need to be solved by the municipality or government. The respondents said that lack of water is the reason for them not cultivating their land, not using the latrine, not having a bath every day, or not practicing handwashing at the five critical times of the day.

The frequency and quantity of rainfall at Sumba island are relatively low compared to other areas in Indonesia. The mean annual rainfall in East Sumba is 830 mm (Messakh et al., 2018), which is the lowest in East Nusa Tenggara province and far below the mean annual rainfall in Indonesia (The World Bank, 2014). In one of our study areas, the main spring dried and people needed to take water from the neighboring village.

The water driller in that area who conducted some studies on soil structure in that area argued that the soil structure plays a role in the water availability in that area. This argument was supported by the published geological map which shows that limestone dominates the lithology in the North and East part of East Sumba (Figure 3) (Effendi and Apandi, 1993). From the map, we may also interpret that the groundwater availability is not only controlled by the rainfall but also the distribution of the lithology below the surface. The map indicates that the groundwater may be found locally in the highly saturated-permeable zone only. The water driller said that the geological situation in East Sumba influences the costs of groundwater exploration and drilling. That is because the success rate of water drilling is highly dependent on the comprehensive results of geological and geophysical surveys to locate the saturated-permeable zone. It was also mentioned by some local inhabitants that local geology negatively influences the costs for construction of latrine as well. The costs to dig a latrine pit is high because the soil is hard.

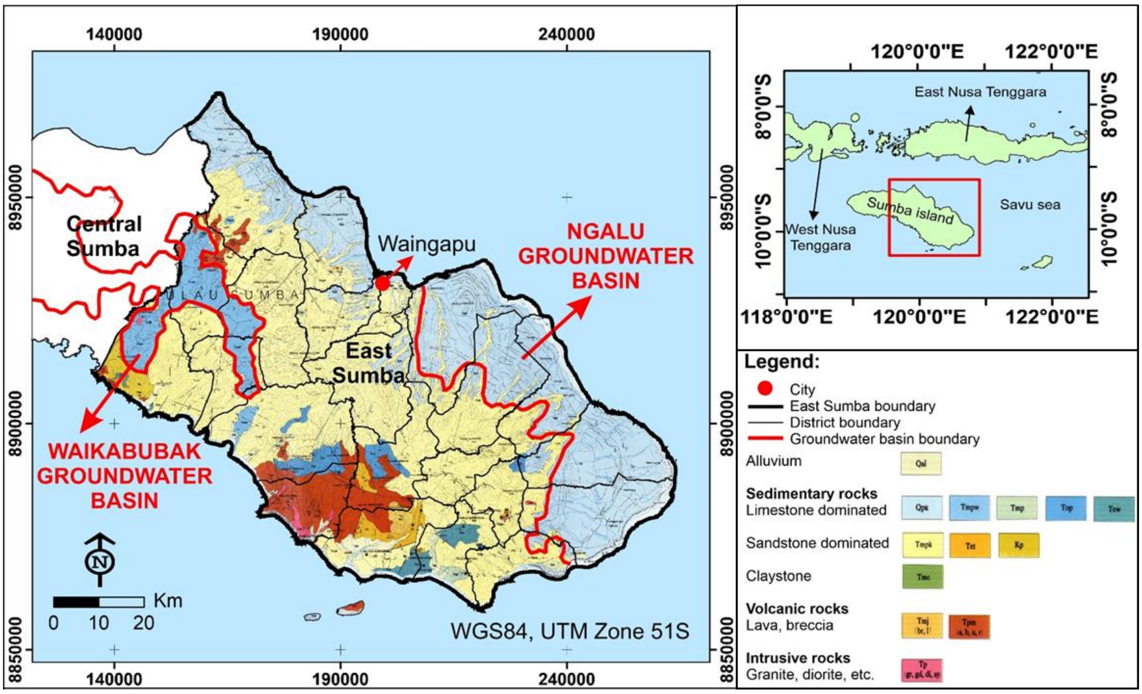


Figure 3. Geological map of the study area; modified from (Effendi and Apandi, 1993).

Further, it was mentioned by some interviewees that a national company opened 12,000 ha of sugarcane plantation in 2020, and planned to open until 50,000 in the coming years. Our respondents from NGOs argue that this activity results in extensive water extraction from both rivers and groundwater, as also discussed in another study in that area (Vel & Makambombu, 2019). In addition, as a result of our interview with a water driller, if the sugarcane plantation is located in a groundwater recharge area, it will significantly reduce the groundwater availability. Some NGOs mentioned that it would compromise the water availability, especially since the companies started to “monopolize” the usage of the river for their activities.

Due to the limestone aquifers, water hardness was often mentioned by the local households as the main water quality issue, instead of fecal contamination. From the data received from the local, commercial, potable water company, the total hardness in their water source, measured by the concentration of ($CaCO_3$), was about 24 mg/L. Furthermore, almost all respondents who we interviewed said they use visual inspection to judge the water quality, i.e. high turbidity or precipitation after boiling means that the water quality is poor.

It was further mentioned by the water supplier that the scattered settlement is a main reason for the high costs of installing a piped network in East Sumba. Not only the hilly topography (Figure 2), but also the local culture were mentioned as reasons for that. Since tribes in East Sumba often had tribal warfare in the past, they live on top of the hills which allow them to observe enemy’s attacks. Moreover, many locals in East Sumba also prefer to stay on their inherited land to avoid ownership disputes.

Despite being “troubled” by the environmental conditions, people in East Sumba still benefit from it. For example, most of the households that we interviewed in the villages mentioned that they did not need to spend money to boil water, because they can obtain the firewood from their own field.

Technological aspect

According to our previous, quantitative study, only 51% of the respondents in the focused villages practiced HWT regularly. Boiling was the common HWT method that people used (85%) (Daniel et al., 2020b). A commercial water filter, produced at Java island, was also found in several houses in one village. Those were sold by a local, private, entrepreneur who got support from an external NGO. However, they lost contact with the NGO and lacked filters to continue the business. In addition, during our household visits, we observed that most of the households used a cloth filter after boiling to filter out the precipitation. This precipitation or sedimentation is a result of water hardness.

Based on the latest report of East Sumba Bureau of Statistics, only 18% households in East Sumba had access to a piped water scheme in 2017, while wells and open sources were used by 44% and 32% of the households in East Sumba, respectively (BPS Statistics of East Sumba Regency, 2018). We also found that some households used rainwater harvesting in the rainy season. However, this option has limited impact due to the low frequency and quantity of rainfall in this area (see section Environmental aspects).

According to the village water board, the most common reasons for the lack of running water from the piped system were pipe damages due to contact with animals or flooding in the rainy season, and illegal tapping from the network. Most of the pipes were located in the open field and being unprotected from livestock, while livestock are mostly free-ranging in and around the village.

Most of the WASH products were produced outside Sumba island. For example, iron pipes were not available and needed to be ordered from Java island. According to one of the district agencies, there had been an initiative to establish sanitation entrepreneur groups by UNICEF in 2015, but they were no longer active due to staff rotation in the related district agency (see section Institutional aspects).

Social aspect

We used the RANAS framework to explain the psychology of people. We grouped and ordered the information that we obtained according to the RANAS framework: *Risk*, *Attitude*, *Norms*, *Ability*, and *Self-regulation*.

Some of our respondents said that “my grandparents did not die even though they always drink raw water. Why do I need to drink boiled water now?” or “I have drunk raw water during my entire life and there is nothing wrong with me”. These perceptions hindered them from drinking treated water. Another perception related to *risk* was that many people in East Sumba still believed that diarrhoea among children is a part of teeth growth, which makes them not taking diarrhoea seriously. Furthermore, a common method used by parents to heal children’s diseases is to bath them in corn boiled water. Despite these facts, the majority of our respondents said that poor water quality is one of the reasons for diarrhoea.

In relation to the *attitude* towards WASH, many people who did not drink treated water said that “I will get headache or flu if I drink boiled water” (beliefs about health disadvantages), or “I am not satisfied if I drink boiled water” (personal feeling), i.e. raw water is colder. For the latter, the hot and dry weather in East Sumba were the reason why locals prefer colder (or fresher) water than boiled or hot water. In addition, some respondents believed that boiled water is *air mati* (dead water) which can cause a headache or flu. However, people who always drink boiled water said the opposite, i.e., raw water cause headache and flu.

There was no specific social *norm* on HWT practice, but there were norms for sanitation and hygiene practices in the community. Some people who strictly followed a local belief, *Marapu*, did not allow the construction of a latrine in their house or sub-village due to the perceived impurity of the toilet. The traditional Sumbanese house, i.e. stilt house (Figure 4), is a representation of *Marapu* belief, which states that there should be a harmony between ancestors, humans, and nature (especially animals). These are represented by the roof, middle part of the house, and under the house, respectively. The structure of the traditional house does not accommodate a latrine. Therefore, respondents argued that this has an influence on the practice of open defecation. In addition, respondents from health agencies mentioned that many people in rural area still believe that feces need to be given to the animals, especially pigs or chickens, as food. As a consequence, people practice open defecation and the house's yard is full of dirt.

Figure 4. The traditional Sumbanese, stilt, house in one sub-village in East Sumba and the surrounding environment. Picture was taken by the first author.

Another social *norm* among the Sumbanese population, which could inhibit WASH, is the taboo on using the same facility among certain family members. For example, the daughter in law is sometimes prohibited from using the same toilet as her parents in law.

Previous sections have already mentioned some factors that can influence a person's *ability* to perform WASH, such as water availability and excessive cultural expenses. Moreover, some respondents said that laziness and bad mentality in the community, e.g. hoping to receive any help from outsiders without the intention to improve their situation, were the main psychological reasons for the poor WASH situation.

The FIETS conceptual map

All findings were summarised in a conceptual map (Figure 5), illustrating the interconnection between all factors responsible for the sustainability of WASH services in East Sumba. The factors were clustered into the five FIETS aspects. The conceptual map shows how a factor in one aspect influences factors in other aspects. For example, as implied previously in the section *Financial aspect*, the *institutional aspect* influences *community willingness to pay* via a factor or variable *trust*.

The conceptual map shows that some of the FIETS aspects have the same "root causes" and are related to the socio-economic characteristics (SEC) of people, such as education level, income, distance to the central market, and local belief. For example, local culture indirectly influenced the *institutional*, *financial*, *environmental,* and *social* aspects. The map also shows how "exogenous" factors that cannot be controlled, affected the situation. For example, the climate contributed to some extent to the *environmental* and *social* aspects, or soil structure influences the *environmental*, *technological*, and *financial* aspects.

The conceptual map also exemplifies the interdependencies between FIETS aspects, for example, the *institutional* aspect influenced the *financial* and *social* aspects. Good institutional quality is expected to result in better management of budgets, attracting more donors, and enhancing people's trust. The good institutional can result in the community who is willing to contribute financially to the WASH program. A good institution also would result in better WASH implementation and promotional activities which can effectively change people's psychology and their behavior. *Technological* aspect influence the *financial* aspect in the context of technology’s cost. Moreover, a good institution could provide more training and increase the skills of the officer.

In the cluster *financial* factors, all possible funding sources for WASH programs were included in the map, including what factors might influence the availability of the funding. The willingness to financially contribute to a WASH program is influenced by *trust*, *quality of the technology*, and *sense of ownership*. Moreover, the affordability to contribute is influenced by *cultural spending*, *income*, and *technology cost*.

Furthermore, the conceptual map summarises four main factors related to the institutional aspects in East Sumba that were often mentioned by interviewees: corruption and nepotism, management effectiveness, leadership, and regulatory quality. Here, we did not distinguish between the level of stakeholders in the conceptual map, e.g., between stakeholders at the village level and the district level.

There are two main discussion topics related to the *environmental* aspect, according to the interviewees: *water availability* and *scattered settlements*. The difficulty in getting water was due to geological characteristics, climate effects, and extensive water extraction.

The three key discussion topics in the *technological* aspect were costs, availability, and quality. The *technology costs* were influenced by two factors from the *environmental* aspect: *soil structure* and *scattered settlement*, as explained in the section *technological* aspect. The functioning of the distribution system was negatively influenced by the lack of local manufacturers in the area.

The connection between factors in the *social* aspect was also inspired by the previous HWT behavior in East Sumba (Daniel et al., 2020b). The social behavior of people was influenced by their psychological perceptions, such as the perception of *risk* or *attitude* towards WASH.

These perceptions were related to their socio-economic characteristics (SEC), such as education or local culture. *Local culture* is a combination of local belief *Marapu*, customs, and individual upbringing.

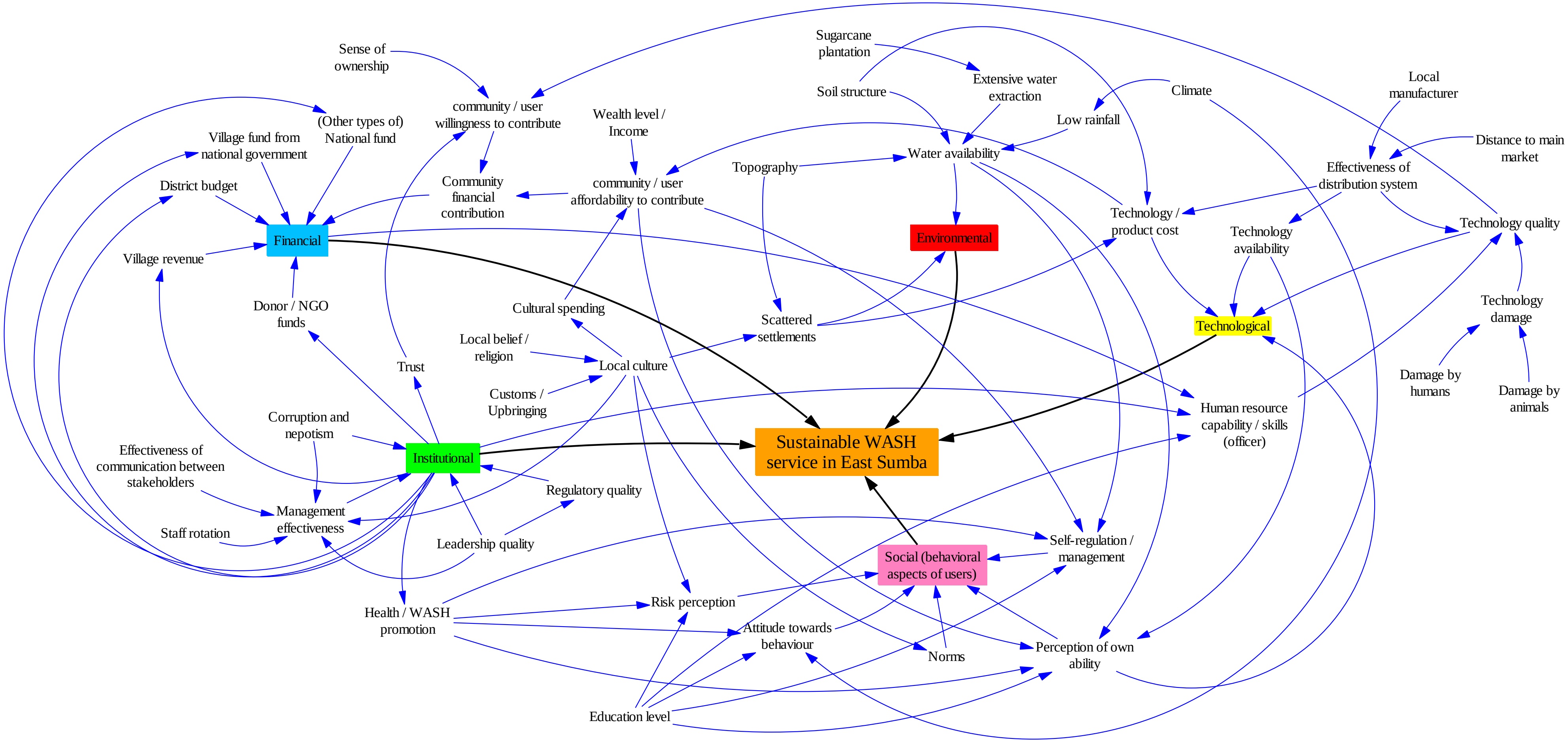


Figure 5. A conceptual map of factors contributing to the sustainability of WASH services in East Sumba. The factors were clustered into five FIETS aspects.

Stakeholder analysis

Figure 6 shows the importance-influence matrix of WASH-related stakeholders. Quadrant A shows the "most affected" actors of the current situation which needed to be handled with care. The community and the village water boards were in quadrant A . In East Sumba, the influence of the village community on WASH programs was relatively small due to the current social system.

The most important WASH stakeholders in East Sumba are presented in quadrant B, i.e. who can make the difference or decision, and there must be a good working relationship with the stakeholders from this quadrant. The village head or board had a significant role in changing the situation, followed by the district health agency and agency for regional development. The influence of the village's board, especially the village's head, was large since most of the village's heads were the most respectful persons in the village and came from a high cast (social level). They also had full authority over the village budget.

Quadrant C consists of stakeholders who could monitor and evaluate the WASH progress. They should be updated about the program and they also could give recommendations, even though their involvement was relatively low. Sub-district boards and village councils are in this quadrant.

Lastly, stakeholders in quadrant D had a limited role in the program but they needed to be satisfied. Donor agencies, such as the World Bank, the Ministry of economic affairs (national level), or other international funding agencies which give the money via local NGOs, and the district major are in this category.

In case of promotional activities, a doctor or health officer was mentioned as the main influential promoters. The WASH promotion was mainly conducted during the health consultation, household visit, or antenatal program. Other promotional activities were at religious places, *Posyandu* (pre and postnatal healthcare information), or schools. Villages in East Sumba usually have more than one *Posyandu*. Promotional activities using social media, radio, or television may not be effective since many houses in rural East Sumba did not have access to electricity. Most of our respondents said that they would start to drink boiled water if they get sick due to the suggestion by the doctor. This was confirmed by the doctors in health posts who said that they always encourage the patient to drink boiled water in every health consultation, especially in case of symptoms which might be caused by unsafe drinking water, such as diarrhoea.

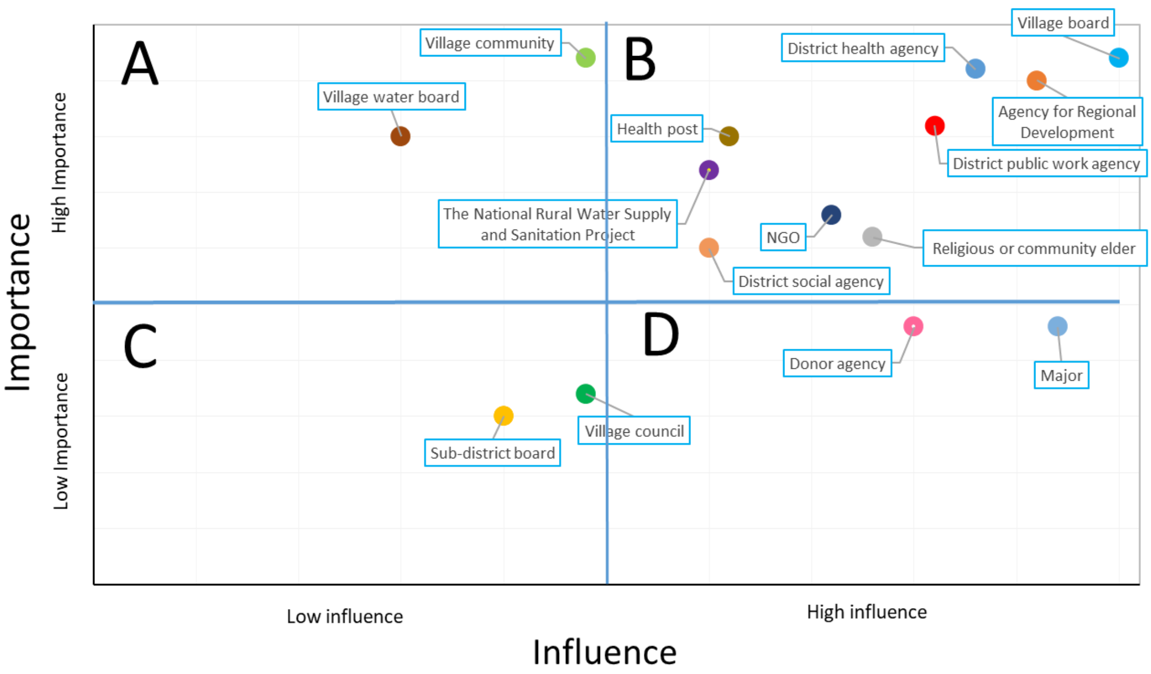


Figure 6. Influence and importance matrix of WASH-related stakeholders in East Sumba.

Key challenges and strategies to sustain WASH services in East Sumba

Based on the findings, we can argue that this area is vulnerable to unsustainable WASH services. Based on the FIETS analysis, we consider three main challenges. First, we argue that the institutions were not strong enough to support the sustainability of WASH. Despite the existence of regulation at the district level, there are weaknesses in the implementation. Second, water scarcity is a problem in this area and WASH cannot be sustained without water provision. Lastly, there is a challenge to change people's behaviour, considering their socio-economic characteristics.

Among all five FIETS aspects, we argue that the institutional aspect being the most critical aspect of sustainable WASH in East Sumba. We found that factors in the institutional aspect influence other factors in other four aspects, as recognized widely also in the WASH domain (Summerill et al., 2010; Ferrero et al., 2019; Herrera, 2019; Machado et al., 2019). Stronger institutions will result in a more reliable financial structure, a higher level of trust by the community, better regulations, better capacity building, and better WASH implementation. Moreover, there is a strong influence from the local culture on current institutional performance which may be unique compared to other WASH studies. The influence of culture on water institutions began to attract the attention of water researchers in the past few years, such as in the socio-hydrology domain (Pande et al., 2020). However, we found that this is rarely discussed in the WASH sector.

We consider the quality of leadership to be the root of the institutional problems in East Sumba, which also influences other aspects (Figure 5). Our interview results suggest that the quality of the leader makes a difference in the project outcome, not only in the WASH sector but in other sectors as well, such as agriculture and economics. Moreover, an inspirational leader who has much interest in WASH was rarely found in East Sumba. Considering the local culture in East Sumba, finding or creating a "champion" or "natural leader", who can drive the community to sustain WASH services, should be a priority during WASH implementation. Previous WASH studies have found that this method is successful in sustaining WASH services in developing countries (Chatterley et al., 2014; Crocker et al., 2016). Since the rural communities in East

Sumba adopt a caste system, the champion should then come from a high-level caste or should be a respected person, like the community or village leader.

Moreover, the *environmenta*l aspect in East Sumba cannot be overlooked, especially the reduction of environmental capacity to provide water. Previous studies mentioned that difficult access to water hinders WASH (Pickering and Davis, 2012; McMichael and Robinson, 2016), and it is probably worsened by climate change (Clasen, 2011). Extensive groundwater extraction is another factor affecting water supply in the area. Therefore, there is a need to create a district policy regarding groundwater extraction to prevent groundwater depletion in the future, especially the extraction by extensive commercial plantations, such as sugar cane being one of the top four most water-intensive crops (WWF, 2006). In addition, the soil structure influences not only the water services but also the latrine construction. This situation is also found in a sanitation program in rural Zambia (Lawrence et al., 2016). That study highlights the importance of design adaption to overcome this physical barrier. However, we did not find any specific innovation in latrine design or construction in East Sumba.

Another discussion topic with the NGOs was about the open defecation program led by the national government. The program pushes the local municipality to focus on constructing the latrine and reducing open defecation rather than water provision, as also suggested by Firmana et al. (2017). However, we found that inadequate water provision is one of the main reasons why people in East Sumba do not use the latrine, even though they have constructed it. In other words, practicing a proper WASH behaviour is difficult without adequate water provision at home (Ray, 2020). Therefore, we emphasize the need for adding more flexibility to the national policy for the location with "special needs" or water scarcity areas, like East Sumba. This can prompt the district government to balance the focus on water provision and sanitation.

Changing people's perceptions regarding appropriate WASH is challenging. Our previous HWT adoption analysis showed that there are some SECs of people, besides local culture, that influence people's psychological related to WASH, e.g., low education level, poor wealth status, and difficult access to water (Daniel et al., 2020b). This finding suggests that sustained WASH depends on the household living standard. Thus, the effort to sustain WASH needs to be accompanied by increasing the household standard of living. This can be a challenge in the case of East Sumba since the district was among the worst 5% in Human Development Index in Indonesia (Badan Pusat Statistik, 2013).

Our findings also show that local perceptions are not in agreement with the scientific knowledge of water quality (Gartin et al., 2010), since people consider water hardness as a problem even though the value is below the standard. Presenting the water hardness, microbial water quality, and their relation to health could resuscitate the target group.

The current WASH situation could not be separated from the local culture as found in other cultural settings (Rainey and Harding, 2005; Mahmood et al., 2011; Routray et al., 2015). A traditional *Marapu* belief system applies a caste system that determines the social status of people. However, there are several consequences to its practice, since people from a low caste are usually poor and poorly educated, have limited access to resources, and also limited decision-making power (Vel & Makambombu, 2010). This leads to inequalities in access to WASH services.

Conclusion

Our study explored the *financial*, *institutional*, *environmental*, *technological*, and *social* aspects that contribute to the current WASH situation in the rural area of East Sumba, Indonesia. We used this area as an example to illustrate the challenges to achieve sustainable

WASH in the context of vulnerable, indigenous, and rural areas in developing countries. We found three main challenges that make this area vulnerable to unsustainable WASH services: weak institutions, difficult access to water supply, and poor socio-economic conditions. Additionally, by summarising the key factors obtained from the interviews in a conceptual map, we discovered the root causes of the current situation and analysed the interconnection between the various factors. For example, local culture is one of the root causes that indirectly influenced all FIETS aspects. Furthermore, we conclude from the stakeholder analysis that the village leaders are the key actors who can drive and influence the sustainability of WASH services in East Sumba. We also highlight the need for analysing the influence of deeply-rooted culture on sustaining WASH services and behavior in developing countries. Finally, we argue that integrating WASH intervention into the prevailing cultural practices is necessary. For example, in our area it is of importance to find a natural leader from a high-level caste to trigger the community to adopt water-related technologies.

Chapter 9

Conclusions and outlook

- Distributing PET bottles for Solar Disinfection (SODIS) in East Sumba -

Conclusions

This thesis presents the factors that influence the adoption of household water treatment (HWT) in developing countries, including drinking water quality and water, sanitation, and hygiene-related (WASH) services. Factors influencing HWT adoption have been found and discussed in this study. However, the main observation is that key factors that drive the adoption of HWT are context-specific. This implies the need to conduct behavioural studies in all WASH behavioural programs. In addition, based on the study case in Indonesia, easier access to water supply influenced household's ability to perform HWT and other WASH behaviour, such as handwashing and regular use of a toilet.

Further, in this thesis, the application of the Bayesian Belief Networks (BBN) was introduced to link the household drinking water quality and sanitary inspection in medium resource settings in rural areas. The results revealed that there were many pathogen exposure routes in household besides drinking water. By simulating and comparing the effect of individual or combination of variables on the water quality, the model confirmed that HWT could eliminate pathogens in drinking water. However, recontamination from poor hygiene practices, such as uncovered drinking water storage or dirty environment, could diminish the positive impact of HWT.

In addition, unsustainable WASH services, especially easy access to water supply, complicated the adoption of HWT or other WASH behaviours. Factors influencing the sustainability of WASH services can be categorised as: (1) endogenous, i.e. it is coming from inside and can be "changed", and (2) exogenous, i.e. coming from outside and cannot be "changed". Examples of endogenous factors were institutional quality and community perception, while topography and climate were examples of exogenous factors.

The specific conclusions in response to each research question introduced in Chapter 1 are highlighted below.

What are the factors that influence the adoption of HWT in low-middle income countries (RQ 1)?

Factors that influence the adoption of HWT in LMICs could be categorised into two main aspects: household socio-economic characteristics (SEC) and household perceptions or psychological factors.

The SEC that were found influential or critical in this study were parent's education, economic level of the household, and being exposed to WASH or HWT promotional activities (see Chapter 2, 4, and 5). However, there were some SEC which were found to be context-specific, i.e. depending on the location, such as access to water or local beliefs.

For the psychological factors, the author followed the Risk, Attitude, Norms, Ability, and Self-regulation (RANAS) theory. Similar to the SEC, psychological factors were also context-specific. However, we found that social norms and attitude were more significant compared to other psychological factors (see Chapter 4 and 5). This suggests that personal feelings towards HWT and influences from peers or community were critical in sustaining the adoption of HWT.

Moreover, the institutional quality was found to be another maindriver of HWT adoption, even though it could be categorised as an exogenous factor that "indirectly" influenced the adoption of HWT (see Chapter 8).

What are the relationships between SEC, psychological factors, and the adoption of HWT (RQ 2)?

Three notable relationships between SEC, psychological factors, and the adoption of HWT were found:

1. There was no single characteristic, either SEC or psychological factor, that individually explained the successful adoption of HWT, as found in the Qualitative Comparative Analysis (QCA) of 41 case studies in developing countries (see Chapter 2).

   This finding was further confirmed by the BBN model based on a case study in Nepal stating that "interventions that only target single socio-economic characteristics do not effectively increase the probability of HWT practice" (see Chapter 4).
2. There were combinations of SEC and psychological factors that determine the successful adoption of HWT.

   The QCA showed that risk perception, i.e. perceived threat due to bad water quality, appeared in three out of five pathways of successful adoption of HWT (see Chapter 2). However, risk perception must be accompanied by other conditions, such as using tap water as a main water source and parents complete primary school. Such combinations characterized the early adopter group, i.e. households that are quick in changing their behaviour and adopt HWT.
3. SEC influenced the adoption of HWT via psychological factors, as shown by a mediation analysis (see Chapter 3).

   The effects of SEC on the adoption of HWT was evident: the better the SEC of the households, the higher the likelihood of them to use HWT regularly. That was because better SEC conditions facilitated the psychology of people positively, for example, the higher the education of the mother, the more confident the households were to use HWT regularly. This highlights the importance of improving the SEC conditions of the target group to improve the HWT adoption.

One of the main implications of these findings is that we cannot analyse SEC and psychological factors at the same "level".

How do we analyse the adoption of HWT taking into account the relationships between SEC and psychological factors (RQ 3)?

The findings from the second research question were translated into a probabilistic hierarchical causal relationship model, from SEC to psychological factors and then to HWT adoption, using a BBN model. Two case studies from rural Nepal and Indonesia were used (see Chapter 4 and 5).

The BBN approach predicted the HWT adoption in the household as a function of its SEC and psychological factors. As a result, the model could indicate the characteristics of early adopter households. For example, it was found that households with a toddler, consisting of educated and relatively wealthy persons, who were aware of and had easy access to HWT products, and had piped water connections, had an increased likelihood to adopt HWT in rural Nepal, i.e. from 18% to 57% (see Chapter 4).

Moreover, the BBN model was able to show how SEC influenced psychological factors. For example, based on a case study in Indonesia, easy access to water positively influenced household's ability to practise HWT regularly. Another example was that households that followed indigenous belief perceived a lower attitude and norm towards HWT than households that did not follow indigenous belief (see Chapter 5).

Is there a feedback effect or reverse causality from the adoption of HWT to the psychology of water use (RQ 4)?

It was found that there was a feedback effect or reverse causality from the adoption of HWT to the psychological factors. This finding suggests a biased estimation of the effect of psychological factors on the adoption of HWT in conventional statistical analyses, such as ordinary least squares or logistic regression (see Chapter 6). Such bi-directional effects should be taken into account in WASH-related behavioural analyses, for example, by using and "instrument variable two-stage regression" approach. However, this approach can only be conducted if valid instruments can be found. Valid instruments mean that they can predict the psychological factors well and the effect of instruments on HWT adoption and/or other WASH-related behaviour is only via the psychological factors. In this study, variables related to institutional quality were found valid as instrumental variables to investigate this feedback effect. However, these variables could not be used in the analysis if study respondents or households are located in the same area or have similar local institutions.

How do we assess the risk related to household drinking water quality and general hygiene practices (RQ 5)?

Factors that influence the water quality were categorised into five main clusters: (1) water quality or condition at the water source, (2) drinking water storage condition, (3) whether or not the water was treated, (4) water management and hygiene condition surrounding the drinking water storage, and (5) "external" variables. An example of external variable is level of water fullness in the storage (see Chapter 7). As a result of an analysis with a BBN model in rural areas in Indonesia, improving general water handling and hygiene conditions in a household would better protect drinking water quality than a single condition, e.g. practising

HWT only. In addition, HWT improved water quality but the effect was more prominent in the context of better sanitation and hygiene conditions.

In this thesis, the performance of four BBN models was compared with varying variables used in the model. It was found that the inclusion of an extra "external" variable besides the standard sanitary inspection variables in the model, i.e. level of fullness in the water storage, improved the model performance. Finally, the results suggested that the BBN approach could be an alternative method for conventional statistical methods to link water quality to sanitary inspection data.

What are contextual factors contributing to the sustainability of WASH services in rural areas (RQ 6)?

The contextual factors that influence the sustainability of WASH services were divided into five main categories: financial, institutional, environmental, technical, and social (see Chapter 8). In the context of the study area in Indonesia, the institutional category was the "leverage point". Leverage point means that a key factor in the system where small changes can result in larger changes in the whole system, or factor that heavily influences other categories. This emphasizes the need to improve WASH-related institutional performance to better plan and execute WASH interventions and policies. By doing this, the institutions could gain more trust from society and stimulate the sustainability of WASH services. There were exogenous environmental factors that threatened WASH services, such as water scarcity, topography, and soil structure. These exogenous factors are relatively difficult to handle but need to be considered in the district WASH-related policies, or even at the national level.

The findings were visualized in a conceptual map showing how those factors interconnected and influenced each other. For example, the map shows how local culture, as one of the root causes, influenced the financial situation of the people.

Study implications and outlook

The thesis could inspire future water-related behavioural studies in developing countries. This thesis recommends to use a systems approach to better interpret water-related human behaviour, e.g. how SEC influence the psychological factors and then the behaviour.

This study gives an example of how a WASH intervention was designed and conducted by considering a pre-intervention survey. In addition to its scientific contribution, the thesis also presents practical recommendations to promote regular use of HWT by the local stakeholders in East Sumba, Indonesia. The need to provide sufficient water supply to the households in the study area is emphasized, because water scarcity is a key to facilitate appropriate WASH behaviour, e.g. HWT adoption or the use of a latrine. Attitudinal factors towards HWT, especially the perception of treated water's taste, were found to be the key to boost the adoption of HWT and need to be targeted (see Chapter 5). Furthermore, the sanitary inspection results showed that there was a high chance of (re)contamination, e.g. the presence of livestock and flies around the water storage (see Chapter 7).

Hence, considering all these aspects, a small intervention was conducted in July - August 2019 by promoting one of the HWT methods, Solar disinfection (SODIS), among households visited in 2018. Based on previous studies, SODIS was considered not changing the taste of water and, if people consume directly from the bottle which was always covered by the lid, the chance of (re)contamination is relatively small. Another purpose of the intervention was to see whether the adoption of SODIS varied among households with varying SEC, in which this may validate the results of the BBN model. However, the next visit to evaluate the intervention, which was planned in March-April 2020, was cancelled due to COVID-19 pandemic.

Future studies should also be directed to find potential instrument variables to analyse the reverse feedback or endogeneity of the psychological factors that are community-specific or in a small scale, e.g. households in the same district. The endogeneity study conducted in this thesis used variables related to institutional quality as instrument variables, comparing several case studies with different institutional quality (see Chapter 6). However, households in the same area od district have the same institutional quality, meaning that institutional quality could not be used as instrument variables in these circumstances.

References

Literature used in this dissertation

“Selalu sitasi dan mention poin-poin yang kita dapat dari orang lain, sekecil apa pun itu”

“Always cite and mention all points that we got from others, no matter how small it is”

- Nulis Jurnal (Youtube channel) -

Abdallah, W., Goergen, M., and O'Sullivan, N. (2015). Endogeneity: How Failure to Correct for it can Cause Wrong Inferences and Some Remedies. *Br. J. Manag.* 26, 791–804. doi:10.1111/1467-8551.12113.

Adler, N. E., and Newman, K. (2002). Socioeconomic Disparities In Health: Pathways And Policies Inequality. *Health Aff.* 2, 60–76. doi:10.1377/hlthaff.21.2.60.

Ahmad, S., Ali, S. H., Mirza, M. U., and Lotia, H. (2017). The limits of water pricing in a developing country metropolis: Empirical lessons from an industrial city of Pakistan. *Water (Switzerland)* 9. doi:10.3390/w9070533.

Aiken, B. A., Stauber, C. E., Ortiz, G. M., and Sobsey, M. D. (2011). An assessment of continued use and health impact of the concrete biosand filter in Bonao, Dominican Republic. *Am. J. Trop. Med. Hyg.* 85, 309–317. doi:10.4269/ajtmh.2011.09-0122.

Ajzen, I. (1991). The theory of planned behavior. *Orgnizational Behav. Hum. Decis. Process.* 50, 179–211. doi:10.1016/0749-5978(91)90020-T.

Alesina, A., and Giuliano, P. (2015). Culture and Institutions. *J. Econ. Lit.* 53, 898–944. doi:10.1257/jel.53.4.898.

Allen, E., Morazan, I. M., and Witt, E. (2018). Actively engaging women is helping solve the global water crisis. *J. Water, Sanit. Hyg. Dev.* 8, 632–639. Available at: https://doi.org/10.2166/washdev.2018.025%0A.

Altherr, A., Mosler, H., Tobias, R., and Butera, F. (2009). Health Education & Behavior Attitudinal and Relational Factors Predicting the Use of Solar Water Disinfection : A Field Study in Nicaragua. *Heal. Educ. Behav.* 35, 207–220. doi:10.1177/1090198106288251.

Appiah, A., Adamowicz, W., Lloyd-Smith, P., and Dupont, D. (2019). Reliability of Drinking Water: Risk Perceptions and Economic Value. *Water Econ. Policy* 5, 1–27. doi:10.1142/S2382624X18500200.

Arnold, B., Arana, B., Mausezahl, D., Hubbard, A., and Colford Jr., J. M. (2009). Evaluation of a pre-existing, 3-year household water treatment and handwashing intervention in rural Guatemala. *Int J Epidemiol* 38, 1651–1661. doi:10.1093/ije/dyp241.

Arnold, R. D., and Wade, J. P. (2015). A definition of systems thinking: A systems approach. *Procedia Comput. Sci.* 44, 669–678. doi:10.1016/j.procs.2015.03.050.

Augsburg, B., and Rodríguez-Lesmes, P. A. (2018). Sanitation and child health in India. *World Dev.* 107, 22–39. doi:10.1016/j.worlddev.2018.02.005.

Aunger, R., and Curtis, V. (2016). Behaviour Centred Design: towards an applied science of behaviour change. *Health Psychol. Rev.* 10, 425–446. doi:10.1080/17437199.2016.1219673.

Badan Pusat Statistik (2013). Tabel Dinamis Subjek Indeks Pembangunan Manusia. *Situs Web BPS*. Available at: https://www.bps.go.id/subject/26/indeks-pembangunan-manusia.html#subjekViewTab6 [Accessed October 28, 2019].

Badan Pusat Statistik (2019a). Proporsi Populasi Penduduk Yang Memiliki Akses Terhadap Layanan Sanitasi Layak Dan Berkelanjutan Menurut Provinsi, 2015 - 2018. *Situs Web BPS*. Available at: https://www.bps.go.id/dynamictable/2018/05/28/1382/proporsi-populasi-penduduk-yang-memiliki-akses-terhadap-layanan-sanitasi-layak-dan-berkelanjutan-menurut-provinsi-2015---2018.html [Accessed October 21, 2019].

Badan Pusat Statistik (2019b). Proporsi Populasi Yang Memiliki Akses Terhadap Layanan Sumber Air Minum Layak Dan Berkelanjutan Menurut Provinsi, 2015 - 2018. *Situs Web*

BPS. Available at: https://www.bps.go.id/dynamictable/2018/05/28/1387/proporsi-populasi-yang-memiliki-akses-terhadap-layanan-sumber-air-minum-layak-dan-berkelanjutan-menurut-provinsi-2015---2018.html [Accessed October 21, 2019].

Bae, Y., and Chang, H. (2012). Adoption of smart TVs: a Bayesian network approach. *Ind. Manag. Data Syst.* 112, 891–910. doi:10.1108/02635571211238509.

Bain, R., Bartram, J., Elliott, M., Matthews, R., McMahan, L., Tung, R., et al. (2012). A summary catalogue of microbial drinking water tests for low and medium resource settings. *Int. J. Environ. Res. Public Health* 9, 1609–1625.

Bain, R., Cronk, R., Hossain, R., Bonjour, S., Onda, K., Wright, J., et al. (2014a). Global assessment of exposure to faecal contamination through drinking water based on a systematic review. *Trop. Med. Int. Heal.* 19, 917–927. doi:10.1111/tmi.12334.

Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T., and Bartram, J. (2014b). Fecal contamination of drinking-water in low-and middle-income countries: a systematic review and meta-analysis. *PLoS Med.* 11, e1001644.

Ball, K., MacFarlane, A., Crawford, D., Savige, G., Andrianopoulos, N., and Worsley, A. (2009). Can social cognitive theory constructs explain socio-economic variations in adolescent eating behaviours? A mediation analysis. *Health Educ. Res.* 24, 496–506. doi:10.1093/her/cyn048.

Bamualim, A. (2000). Livestock Production and Fire Management in East Nusa Tenggara. in *Fire and Sustainable Agricultural and Forestry Development in Eastern Indonesia and Northern Australia. Proceedings of an international workshop held at Northern Territory University, Darwin, Australia, 13–15 April 1999*, 69–72.

Barstow, C. K., Nagel, C. L., Clasen, T. F., and Thomas, E. A. (2016). Process evaluation and assessment of use of a large scale water filter and cookstove program in Rwanda. *BMC Public Health* 16, 584. doi:10.1186/s12889-016-3237-0.

Barton, D. N., Kuikka, S., Varis, O., Uusitalo, L., Henriksen, H. J., Borsuk, M., et al. (2012). Bayesian networks in environmental and resource management. *Integr. Environ. Assess. Manag.* 8, 418–429. doi:10.1002/ieam.1327.

Bascle, G. (2008). Controlling for endogeneity with instrumental variables in strategic management research. *Strateg. Organ.* 6, 285–387. Available at: http://so.sagepub.com.

Becker, S. (2016). Using instrumental variables to establish causality. *IZA World Labor*, 1–10. doi:10.15185/izawol.250.

Behailu, B. M., Pietilä, P. E., and Katko, T. S. (2016). Indigenous Practices of Water Management for Sustainable Services. *SAGE Open* 6, 215824401668229. doi:10.1177/2158244016682292.

Bennett, D. (2012). Does clean water make you dirty? Water supply and sanitation in the Philippines. *J. Hum. Resour.* 47, 146–173. doi:10.3368/jhr.47.1.146.

Bertone, E., Sahin, O., Richards, R., and Roiko, A. (2016). Extreme events, water quality and health: A participatory Bayesian risk assessment tool for managers of reservoirs. *J. Clean. Prod.* 135, 657–667. doi:10.1016/j.jclepro.2016.06.158.

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., Onis, M. De, et al. (2011). Maternal and Child Nutrition 1 Maternal and child undernutrition and overweight in low-income and middle-income countries. doi:10.1016/S0140-6736(13)60937-X.

Blanca, M. J., Alarcón, R., and Bono, R. (2018). Current practices in data analysis procedures in psychology: What has changed? *Front. Psychol.* 9. doi:10.3389/fpsyg.2018.02558.

Boateng, D., Tia-Adjei, M., and Adams, E. A. (2013). Determinants of Household Water Quality in the Tamale Metropolis, Ghana. *J. Environ. Earth Sci.* 3, 70–77. Available at: http://www.iiste.org/Journals/index.php/JEES/article/view/6364.

Boisson, S., Kiyombo, M., Sthreshley, L., Tumba, S., Makambo, J., and Clasen, T. (2010). Field assessment of a novel household-based water filtration device: a randomised, placebo-controlled trial in the Democratic Republic of Congo. *PLoS One* 5, e12613.

Boisson, S., Stevenson, M., Shapiro, L., Kumar, V., Singh, L. P., Ward, D., et al. (2013). Effect of household-based drinking water chlorination on diarrhoea among children under five in Orissa, India: a double-blind randomised placebo-controlled trial. *PLoS Med* 10, e1001497. doi:10.1371/journal.pmed.1001497.

Bollen, K. A., and Pearl, J. (2013). "Eight myths about causality and structural equation models," in *Handbook of causal analysis for social research* (Springer Netherlands), 301– 328.

Bollmann, G., Rouzinov, S., Berchtold, A., and Rossier, J. (2019). Illustrating instrumental variable regressions using the career adaptability - Job satisfaction relationship. *Front. Psychol.* 10. doi:10.3389/fpsyg.2019.01481.

Bound, J., Jaeger, D. A., and Baker, R. M. (1995). Problems with instrumental variables estimation when the correlation between the instruments and the endogenous explanatory variable is weak. *J. Am. Stat. Assoc.* 90, 443–450. doi:10.1080/01621459.1995.10476536.

BPS Statistics of East Sumba Regency (2018). Persentase Rumah Tangga menurut Sumber Air Utama yang Digunakan Untuk Minum di Kabupaten Sumba Timur, 2015-2017. *Stat.*

Sumba Timur Regency. Available at: https://sumbatimurkab.bps.go.id/dynamictable/2018/11/12/50/persentase-rumah-tangga-menurut-sumber-air-utama-yang-digunakan-untuk-minum-di-kabupaten-sumba-timur-2015-2017.html [Accessed April 1, 2020].

Braveman, P., and Gottlieb, L. (2002). The Social Determinants of Health : It ' s Time to Consider the Causes of the Causes. *Public Health Rep.* 129, 19–31. doi:https://doi.org/10.1377/hlthaff.21.2.60.

Brick, T., Primrose, B., Chandrasekhar, R., Roy, S., Muliyil, J., and Kang, G. (2004). Water contamination in urban south India: household storage practices and their implications for water safety and enteric infections. *Int. J. Hyg. Environ. Health* 207, 473–80. doi:10.1078/1438-4639-00318.

Bromley, D. W., and Anderson, G. (2018). Does Water Governance Matter? *Water Econ. Policy* 4, 1–32. doi:10.1142/S2382624X17500023.

Brown, J., and Clasen, T. (2012). High adherence is necessary to realize health gains from water quality interventions. *PLoS One* 7, 1–9. doi:10.1371/journal.pone.0036735.

Brown, J., Proum, S., and Sobsey, M. D. (2009). Sustained use of a household-scale water filtration device in rural Cambodia. *J. Water Health* 7, 404–412.

Businelle, M. S., Kendzor, D. E., Reitzel, L. R., Costello, T. J., Cofta-Woerpel, L., Li, Y., et al. (2010). Mechanisms Linking Socioeconomic Status to Smoking Cessation: A Structural Equation Modeling Approach. *Heal. Psychol.* 29, 262–273. doi:10.1037/a0019285.

Cain, J. (2001). *Planning improvements in natural resources management*. oxfordshire: UK Centre for Ecology & Hydrology.

Cairncross, S. (1992). Sanitation and water supply : practical lessons from the decade. *world bank.*

Casanova, L. M., Walters, A., Naghawatte, A., and Sobsey, M. D. (2012a). A post-implementation evaluation of ceramic water filters distributed to tsunami-affected communities in Sri Lanka. *J. Water Health* 10, 209–220. doi:10.2166/wh.2012.181.

Casanova, L. M., Walters, A., Naghawatte, A., and Sobsey, M. D. (2012b). Factors affecting continued use of ceramic water purifiers distributed to tsunami-affected communities in Sri Lanka. *Trop. Med. Int. Heal.* 17, 1361–1368.

Chatterley, C., Javernick-Will, A., Linden, K. G., Alam, K., Bottinelli, L., and Venkatesh, M. (2014). A qualitative comparative analysis of well-managed school sanitation in Bangladesh. *BMC Public Health* 14, 6. doi:10.1186/1471-2458-14-6.

Chen, S. A., and Pollino, C. (2010). Guidelines for Good Practice in Bayesian Network Modelling. Available at: http://www.iemss.org/iemss2010/papers/S00/S.00.07.Guidelines for good practice in Bayesian network modelling - SERENA CHEN.pdf.

Christen, A., Duran Pacheco, G., Hattendorf, J., Arnold, B. F., Cevallos, M., Indergand, S., et al. (2011). Factors associated with compliance among users of solar water disinfection in rural Bolivia. *BMC Public Health* 11, 210. doi:10.1186/1471-2458-11-210.

Clasen, T. (2009). Scaling up household water treatment among low-income populations. *Geneva World Heal. Organ.*

Clasen, T. F. (2011). “Household Water Treatment and Safe Storage in Low-Income Countries,” in *Water and Sanitation-Related Diseases and the Environment: Challenges, Interventions, and Preventive Measures*, 219–230. doi:10.1002/9781118148594.ch18.

Clasen, T. F., and Mintz, E. D. (2004). International network to promote household water treatment and safe storage. *Emerg. Infect. Dis.* 10, 1179.

Clasen, T., Mclaughlin, C., Nayaar, N., Boisson, S., Gupta, R., Desai, D., et al. (2008). Microbiological Effectiveness and Cost of Disinfecting Water by Boiling in Semi-urban India. *Am J Trop Med Hyg* 79, 407–413.

Clasen, T., Schmidt, W.-P., Rabie, T., Roberts, I., and Cairncross, S. (2007a). Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *Bmj* 334, 782.

Clasen, T., Schmidt, W. P., Rabie, T., Roberts, I., and Cairncross, S. (2007b). Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *Bmj* 334, 782. doi:10.1136/bmj.39118.489931.BE.

Cohen, A., Tao, Y., Luo, Q., Zhong, G., Romm, J., Colford, J. M., et al. (2015). Microbiological evaluation of household drinking water treatment in rural China shows benefits of electric kettles: A cross-sectional study. *PLoS One* 10, 1–16. doi:10.1371/journal.pone.0138451.

Collaborators, G. D. D. (2017). Estimates of global, regional, and national morbidity, mortality, and aetiologies of diarrhoeal diseases: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet. Infect. Dis.* 17, 909–948. doi:10.1016/S1473-3099(17)30276-1.

Contzen, N., and Marks, S. J. (2018). Increasing the regular use of safe water kiosk through collective psychological ownership: A mediation analysis. *J. Environ. Psychol.* 57, 45–52. doi:10.1016/j.jenvp.2018.06.008.

Contzen, N., and Mosler, H. (2015). RANAS (Risks, Attitudes, Norms, Abilities, and Self-regulation) methodological fact sheets - 6 methodological fact sheets on behavior change.

Crampton, A., and Ragusa, A. T. (2016). Exploring perceptions and behaviors about drinking water in Australia and New Zealand: Is it risky to drink water, when and why? *Hydrology* 3, 8. doi:10.3390/hydrology3010008.

Crocker, J., Abodoo, E., Asamani, D., Domapielle, W., Gyapong, B., and Bartram, J. (2016). Impact Evaluation of Training Natural Leaders during a Community-Led Total Sanitation Intervention: A Cluster-Randomized Field Trial in Ghana. *Environ. Sci. Technol.* 50, 8867–8875. doi:10.1021/acs.est.6b01557.

Croft, T. N., Marshall, A. M. J., and Allen, C. K. (2018). Guide to DHS Statistics. Available at: www.DHSprogram.com.

Cronin, A. A., Breslin, N., Gibson, J., and Pedley, S. (2006). Monitoring source and domestic water quality in parallel with sanitary risk identification in Northern Mozambique to prioritise protection interventions. *J. Water Health* 4, 333–345. doi:10.2166/wh.2006.029.

Cronk, R., and Bartram, J. (2017). Factors Influencing Water System Functionality in Nigeria and Tanzania: A Regression and Bayesian Network Analysis. *Environ. Sci. Technol.* 51, 11336–11345. doi:10.1021/acs.est.7b03287.

Curtis, V. (2019). Explaining the outcomes of the “Clean India” campaign: Institutional behaviour and sanitation transformation in India. *BMJ Glob. Heal.* 4. doi:10.1136/bmjgh-2019-001892.

Dai, H., Chen, X., Ye, M., Song, X., Hammond, G., Hu, B., et al. (2019). Using Bayesian Networks for Sensitivity Analysis of Complex Biogeochemical Models. *Water Resour.*

Res. 55, 3541–3555. doi:10.1029/2018WR023589.

Daniel, D., Diener, A., Pande, S., Jansen, S., Marks, S., Meierhofer, R., et al. (2019). Understanding the effect of socio-economic characteristics and psychosocial factors on household water treatment practices in rural Nepal using Bayesian Belief Networks. *Int. J. Hyg. Environ. Health* 222, 847–855. doi:10.1016/j.ijheh.2019.04.005.

Daniel, D., Diener, A., van de Vossenberg, J., Bhatta, M., and Marks, S. J. (2020a). Assessing Drinking Water Quality at the Point of Collection and within Household Storage Containers in the Hilly Rural Areas of Mid and Far-Western Nepal. *Int. J. Environ. Res. Public Health* 17, 2172. doi:10.3390/ijerph17072172.

Daniel, D., Marks, S. J., Pande, S., and Rietveld, L. (2018). Socio-environmental drivers of sustainable adoption of household water treatment in developing countries. *npj Clean Water* 1. doi:10.1038/s41545-018-0012-z.

Daniel, D., Pande, S., and Rietveld, L. (2020b). Socio-economic and Psychological Determinants for Household Water Treatment Practices in Indigenous - Rural Indonesia.

Daniel, D., Pande, S., and Rietveld, L. (2020c). The effect of socio-economic characteristics on the use of household water treatment via psychosocial factors: a mediation analysis. *Hydrol. Sci. J.* 65, 2350–2358. doi:10.1080/02626667.2020.1807553.

Daniel, D., Sirait, M., and Pande, S. (2020d). A Hierarchical Bayesian Belief Network Model of Household Water Treatment Behaviour in a Suburban Area: A Case Study of Palu - Indonesia. *PLoS One*. doi:10.1371/journal.pone.0241904.

Danny V. Colombara, Ibrahim Abdel-Messih Khalil, Puja C. Rao , Christopher Troeger, Mohammad H. Forouzanfar, Mark S. Riddle, A. H. M. (2016). Chronic Health Consequences of Acute Enteric Infections in the Developed World. *Am. J.*

Gastroenterol. Suppl. 3, 12–24. doi:10.1038/ajgsup.2016.10.

Dasgupta, P. (2004). Valuing health damages from water pollution in urban Delhi, India: a health production function approach. *Environ. Dev. Econ.* 9, S1355770X03001098. doi:10.1017/S1355770X03001098.

Davis, R., Campbell, R., Hildon, Z., Hobbs, L., and Michie, S. (2015). Theories of behaviour and behaviour change across the social and behavioural sciences : a scoping review. *Health Psychol. Rev.* 9, 323–344. doi:10.1080/17437199.2014.941722.

Dearden, P., Jones, S., Sartorius, R., and CIDT (2003). Tools for Development. A handbook for those engaged in development activity. *Perform. Eff. Dep. Dep. Int. Dev. Univ. Wolverhampt.*, 142. doi:10.1109/ICM.2008.5393823.

Death, R. G., Death, F., Stubbington, R., Joy, M. K., and van den Belt, M. (2015). How good are Bayesian belief networks for environmental management? A test with data from an agricultural river catchment. *Freshw. Biol.* 60, 2297–2309. doi:10.1111/fwb.12655.

Dequech, D. (2006). Institutions and Norms in Institutional Economics and sociology. *J. Econ. Issues* 40, 473–481.

Dey, N. C., Parvez, M., Dey, D., Saha, R., Ghose, L., Barua, M. K., et al. (2017). Microbial contamination of drinking water from risky tubewells situated in different hydrological regions of Bangladesh. *Int. J. Hyg. Environ. Health* 220, 621–636. doi:10.1016/j.ijheh.2016.12.007.

Díaz, J.-J., and Andrade, R. (2015). An exploration of the impact of water and sanitation on child health in Peru, 3ie Grantee Final Report. New Delhi.

Diener, A., Schertenleib, A., Daniel, D., Kenea, M., Pratama, I., Bhatta, M., et al. (2017).

Adaptable drinking-water laboratory unit for decentralised testing in remote and alpine regions. in (Loughborough: 40th WEDC International Conference), 1–7.

Do, C. B., and Batzoglou, S. (2008). What is the expectation maximization algorithm? *Nat. Biotechnol.* 26, 897–899. doi:10.1038/nbt1406.

Doria, M. de F. (2010). Factors influencing public perception of drinking water quality. *Water Policy* 12, 1–7. doi:10.2166/wp.2009.051.

Dreibelbis, R., and Winch, P. (2013). The integrated behavioural model for water, sanitation, and hygiene: a systematic review of behavioural models and a framework for designing and evaluating. *BMC public*. Available at: http://bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-13-1015.

Dreibelbis, R., Winch, P. J., Leontsini, E., Hulland, K. R., Ram, P. K., Unicomb, L., et al. (2013). The Integrated Behavioural Model for Water, Sanitation, and Hygiene: a systematic review of behavioural models and a framework for designing and evaluating behaviour change interventions in infrastructure-restricted settings. *BMC Public Health* 13, 1015. doi:10.1186/1471-2458-13-1015.

Druzdzel, M. J., and Sowinski, T. (1995). GeNIe Modeler. Available at: https://www.bayesfusion.com/.

du Preez, M., Conroy, R. M., Ligondo, S., Hennessy, J., Elmore-Meegan, M., Soita, A., et al. (2011). Randomized Intervention Study of Solar Disinfection of Drinking Water in the Prevention of Dysentery in Kenyan Children Aged Under 5 Years. *Environ. Sci. Technol.* 45, 9315–23. doi:10.1021/es2018835.

Du Preez, M., McGuigan, K. G., and Conroy, R. M. (2010). Solar disinfection of drinking water in the prevention of dysentery in South African children aged under 5 years: The role of participant motivation. *Environ. Sci. Technol.* 44, 8744–8749. doi:10.1021/es103328j.

Dubois, A. E., Crump, J. A., Keswick, B. H., Slutsker, L., Quick, R. E., Vulule, J. M., et al. (2010). Determinants of use of household-level water chlorination products in rural Kenya, 2003-2005. *Int J Env. Res Public Heal.* 7, 3842–3852. doi:10.3390/ijerph7103842.

DuBois, A. E., Crump, J. A., Keswick, B. H., Slutsker, L., Quick, R. E., Vulule, J. M., et al. (2010). Determinants of use of household-level water chlorination products in Rural Kenya, 2003-2005. *Int. J. Environ. Res. Public Health* 7, 3842–3852. doi:10.3390/ijerph7103842.

Duke, W. F., Nordin, R. N., Baker, D., and Mazumder, A. (2006). The use and performance of BioSand filters in the Artibonite Valley of Haiti: a field study of 107 households. *Rural Remote Heal. [electronic Resour.* 6, 570.

Dutch WASH Alliance FIETS sustainability approach. 16.

Dwipayanti, N. M. U., Rutherford, S., and Chu, C. (2019). Cultural determinants of sanitation uptake and sustainability: local values and traditional roles in rural Bali, Indonesia. *J. Water, Sanit. Hyg. Dev.* 9, 438–449. doi:10.2166/washdev.2019.178.

Earwaker, P., and Webster, J. (2009). Evaluation of the long - term sustainability of biosand filters in rural Ethiopia. *Water, Sanit. Hyg. Sustain. Dev. multisectoral approaches. Proc. 34th WEDC Int. Conf.*, 154–158. Available at: http://wedc.lboro.ac.uk/resources/conference/34/Earwaker_P_-_223.pdf.

Effendi, A. C., and Apandi, T. (1993). Geological Map of The Waikabubak and Waingapu Sheets, Nusatenggara.

Eisenberg, J. N. S., Trostle, J., Sorensen, R. J. D., and Shields, K. F. (2012). Toward a systems approach to enteric pathogen transmission: from individual independence to community interdependence. *Annu. Rev. Public Health* 33, 239–57. doi:10.1146/annurev-publhealth-031811-124530.

El Khanji, S., and Hudson, J. (2016). Water utilization and water quality in endogenous economic growth. *Environ. Dev. Econ.* 21, 626–648. doi:10.1017/S1355770X16000061.

Elala, D., Labhasetwar, P., and Tyrrel, S. F. (2011). Deterioration in water quality from supply chain to household and appropriate storage in the context of intermittent water supplies. *Water Sci. Technol. Water Supply* 11, 400. doi:10.2166/ws.2011.064.

Enger, K. S., Nelson, K. L., Rose, J. B., and Eisenberg, J. N. S. (2013). The joint effects of efficacy and compliance: A study of household water treatment effectiveness against childhood diarrhea. *Water Res.* 47, 1181–1190. doi:10.1016/j.watres.2012.11.034.

Ercumen, A., Naser, A. M., Arnold, B. F., Unicomb, L., Colford, J. M., and Luby, S. P. (2017a). Can sanitary inspection surveys predict risk of microbiological contamination of groundwater sources? Evidence from shallow tubewells in rural Bangladesh. *Am. J. Trop. Med. Hyg.* 96, 561–568. doi:10.4269/ajtmh.16-0489.

Ercumen, A., Naser, A. M., Unicomb, L., Arnold, B. F., Colford, J. M., and Luby, S. P. (2015). Effects of source-versus household contamination of tubewell water on child diarrhea in Rural Bangladesh: A randomized controlled trial. *PLoS One* 10, 1–22. doi:10.1371/journal.pone.0121907.

Ercumen, A., Pickering, A. J., Kwong, L. H., Arnold, B. F., Parvez, S. M., Alam, M., et al. (2017b). Animal Feces Contribute to Domestic Fecal Contamination: Evidence from E. coli Measured in Water, Hands, Food, Flies, and Soil in Bangladesh. *Environ. Sci.*

Technol. 51, 8725–8734. doi:10.1021/acs.est.7b01710.

Esrey, S. A., and Habicht, J. (1986). Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. *Epidemiol. Rev.* 8, 117–128.

ESRI (2011). ArcGIS Desktop. Available at: http://desktop.arcgis.com.

Ferrero, G., Setty, K., Rickert, B., George, S., Rinehold, A., DeFrance, J., et al. (2019). Capacity building and training approaches for water safety plans: A comprehensive literature review. *Int. J. Hyg. Environ. Health* 222, 615–627. doi:10.1016/j.ijheh.2019.01.011.

Fewster, E., Mol, A., and Wiesent–Brandsma, C. (2004). The long-term sustainability of household bio-sand filtration. *30th WEDC Int. Conf. Vientiane, Lao PDR, 2004*, 558–561.

Fiebelkorn, A. P., Person, B., Quick, R. E., Vindigni, S. M., Jhung, M., Bowen, A., et al. (2012). Systematic review of behavior change research on point-of-use water treatment interventions in countries categorized as low- to medium-development on the human development index. *Soc Sci Med* 75, 622–633. doi:10.1016/j.socscimed.2012.02.011.

Figueroa, M., and Kincaid, D. (2010). Social, cultural and behavioral correlates of household water treatment and storage. *Cent. Publ. HCI 2010-1 Heal. Commun. Insights, Balt. Johns Hopkins Bloom. Sch. Public Heal. Cent. Commun. Programs*, 0–55. Available at: http://ccp.jhu.edu/wp-content/uploads/Household-Water-Treatment-and-Storage-2010.pdf.

Fiore, M., Minnings, K., and Fiore, L. (2010). Assessment of biosand filter performance in rural communities in southern coastal Nicaragua: an evaluation of 199 households. *Rural Remote Health*, 1–8.

Firmana, A. S., Hasanbasri, M., and Iravati, S. (2017). Pembiayaan Kesehatan Operasional Program Sanitasi Total Berbasis Masyarakat (STBM) Di Dinas Kesehatan Kabupaten Sumbawa Barat. *J. Kebijak. Kesehat. Indones.* 6, 29–37. Available at: https://drive.google.com/file/d/0Bzt046lJwc-DVzl3RVlhZTZkWm8/view.

Fisher, M. B., Shields, K. F., Chan, T. U., Christenson, E., Cronk, R. D., Leker, H., et al. (2015). Understanding handpump sustainability: Determinants of rural water source functionality in the Greater AframPlains region of Ghana. *Water Resour. Res.* 51, 8431e8449. doi:10.1002/2014WR016770.

Foster, E. M., and McLanahan, S. (1996). An illustration of the use of instrumental variables: Do neighborhood conditions affect a young person’s chance of finishing high school? *Psychol. Methods* 1, 249–260. doi:10.1037/1082-989X.1.3.249.

Fotue Totouom, A. L., Sikod, F., and Abba, I. (2012). Household Choice of Purifying Drinking Water in Cameroon. *Environ. Manag. Sustain. Dev.* 1, 101–115. doi:10.5296/emsd.v1i2.1642.

Fowler, C. T. (2003). The ecological implications of ancestral religion and reciprocal exchange in a sacred forest in Karendi (Sumba, Indonesia). *Worldviews Environ. Cult. Relig.* 7, 303–329. doi:10.1163/156853503322709155.

Freeman, M. C., Trinies, V., Boisson, S., Mak, G., and Clasen, T. (2012). Promoting Household Water Treatment through Women’s Self Help Groups in Rural India: Assessing Impact on Drinking Water Quality and Equity. *PLoS One* 7. doi:10.1371/journal.pone.0044068.

French, M. T., and Popovici, I. (2011). That instrument is lousy! In search of agreement when using instrumental variables estimation in substance use research. *Health Econ.* 20, 127–

146. doi:10.1002/hec.1572.

Friedrich, M. N. D., Binkert, M. E., and Mosler, H. J. (2017). Contextual and Psychosocial Determinants of Effective Handwashing Technique: Recommendations for interventions from a case study in Harare, Zimbabwe. *Am. J. Trop. Med. Hyg.* 96, 430–436. doi:10.4269/ajtmh.16-0553.

Gamma, A. E., Slekiene, J., von Medeazza, G., Asplund, F., Cardoso, P., and Mosler, H.-J. (2017). Contextual and psychosocial factors predicting Ebola prevention behaviours using the RANAS approach to behaviour change in Guinea-Bissau. *BMC Public Health* 17, 446. doi:10.1186/s12889-017-4360-2.

Garn, J. V., Brumback, B. A., Drews-Botsch, C. D., Lash, T. L., Kramer, M. R., and Freeman, M. C. (2016). Estimating the effect of school water, sanitation, and hygiene improvements on pupil health outcomes. *Epidemiology* 27, 752–760. doi:10.1097/EDE.0000000000000522.

Gartin, M., Crona, B., Wutich, A., and Westerhoff, P. (2010). Urban ethnohydrology: Cultural knowledge of water quality and water management in a desert city. *Ecol. Soc.* 15. doi:10.5751/ES-03808-150436.

Gecková, A. M., Stewart, R., Van Dijk, J. P., Orosová, O., Groothoff, J. W., and Post, D. (2005). Influence of socio-economic status, parents and peers on smoking behaviour of adolescents. *Eur. Addict. Res.* 11, 204–209. doi:10.1159/000086403.

George, C. M., Jung, D. S., Saif-Ur-Rahman, K. M., Monira, S., Sack, D. A., Rashid, M. U., et al. (2016). Sustained uptake of a hospital-based handwashing with soap and water treatment intervention (cholera-hospital-based intervention for 7 days [CHoBI7]): A randomized controlled trial. *Am. J. Trop. Med. Hyg.* 94, 428–436. doi:10.4269/ajtmh.15-

0502.

Gerwel-Jensen, L., Rautanen, S. L., and White, P. (2015). Strengthening behaviour change communication in western Nepal: how can we do better? *Waterlines* 34, 330–346. doi:10.3362/1756-3488.2015.030.

Ginja, S., Gallagher, S., and Keenan, M. (2019). Water, sanitation and hygiene (WASH) behaviour change research: why an analysis of contingencies of reinforcement is needed. *Int. J. Environ. Health Res.* 00, 1–14. doi:10.1080/09603123.2019.1682127.

Goldman, N., Pebley, A. R., and Beckett, M. (2001). Diffusion of ideas about personal hygiene and contamination in poor countries: Evidence from Guatemala. *Soc. Sci. Med.* 52, 53–69. doi:10.1016/S0277-9536(00)00122-2.

Greif, A. (2006). Institutions and the path to the modern economy: Lessons from medieval trade. *Institutions Path to Mod. Econ. Lessons from Mediev. Trade*, 1–505. doi:10.1017/CBO9780511791307.

Greiner, M., Pfeiffer, D., and Smith, R. D. (2000). Principles and practical application of the receiver-operating characteristic analysis for diagnostic tests. *Prev. Vet. Med.* 45, 23–41. doi:10.1016/S0167-5877(00)00115-X.

Gruber, J. S., Reygadas, F., Arnold, B. F., Ray, I., Nelson, K., and Colford, J. M. (2013). A stepped wedge, cluster-randomized trial of a household UV-disinfection and safe storage drinking water intervention in rural Baja California Sur, Mexico. *Am. J. Trop. Med. Hyg.* 89, 238–245. doi:10.4269/ajtmh.13-0017.

Gundry, S., Wright, J., Conroy, R., and others (2004). A systematic review of the health outcomes related to household water quality in developing countries. *J. Water Health* 2, 1–14. Available at:

http://www.bristol.ac.uk/aquapol%5Cnhttp://www.iwaponline.com/jwh/002/0001/0020001.pdf.

Gupta, S. K., Islam, M. S., Johnston, R., Ram, P. K., and Luby, S. P. (2008). The chulli water purifier: acceptability and effectiveness of an innovative strategy for household water treatment in Bangladesh. *Am. J. Trop. Med. Hyg.* 78, 979–984.

Gwenzi, W., Chaukura, N., Noubactep, C., and Mukome, F. N. D. (2017). Biochar-based water treatment systems as a potential low-cost and sustainable technology for clean water provision. *J. Environ. Manage.* 197, 732–749. doi:10.1016/j.jenvman.2017.03.087.

Hall, D. C., and Le, Q. B. (2017). Use of Bayesian networks in predicting contamination of drinking water with E. coli in rural Vietnam. *Trans. R. Soc. Trop. Med. Hyg.* 111, 270–277. doi:10.1093/trstmh/trx043.

Hamer, T., Dieperink, C., Tri, V. P. D., Otter, H. S., and Hoekstra, P. (2020). The rationality of groundwater governance in the Vietnamese Mekong Delta's coastal zone. *Int. J. Water Resour. Dev.* 36, 127–148. doi:10.1080/07900627.2019.1618247.

Harris, J. (2005). Challenges to the commercial viability of point-of-use (POU) water treatment systems in low-income settings. *Unpubl. master's thesis*.

Harris, J. R., Greene, S. K., Thomas, T. K., Ndivo, R., Okanda, J., Masaba, R., et al. (2009). Effect of a point-of-use water treatment and safe water storage intervention on diarrhea in infants of HIV-infected mothers. *J Infect Dis* 200, 1186–1193. doi:10.1086/605841.

Hartinger, S. M., Lanata, C. F., Hattendorf, J., Verastegui, H., Gil, A. I., Wolf, J., et al. (2016). Improving household air, drinking water and hygiene in rural Peru: a community-randomized-controlled trial of an integrated environmental home-based intervention package to improve child health. *Int. J. Epidemiol.*, dyw242.

doi:10.1093/ije/dyw242.

Hayes, A. F. (2018). *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*. 2nd ed. New York: Guilford Press.

Herrera, V. (2019). Reconciling global aspirations and local realities: Challenges facing the Sustainable Development Goals for water and sanitation. *World Dev.* 118, 106–117. doi:10.1016/j.worlddev.2019.02.009.

Houweling, T. A. J., Kunst, A. E., and Mackenbach, J. P. (2003). Measuring health inequality among children in developing countries: Does the choice of the indicator of economic status matter? *Int. J. Equity Health* 2, 1–12. doi:10.1186/1475-9276-2-1.

Howard, G., Ahmed, M. F., Teunis, P., Mahmud, S. G., Davison, A., and Deere, D. (2007). Identification and management of microbial contaminations in a surface drinking water source. *J. Water Health* 5, 67–79. doi:10.2166/wh.2006.056.

Huber, J., Viscusi, W. K., and Bell, J. (2017). Dynamic relationships between social norms and pro-environmental behavior: evidence from household recycling. *Behav. Public Policy* 4, 1–25. doi:10.1017/bpp.2017.13.

Hunter, P. R. (2009). Household water treatment in developing countries: Comparing different intervention types using meta-regression. *Environ. Sci. Technol.* 43, 8991–8997. doi:10.1021/es9028217.

Hunter, P. R., Zmirou-Navier, D., and Hartemann, P. (2009). Estimating the impact on health of poor reliability of drinking water interventions in developing countries. *Sci Total Env.* 407, 2621–2624. doi:10.1016/j.scitotenv.2009.01.018.

Hutton, G., and Bartram, J. (2008). Global costs of attaining the Millennium Development

Goal for water supply and sanitation. *Bull. World Health Organ.* 86, 13–19.

Hutton, G., Haller, L., and Bartram, J. (2007). Economic and health effects of increasing coverage of low cost household drinking-water supply and sanitation interventions to countries off-track to meet MDG target 10. 68. Available at: http://www.who.int/water_sanitation_health/economic/mdg10_offtrack/en/index.html.

ICF (2018). Demographic and Health Surveys Standard Recode Manual for DHS7. Rockville, Maryland, U.S.A.

Inauen, J., Hossain, M. M., Johnston, R. B., and Mosler, H. J. (2013). Acceptance and Use of Eight Arsenic-Safe Drinking Water Options in Bangladesh. *PLoS One* 8. doi:10.1371/journal.pone.0053640.

Jagals, P. (2006). Does improved access to water supply by rural households enhance the concept of safe water at the point of use? A case study from deep rural South Africa. *Water Sci. Technol.* 54, 9. doi:10.2166/wst.2006.441.

Jain, M., Lim, Y., Arce-Nazario, J. A., and Uriarte, M. (2014). Perceptional and socio-demographic factors associated with household drinking water management strategies in rural puerto rico. *PLoS One* 9. doi:10.1371/journal.pone.0088059.

Jiménez, A., Mtango, F. F., and Cairncross, S. (2014). What role for local government in sanitation promotion? Lessons from Tanzania. *Water Policy* 16, 1104–1120. doi:10.2166/wp.2014.203.

Johnston, R. B., Hanchett, S., and Khan, M. H. (2010). The socio-economics of arsenic removal. *Nat. Geosci.* 3, 2–3. doi:10.1038/ngeo735.

Johnstone, N., and Serret, Y. (2012). Determinants of bottled and purified water consumption:

Results based on an OECD survey. *Water Policy* 14, 668–679. doi:10.2166/wp.2011.048.

Kallman, E., Oyadenel-Craver, V. A., and Smith, J. A. (2010). Ceramic Filters Impregnated with Silver Nanoparticles for Point-of-Use Water Treatment in Rural Guatemala. *J. Environ. Eng.* 137, 407–415. doi:10.1061/(ASCE)EE.1943-7870 .0000330.

Kaufmann, D., Kraay, A., and Mastruzzi, M. (2010). The worldwide governance indicators: Methodology and analytical issues. doi:10.1017/S1876404511200046.

Kesmodel, U. S. (2018). Cross-sectional studies – what are they good for? *Acta Obstet. Gynecol. Scand.* 97, 388–393. doi:10.1111/aogs.13331.

Kley, L. S.- van der, and Reijerkerk, L. (2009). *Water a way of life*. Leiden: CRC Press/Balkema.

Kraemer, S. M., and Mosler, H.-J. (2010). Persuasion factors influencing the decision to use sustainable household water treatment. *Int. J. Environ. Health Res.* 20, 61–79. doi:10.1080/09603120903398301.

Kraemer, S. M., and Mosler, H. J. (2012). Effectiveness and Effects of Promotion Strategies for Behaviour Change: Solar Water Disinfection in Zimbabwe. *Appl. Psychol.* 61, 392–414. doi:10.1111/j.1464-0597.2011.00475.x.

Krejcie, R. V., and Morgan, D. W. (1970). Determining Sample Size for Research Activities. *Educ. Psychol. Meas.* 30, 607–610. doi:https://doi.org/10.1177/001316447003000308.

Landuyt, D., Broekx, S., D'hondt, R., Engelen, G., Aertsens, J., and Goethals, P. L. M. (2013). A review of Bayesian belief networks in ecosystem service modelling. *Environ. Model. Softw.* 46, 1–11. doi:10.1016/j.envsoft.2013.03.011.

Lantagne, D. S., Quick, R. E., and Mintz, E. D. (2011). *Household water treatment and safe storage options in developing countries: a review of current implementation practices*.

Larson, K. L., Hansen, C., Ritz, M., and Carreño, D. (2016). Acceptance and Impact of Point-of-Use Water Filtration Systems in Rural Guatemala. *J. Nurs. Scholarsh.*, 1–7. doi:10.1111/jnu.12260.

Latkin, C., Donnell, D., Liu, T. Y., Davey-Rothwell, M., Celentano, D., and Metzger, D. (2013). The dynamic relationship between social norms and behaviors: The results of an HIV prevention network intervention for injection drug users. *Addiction* 108, 934–943. doi:10.1111/add.12095.

Lawrence, J. J., Yeboah-Antwi, K., Biemba, G., Ram, P. K., Osbert, N., Sabin, L. L., et al. (2016). Beliefs, behaviors, and perceptions of community-led total sanitation and their relation to improved Sanitation in Rural Zambia. *Am. J. Trop. Med. Hyg.* 94, 553–562. doi:10.4269/ajtmh.15-0335.

Legewie, N. (2013). An Introduction to Applied Data Analysis with Qualitative Comparative Analysis. *Forum Qual. Sozialforsch. / Forum Qual. Soc. Res.* Available at: http://www.qualitative-research.net/index.php/fqs/article/view/1961/3594 [Accessed January 24, 2017].

Legros, S., and Cislaghi, B. (2020). Mapping the Social-Norms Literature: An Overview of Reviews. *Perspect. Psychol. Sci.* 15, 62–80. doi:10.1177/1745691619866455.

Levy, K., Nelson, K. L., Hubbard, A., and Eisenberg, J. N. (2008). Following the water: a controlled study of drinking water storage in northern coastal Ecuador. *Env. Heal. Perspect* 116, 1533–1540. doi:10.1289/ehp.11296.

Liang, K., Sobsey , M., and Stauber, C. (2010). Improving Household Drinking Water

Quality: Use of BioSand Filters in Cambodia. *Water Sanit. Progr.* May.

Lilje, J., Kessely, H., and Mosler, H. J. (2015). Factors determining water treatment behavior for the prevention of cholera in Chad. *Am. J. Trop. Med. Hyg.* 93, 57–65. doi:10.4269/ajtmh.14-0613.

Lilje, J., and Mosler, H.-J. (2017). Socio-psychological determinants for safe drinking water consumption behaviors: a multi-country review. *J. Water Sanit. Hyg. Dev.* 7, 13–24. doi:https://doi.org/10.2166/washdev.2017.080.

Lilje, J., and Mosler, H. J. (2018). Effects of a behavior change campaign on household drinking water disinfection in the Lake Chad basin using the RANAS approach. *Sci. Total Environ.* 619–620, 1599–1607. doi:10.1016/j.scitotenv.2017.10.142.

Local Burden of Disease Child Growth Failure Collaborators (2020). Mapping child growth failure across low- and middle-income countries. *Nature* 577, 231–234. doi:10.1038/s41586-019-1878-8.

Loharikar, A., Russo, E., Sheth, A., Menon, M., Kudzala, A., Tauzie, B., et al. (2013). Long-term impact of integration of household water treatment and hygiene promotion with antenatal services on maternal water treatment and hygiene practices in Malawi. *Am. J. Trop. Med. Hyg.* 88, 267–274. doi:10.4269/ajtmh.2012.11-0375.

Luby, S., Agboatwalla, M., Raza, A., Sobel, J., Mintz, E., Baier, K., et al. (2001). A low-cost intervention for cleaner drinking water in Karachi, Pakistan. *Int. J. Infect. Dis.* 5, 144–150. doi:10.1016/S1201-9712(01)90089-X.

Luby, S. P., Agboatwalla, M., Hoekstra, R. M., Rahbar, M. H., Billhimer, W., and Keswick, B. H. (2004). Delayed effectiveness of home-based interventions in reducing childhood diarrhea, Karachi, Pakistan. *Am. J. Trop. Med. Hyg.* 71, 420–427. doi:71/4/420 [pii].

Lucas, P. J., Cabral, C., and Colford, J. M. (2011). Dissemination of drinking water contamination data to consumers: A systematic review of impact on consumer behaviors. *PLoS One* 6. doi:10.1371/journal.pone.0021098.

Lule, J. R., Mermin, J., Ekwaru, J. P., Malamba, S., Downing, R., Ransom, R., et al. (2005). Effect of home-based water chlorination and safe storage on diarrhea among persons with human immunodeficiency virus in Uganda. *Am. J. Trop. Med. Hyg.* 73, 926–933. doi:73/5/926 [pii].

Luzi, S., Tobler, M., Suter, F., and Meierhofer, R. (2016). *SODIS manual Guidance on solar water disinfection*. Du: Eawag, Swiss Federal Institute of Aquatic Science and Technology Available at: www.sodis.ch.

Machado, A. V. M., Santos, J. A. N. dos, Quindeler, N. da S., and Alves, L. M. C. (2019). Critical Factors for the Success of Rural Water Supply Services in Brazil. *Water* 11, 1–14. doi:doi.org/10.3390/w11102180.

Mackinnon, D. P., Fairchild, A. J., and Fritz, M. S. (2007). Mediation Analysis. *Annu. Rev. Psychol.* 58, 593–614. doi:10.1146/annurev.psych.58.110405.085542.Mediation.

Macleod, J., and Davey Smith, G. (2003). Psychosocial factors and public health: A suitable case for treatment? *J. Epidemiol. Community Health* 57, 565–570. doi:10.1136/jech.57.8.565.

Mahmood, Q., Baig, S. A., Nawab, B., Shafqat, M. N., Pervez, A., and Zeb, B. S. (2011). Development of low cost household drinking water treatment system for the earthquake affected communities in Northern Pakistan. *Desalination* 273, 316–320.

Manstead, A. S. R. (2018). The psychology of social class : How socioeconomic status impacts thought , feelings , and behaviour. *Br. J. Soc. Psychol.* 57, 267–291.

doi:10.1111/bjso.12251.

Marcot, B. G., Steventon, J. D., Sutherland, G. D., and McCann, R. K. (2006). Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. *Can. J. For. Res.* 36, 3063–3074. doi:10.1139/x06-135.

Martinez, S. A., Beebe, L. A., Thompson, D. M., Wagener, T. L., Terrell, D. R., and Campbell, J. E. (2018). A structural equation modeling approach to understanding pathways that connect socioeconomic status and smoking. *PLoS One* 13, e0192451. doi:10.1371/journal.pone.0192451.

Mausezahl, D., Christen, A., Pacheco, G. D., Tellez, F. A., Iriarte, M., Zapata, M. E., et al. (2009). Solar drinking water disinfection (SODIS) to reduce childhood diarrhoea in rural Bolivia: A cluster-randomized, controlled trial. *PLoS Med.* 6. doi:10.1371/journal.pmed.1000125.

McGuigan, K. G., Samaiyar, P., Du Preez, M., and Conroy, R. (2011). A high compliance randomised controlled field trial of solar disinfection (SODIS) of drinking water and its impact on childhood diarrhoea in rural Cambodia. *Environ. Sci. Technol.*, 7862–7867. doi:10.1021/es201313x.

McMichael, C., and Robinson, P. (2016). Drivers of sustained hygiene behaviour change: A case study from mid-western Nepal. *Soc. Sci. Med.* 163, 28–36. doi:10.1016/j.socscimed.2016.06.051.

Mekonnen, M. M., and Hoekstra, A. Y. (2016). Four billion people facing severe water scarcity. *Sci. Adv.* 2, e1500323–e1500323. doi:10.1126/sciadv.1500323.

Mellor, J. E., Smith, J. A., Samie, A., and Dillingham, R. A. (2013). Coliform sources and mechanisms for regrowth in household drinking water in Limpopo, South Africa. *J.*

Environ. Eng. (United States) 139, 1152–1161. doi:10.1061/(ASCE)EE.1943-7870.0000722.

Messakh, J. J., Moy, D. L., Mojo, D., and Maliti, Y. (2018). The linkage between household water consumption and rainfall in the semi-arid region of East Nusa Tenggara, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 106. doi:10.1088/1755-1315/106/1/012084.

Misati, A. G., Ogendi, G., Peletz, R., Khush, R., and Kumpel, E. (2017). Can sanitary surveys replace water quality testing? Evidence from Kisii, Kenya. *Int. J. Environ. Res. Public Health* 14, 152–164. doi:10.3390/ijerph14020152.

Mosler, H.-J. (2012a). A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: a conceptual model, a review, and a guideline. *Int. J. Environ. Health Res.* 22, 431–449. doi:10.1080/09603123.2011.650156.

Mosler, H.-J. (2012b). A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: A conceptual model, a review, and a guideline. *Int. J. Environ. Health Res.* 22, 431–449. doi:10.1080/09603123.2011.650156.

Mosler, H., and Contzen, N. (2016). Systematic Behavior Change in Water Sanitation and Hygiene A practical guide using the RANAS approach, Version 1.1. 99.

Mosler, H. J., and Kraemer, S. (2012). Which psychological factors change when habitual water treatment practices alter? *J. Public Heal.* 20, 71–79. doi:10.1007/s10389-011-0435-1.

Mosler, H. J., Kraemer, S. M., and Johnston, R. B. (2013). Achieving long-term use of solar water disinfection in Zimbabwe. *Public Health* 127, 92–98. doi:10.1016/j.puhe.2012.09.001.

Müller, M. F., and Levy, M. C. (2019). Complementary Vantage Points: Integrating Hydrology and Economics for Sociohydrologic Knowledge Generation. *Water Resour. Res.* 55, 2549–2571. doi:10.1029/2019WR024786.

Munamati, M., Nhapi, I., and Misi, S. (2016). Exploring the determinants of sanitation success in Sub-Saharan Africa. *Water Res.* 103, 435–443. doi:10.1016/j.watres.2016.07.030.

Nadkarni, S., and Shenoy, P. P. (2004). A causal mapping approach to constructing Bayesian networks. *Decis. Support Syst.* 38, 259–281. doi:10.1016/S0167-9236(03)00095-2.

Nagata, J. M., Valeggia, C. R., Smith, N. W., Barg, F. K., Guidera, M., and Bream, K. D. W. (2011). Criticisms of chlorination: social determinants of drinking water beliefs and practices among the Tz'utujil Maya. *Rev. Panam. Salud Publica* 29, 9–16. doi:Cited By (since 1996) 1\nExport Date 9 July 2012\nSource Scopus.

Nauges, C., and Berg, C. Van Den (2009). Perception of health risk and averting behavior: An analysis of household water consumption in Southwest Sri Lanka. *Toulouse Sch. Econ. Work. Pap.*, 1–33.

Nauges, C., and Van Den Berg, C. (2009). Perception of Health Risk and Averting Behavior : An Analysis of Household Water Consumption in Southwest Sri Lanka. Toulouse.

Navab-Daneshmand, T., Friedrich, M. N. D., Gächter, M., Montealegre, M. C., Mlambo, L. S., Nhiwatiwa, T., et al. (2018). Escherichia coli contamination across multiple environmental compartments (soil, hands, drinking water, and handwashing water) in urban Harare: Correlations and risk factors. *Am. J. Trop. Med. Hyg.* 98, 803–813. doi:10.4269/ajtmh.17-0521.

Ngai, T. K. K., Murcott, S., Shrestha, R. R., Dangol, B., and Maharjan, M. (2006).

Development and dissemination of Kanchan™ Arsenic Filter in rural Nepal. *Water Sci. Technol. Water Supply* 6, 137–146.

Ngai, T. K. K., Shrestha, R. R., Dangol, B., Maharjan, M., and Murcott, S. E. (2007). Design for sustainable development—household drinking water filter for arsenic and pathogen treatment in Nepal. *J. Environ. Sci. Heal. Part A* 42, 1879–1888. Available at: http://www.tandfonline.com/doi/abs/10.1080/10934520701567148?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%3Dpubmed&.

Nissui Pharmaceutical Co. Ltd CompactDry "Nissui" EC Illustration Manual. *Nissui Pharm. Co. Ltd*. Available at: https://www.nissui-pharm.co.jp/english/pdf/products/global/illustration-manual_/CompactDryNissuiEC-IllustrationManual.pdf [Accessed September 7, 2020].

Ojomo, E., Elliott, M., Goodyear, L., Forson, M., and Bartram, J. (2015). Sustainability and scale-up of household water treatment and safe storage practices: Enablers and barriers to effective implementation. *Int. J. Hyg. Environ. Health* 218, 704–713. doi:10.1016/j.ijheh.2015.03.002.

Okurut, K., Kulabako, R. N., Chenoweth, J., and Charles, K. (2015). Assessing demand for improved sustainable sanitation in low-income informal settlements of urban areas: A critical review. *Int. J. Environ. Health Res.* 25, 81–95. doi:10.1080/09603123.2014.893570.

Onda, K., LoBuglio, J., and Bartram, J. (2012). Global access to safe water: accounting for water quality and the resulting impact on MDG progress. *Int. J. Environ. Res. Public Health* 9, 880–894.

Opryszko, M. C., Majeed, S. W., Hansen, P. M., Myers, J. A., Baba, D., Thompson, R. E., et al. (2010). Water and hygiene interventions to reduce diarrhoea in rural Afghanistan: A randomized controlled study. *J. Water Health* 8, 687–702. doi:10.2166/wh.2010.121.

Orgill, J., Shaheed, A., Brown, J., and Jeuland, M. (2013). Water quality perceptions and willingness to pay for clean water in peri-urban Cambodian communities. *J. Water Health* 11, 489–506. doi:10.2166/wh.2013.212.

Padilla, D. (2012). The Effectiveness Of Water , Hygiene , and Sanitation Interventions In Lowering Diarrheal Morbidity Across The Globe : A Systematic Review and Qualitative Analysis of Relevant Primary Literature. Arizona.

Pande, S., Keyzer, M. A., Arouna, A., and Sonneveld, B. G. J. S. (2008). Addressing diarrhea prevalence in the West African Middle Belt: social and geographic dimensions in a case study for Benin. *Int. J. Health Geogr.* 7, 17. doi:10.1186/1476-072X-7-17.

Pande, S., Roobavannan, M., Kandasamy, J., Sivapalan, M., Hombing, D., Lyu, H., et al. (2020). A Socio-Hydrological Perspective on the Economics of Water Resources Development and Management. *Oxford Res. Encycl. Environ. Sci.* doi:10.1093/acrefore/9780199389414.013.657.

Pande, S., and Sivapalan, M. (2017). Progress in socio-hydrology: a meta-analysis of challenges and opportunities. *Wiley Interdiscip. Rev. Water* 4, e1193. doi:10.1002/wat2.1193.

Parker, A. A., Stephenson, R., Riley, P. L., Ombeki, S., Komolleh, C., Sibley, L., et al. (2006). Sustained high levels of stored drinking water treatment and retention of hand-washing knowledge in rural Kenyan households following a clinic-based intervention. *Epidemiol. Infect.* 134, 1029–36. doi:10.1017/S0950268806005954.

Peal, A. J., Evans, B. E., and van der Voorden, C. (2010). *Hygiene and sanitation software:*

an overview of approaches. Geneva, Switzerland: Water Supply & Sanitation Collaborative Council.

Pearl, J. (1988). *Probabilistic reasoning in intelligent systems: networks of plausible inference*. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc.

Pearl, J. (2001). Direct and Indirect Effects. in *the Seventeenth Conference on Uncertainy in Artificial Intelligence* (San Francisco, CA, USA). Available at: https://ftp.cs.ucla.edu/pub/stat_ser/R273-U.pdf.

Peletz, R., Simuyandi, M., Simunyama, M., Sarenje, K., Kelly, P., and Clasen, T. (2013). Follow-up study to assess the use and performance of household filters in Zambia. *Am. J. Trop. Med. Hyg.* 89, 1190–1194.

Penakalapati, G., Swarthout, J., Delahoy, M. J., McAliley, L., Wodnik, B., Levy, K., et al. (2017). Exposure to Animal Feces and Human Health: A Systematic Review and Proposed Research Priorities. *Environ. Sci. Technol.* 51, 11537–11552. doi:10.1021/acs.est.7b02811.

Peter-Varbanets, M., Johnston, R., Meierhofer, R., Kage, F., Müller, S., and Pronk, W. (2011). Gravity Driven Membrane Disinfection for household drinking water treatment. in *35th WEDC International Conference, Loughborough, UK* (Loughborough: WEDC International Conference), 1–8.

Peters, D. H. (2014). The application of systems thinking in health : why use systems thinking ? *Heal. Res. Policy Syst.* 12, 1–6. doi:https://doi.org/10.1186/1478-4505-12-51.

Phan, T. D., Smart, J. C. R., Capon, S. J., Hadwen, W. L., and Sahin, O. (2016). Applications of Bayesian belief networks in water resource management: A systematic review. *Environ. Model. Softw.* 85, 98–111. doi:10.1016/j.envsoft.2016.08.006.

Picauly, I., and Toy, S. M. (2013). Analisis Determinan Dan Pengaruh Stunting Terhadap Prestasi Belajar Anak Sekolah Di Kupang Dan Sumba Timur, Ntt. *J. Gizi dan Pangan* 8, 55. doi:10.25182/jgp.2013.8.1.55-62.

Pickering, A. J., and Davis, J. (2012). Freshwater Availability and Water Fetching Distance Affect Child Health in Sub-Saharan Africa. *Environ. Sci. Technol.* doi:10.1021/es203177v.

Pickering, A., Swarthout, J., Mureithi, M., Mboya, J., Arnold, B., Wolfe, M., et al. (2019). Can individual and integrated water, sanitation, and handwashing interventions reduce fecal contamination in the household environment? Evidence from the WASH Benefits cluster-randomized trial in rural Kenya. doi:10.1101/731992.

Podgorski, J., and Berg, M. (2020). Global threat of arsenic in groundwater. *Science (80-.).* 368, 845–850. doi:10.1126/science.aba1510.

Prüss-Ustün, A., Bartram, J., Clasen, T., Colford, J. M., Cumming, O., Curtis, V., et al. (2014). Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: A retrospective analysis of data from 145 countries. *Trop. Med. Int. Heal.* 19, 894–905. doi:10.1111/tmi.12329.

QGIS Development Team (2017). QGIS Geographic Information System ver. 2.18.4. Available at: https://download.qgis.org/.

Ragin, C. C. (2008). Redesigning Social Inquiry. *Econ. Soc. Res. Counc. Res. Methods Festival, Saint Catherine's Coll. Oxford Univ.*, 1–30. doi:10.7208/chicago/9780226702797.001.0001.

Rahut, D. B., Behera, B., and Ali, A. (2015). Household access to water and choice of treatment methods: Empirical evidence from Bhutan. *Water Resour. Rural Dev.* 5, 1–16.

doi:10.1016/j.wrr.2014.09.003.

Rainey, R. C., and Harding, A. K. (2005). Acceptability of solar disinfection of drinking water treatment in Kathmandu Valley, Nepal. *Int. J. Environ. Health Res.* 15, 361–372.

Ram, P. K., Kelsey, E., Rasoatiana, Miarintsoa, R. R., Rakotomalala, O., Dunston, C., et al. (2007). Bringing safe water to remote populations: an evaluation of a portable point-of-use intervention in rural Madagascar. *Am. J. Public Health* 97, 398–400.

Ray, I. (2020). Viewpoint – Handwashing and COVID-19: Simple, right there…? *World Dev.* 135. doi:10.1016/j.worlddev.2020.105086.

Reller, M. E., Mendoza, C. E., Lopez, M. B., Alvarez, M., Hoekstra, R. M., Olson, C. A., et al. (2003). A randomized controlled trial of household-based flocculant-disinfectant drinking water treatment for diarrhea prevention in rural Guatemala. *Am. J. Trop. Med. Hyg.* 69, 411–419.

Roberts, M. R., and Whited, T. M. (2012). Endogeneity in Empirical Corporate Finance. *SSRN Electron. J.* doi:10.2139/ssrn.1748604.

Robinson, D. T., Schertenleib, A., Kunwar, B. M., Shrestha, R., Bhatta, M., and Marks, S. J. (2018). Assessing the impact of a risk-based intervention on piped water quality in rural communities: The case of mid-western Nepal. *Int. J. Environ. Res. Public Health* 15, 1616–1639. doi:10.3390/ijerph15081616.

Rodriguez, J. L., Galang, D. D., Balila, E. A., and Mergal, V. C. (2014). Influence of Socio-cultural and Economic Environment on Adolescents ' Sexual Behavior as Mediated by Knowledge , Attitude and Beliefs. 4, 1–5.

Rogers, E. M. (2003). *Diffusion of Innovations*. 5th ed. New York: Free Press.

Roma, E., Bond, T., and Jeffrey, P. (2014). Factors involved in sustained use of point-of-use water disinfection methods: A field study from Flores Island, Indonesia. *J. Water Health* 12, 573–583. doi:10.2166/wh.2014.109.

Roobavannan, M., Van Emmerik, T. H. M., Elshafei, Y., Kandasamy, J., Sanderson, M. R., Vigneswaran, S., et al. (2018). Norms and values in sociohydrological models. *Hydrol. Earth Syst. Sci.* 22, 1337–1349. doi:10.5194/hess-22-1337-2018.

Routray, P., Schmidt, W. P., Boisson, S., Clasen, T., and Jenkins, M. W. (2015). Socio-cultural and behavioural factors constraining latrine adoption in rural coastal Odisha: An exploratory qualitative study. *BMC Public Health* 15. doi:10.1186/s12889-015-2206-3.

Rucker, D. D., Preacher, K. J., Tormala, Z. L., and Petty, R. E. (2011). Mediation Analysis in Social Psychology: Current Practices and New Recommendations. *Soc. Personal. Psychol. Compass* 5, 359–371. doi:10.1111/j.1751-9004.2011.00355.x.

Schlegelmilch, M. P., Lakhani, A., Saunders, L. D., and Jhangri, G. S. (2016). Evaluation of water, sanitation and hygiene program outcomes shows knowledge behavior gaps in coast province, Kenya. *Pan Afr. Med. J.* 23, 1–11. doi:10.11604/pamj.2016.23.145.7546.

Schmidt, W., and Cairncross, S. (2009a). Household Water Treatment in Poor Populations : Is There Enough Evidence for Scaling up Now ? *Environ. Sci. Technol.* 43, 9–10. doi:10.1021/es802232w.

Schmidt, W., and Cairncross, S. (2009b). Household Water Treatment in Poor Populations : Is There Enough Evidence for Scaling up Now ? Household Water Treatment in Poor Populations : Is There Enough Evidence for Scaling up Now ? *Environ. Sci. Technol.* 43, 986–992. doi:10.1021/es802232w.

Schneider, A., Hommel, G., and Blettner, M. (2010). Linear regression analysis — part 14 of a series on evaluation of scientific publications. *Dtsch. Arztebl.* 107, 776–782. doi:10.3238/arztebl.2010.0776.

Schoon, I. (2002). [The long-term influence of socio-economic disadvantage on the psychosocial adjustment of women]. *Z. Psychosom. Med. Psychother.* 48, 381–95. Available at: http://www.ncbi.nlm.nih.gov/pubmed/12407496.

Sehring, J., Korhonen-Kurki, K., and Brockhaus, M. (2013). Qualitative Comparative Analysis (QCA) An application to compare national REDD + policy processes. *Cent. Int. For. Res.*, 34. doi:10.17528/cifor/004278.

Seimetz, E., Boyayo, A. M., and Mosler, H. J. (2016). The influence of contextual and psychosocial factors on handwashing. *Am. J. Trop. Med. Hyg.* 94, 1407–1417. doi:10.4269/ajtmh.15-0657.

Shiras, T., Cumming, O., Brown, J., Muneme, B., Nala, R., and Dreibelbis, R. (2018). Shared latrines in Maputo, Mozambique: Exploring emotional well-being and psychosocial stress. *BMC Int. Health Hum. Rights* 18. doi:10.1186/s12914-018-0169-z.

Sisson, A. J., Wampler, P. J., Rediske, R. R., McNair, J. N., and Frobish, D. J. (2013). Long-term field performance of biosand filters in the Artibonite Valley, Haiti. *Am. J. Trop. Med. Hyg.* 88, 862–867. doi:10.4269/ajtmh.12-0345.

Snoad, C., Nagel, C., Bhattacharya, A., and Thomas, E. (2017). The effectiveness of sanitary inspections as a risk assessment tool for thermotolerant coliform bacteria contamination of rural drinking water: A review of data from West Bengal, India. *Am. J. Trop. Med. Hyg.* 96, 976–983. doi:10.4269/ajtmh.16-0322.

Sobsey, M. D., Stauber, C. E., Casanova, L. M., Brown, J. M., and Elliott, M. A. (2008). Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world. *Environ. Sci. Technol.* 42, 4261–4267.

Sonego, I. L., Huber, A. C., and Mosler, H. (2013). Does the Implementation of Hardware Need Software? A Longitudinal Study on Fluoride-Removal Filter Use in Ethiopia. *Environ. Sci. Technol.* 47.

Sonego, I. L., and Mosler, H. J. (2016). Spot-checks to measure general hygiene practice. *Int. J. Environ. Health Res.* 26, 554–571. doi:10.1080/09603123.2016.1217314.

Stiffman, A. R., Hadley-Ives, E., Elze, D., Johnson, S., and Doré, P. (1999). Impact of environment on adolescent mental health and behavior: structural equation modeling. *Am. J. Orthopsychiatry* 69, 73–86. doi:10.1017/CBO9781107415324.004.

Stocker, A., and Mosler, H. J. (2015). Contextual and sociopsychological factors in predicting habitual cleaning of water storage containers in rural Benin. *Water Resour. Res.* 51, 2000–2008. doi:10.1002/2014WR016005.

Stockman, L. J., Fischer, T. K., Deming, M., Ngwira, B., Bowie, C., Cunliffe, N., et al. (2007). Point-of-use water treatment and use among mothers in Malawi. *Emerg. Infect. Dis.* 13, 1077–1080. doi:10.3201/eid1307.060767.

Summerill, C., Pollard, S. J. T., and Smith, J. A. (2010). The role of organizational culture and leadership in water safety plan implementation for improved risk management. *Sci. Total Environ.* 408, 4319–4327. doi:10.1016/j.scitotenv.2010.06.043.

Sungkar, S., Pohan, A. P. N., Ramadani, A., Albar, N., Azizah, F., Nugraha, A. R. A., et al. (2015). Heavy burden of intestinal parasite infections in Kalena Rongo village, a rural area in South West Sumba, eastern part of Indonesia: A cross sectional study. *BMC Public Health* 15, 1–6. doi:10.1186/s12889-015-2619-z.

Sutton, J., and Austin, Z. (2015). Qualitative research: Data collection, analysis, and management. *Can. J. Hosp. Pharm.* 68, 226–231. doi:10.4212/cjhp.v68i3.1456.

Tabellini, G. (2010). Culture and institutions: Economic development in the regions of Europe. *J. Eur. Econ. Assoc.* 8, 677–716. doi:10.1162/jeea_a_00001.

Tamas, A. (2009). Successful promotion of solar water disinfection (SODIS).

Tang, C., Yi, Y., Yang, Z., and Sun, J. (2016). Risk analysis of emergent water pollution accidents based on a Bayesian Network. *J. Environ. Manage.* 165, 199–205. doi:10.1016/j.jenvman.2015.09.024.

Tavakol, M., and Dennick, R. (2011). Making sense of Cronbach's alpha. *Int. J. Med. Educ.* 2, 53–55. doi:10.5116/ijme.4dfb.8dfd.

The World Bank (2014). Average precipitation in depth (mm per year) - Indonesia. *World Bank.* Available at: (Messakh, Moy, Mojo, & Maliti, 2018). [Accessed November 4, 2019].

Tidwell, J. B., Chipungu, J., Bosomprah, S., Aunger, R., Curtis, V., and Chilengi, R. (2019). Effect of a behaviour change intervention on the quality of peri-urban sanitation in Lusaka, Zambia: a randomised controlled trial. *Lancet Planet. Heal.* 3, e187–e196. doi:10.1016/S2542-5196(19)30036-1.

Tilley, E., Strande, L., Lüthi, C., Mosler, H.-J., Udert, K. M., Gebauer, H., et al. (2014). Looking beyond Technology: An Integrated Approach to Water, Sanitation and Hygiene in Low Income Countries. *Environ. Sci. Technol.* 48, 9965–9970. doi:10.1021/es501645d.

Tim Riskesdas (2019). Laporan nasional RISKESDAS 2018. Jakarta, Indonesia.

Trevett, A. F., Carter, R. C., and Tyrrel, S. F. (2004). Water quality deterioration: A study of household drinking water quality in rural Honduras. *Int. J. Environ. Health Res.* 14, 273–283. doi:10.1080/09603120410001725612.

Troy, T. J., Konar, M., Srinivasan, V., and Thompson, S. (2015). Moving sociohydrology forward: A synthesis across studies. *Hydrol. Earth Syst. Sci.* 19, 3667–3679. doi:10.5194/hess-19-3667-2015.

UN General Assembly (2015). Transforming our world: The 2030 Agenda for Sustainable Development (Vol. A/RES/70/1). doi:10.1007/s13398-014-0173-7.2.

UNESCO-International Hydrological Programme (2015). Water in the post-2015 development agenda and sustainable development goals Discussion paper. *Unesco*, 11.

UNICEF, and WHO (2019). *Progress on household drinking water, sanitation and hygiene 2000-2017. Special focus on inequalities*.

Usman, M. A., Gerber, N., and von Braun, J. (2019). The Impact of Drinking Water Quality and Sanitation on Child Health: Evidence from Rural Ethiopia. Bonn doi:10.1080/00220388.2018.1493193.

Valcourt, N., Javernick-will, A., Walters, J., and Linden, K. (2020). System approaches to water, sanitation, and hygiene: A systematic literature review. *Int. J. Environ. Res. Public Health* 17. doi:10.3390/ijerph17030702.

Vásquez, W. F., Mozumder, P., and Franceschi, D. (2015). Water Quality, Household Perceptions and Averting Behavior: Evidence from Nicaragua. *Water Econ. Policy* 1. doi:10.1142/S2382624X15500113.

Vel, J. A. C., and Makambombu, S. (2010). Access to Agrarian Justice in Sumba, Eastern

Indonesia. *Law, Soc. Justice Glob. Dev.* 2010, 1–22. Available at: https://warwick.ac.uk/fac/soc/law/elj/lgd/2010_1/vel_makambombu.

Vel, J., and Makambombu, S. (2019). Strategic Framing of Adat in Land-Acquisition Politics in East Sumba. *Asia Pacific J. Anthropol.* 20, 435–452. doi:10.1080/14442213.2019.1670239.

Verbeek, M. (2017). Using linear regression to establish empirical relationships. *IZA World Labor* 336. doi:10.15185/izawol.336.

Vyas, S., and Kumaranayake, L. (2006). Constructing socio-economic status indices: How to use principal components analysis. *Health Policy Plan.* 21, 459–468. doi:10.1093/heapol/czl029.

Waddington, H., and Snilstveit, B. (2009). Effectiveness and sustainability of water, sanitation, and hygiene interventions in combating diarrhoea. *J. Dev. Eff.* 1, 295–335. doi:10.1080/19439340903141175.

Wagner, E. G., Lanoix, J. N., and World Health Organization (1958). *Excreta disposal for rural areas and small communities.* Geneva, Switzerland: World Health Organization doi:10.5694/j.1326-5377.1959.tb88741.x.

Wasonga, J., Okowa, M., and Kioli, F. (2016). Sociocultural Determinants to Adoption of Safe Water, Sanitation, and Hygiene Practices in Nyakach, Kisumu County, Kenya: A Descriptive Qualitative Study. *J. Anthropol.* 2016, 1–5. doi:10.1155/2016/7434328.

Waterworth, P., Pescud, M., Braham, R., Dimmock, J., and Rosenberg, M. (2015). Factors influencing the health behaviour of indigenous Australians: Perspectives from support people. *PLoS One* 10, 1–17. doi:10.1371/journal.pone.0142323.

Wayland, J. (2018). Constraints on foreign aid effectiveness in the water, sanitation, and hygiene (WaSH) sector. *J. Water Sanit. Hyg. Dev.* 8, 44–52. doi:10.2166/washdev.2017.095.

Wells, N. M., and Harris, J. D. (2007). Housing quality, psychological distress, and the mediating role of social withdrawal: A longitudinal study of low-income women. *J. Environ. Psychol.* 27, 69–78. doi:10.1016/j.jenvp.2006.11.002.

Wheeler, J., and Agha, S. (2013). Use of Certeza point-of-use water treatment product in Mozambique. *J. Water, Sanit. Hyg. Dev.* 3, 341–348. doi:10.2166/washdev.2013.198.

White, K. M., Jimmieson, N. L., Obst, P. L., Graves, N., Barnett, A., Cockshaw, W., et al. (2015). Using a theory of planned behaviour framework to explore hand hygiene beliefs at the “5 critical moments” among Australian hospital-based nurses 59. *BMC Health Serv. Res.* 15. doi:10.1186/s12913-015-0718-2.

WHO; UNICEF (2017a). Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG baselines. Geneva, Switzerland.

WHO; UNICEF (2017b). Safely managed drinking water - thematic report on drinking water 2017. Geneva, Switzerland Available at: https://data.unicef.org/resources/safely-managed-drinking-water/.

WHO (1997). *Surveillance and control of community supplies, Guidelines for Drinking-water Quality*. 2nd ed. Geneva, Switzerland: WHO doi:10.1016/S1462-0758(00)00006-6.

WHO (2007). *Combating waterborne disease at the household level / International Network to Promote Household Water Treatment and Safe Storage, World Health Organization*. Geneva, Switzerland: World Health Organization (WHO) Available at: http://www.who.int/iris/handle/10665/43621.

WHO (2009). *Scaling up household water treatment among low-income populations / Prepared by Thomas F. Clasen*. Geneva, Switzerland: World Health Organization Available at: https://apps.who.int/iris/handle/10665/70049.

WHO (2012). *Water safety planning for small community water supplies: step-by-step risk management guidance for drinking-water supplies in small communities*. Geneva, Switzerland: WHO Available at: http://www.who.int/iris/handle/10665/75145.

WHO (2017). *Guidelines for Drinking-Water Quality: Fourth Edition Incorporating The First Addendum*. 4th ed. Geneva: World Health Organization Available at: http://apps.who.int/iris/bitstream/10665/254637/1/9789241549950-eng.pdf.

WHO Western Pacific Region (2013). *Household Household Water Water Treatment Treatment and and Safe Safe Storage Manual for Participant*. Manila: World Health Organization.

Williams, H. A., Gaines, J., Patrick, M., Berendes, D., Fitter, D., and Handzel, T. (2015). Perceptions of health communication, water treatment and sanitation in Artibonite Department, Haiti, March-April 2012. *PLoS One* 10, 1–17. doi:10.1371/journal.pone.0142778.

Wilson Van Voorhis, C. R., and Morgan, B. L. (2007). Understanding Power and Rules of Thumb for Determining Sample Sizes. *Tutor. Quant. Methods Psychol.* 3, 43–50. doi:10.20982/tqmp.03.2.p043.

Winter, S., Dreibelbis, R., and Barchi, F. (2018). Context matters : a multicountry analysis of individual- and neighbourhood-level factors associated with women ' s sanitation use in sub-Saharan Africa. *Trop. Med. Int. Heal.* 23, 173–192. doi:10.1111/tmi.13016.

Wolf, J., Hunter, P. R., Freeman, M. C., Cumming, O., Clasen, T., Bartram, J., et al. (2018).

Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. *Trop. Med. Int. Heal.* 23, 508–525. doi:10.1111/tmi.13051.

Wood, S., Foster, J., and Kols, A. (2012). Understanding why women adopt and sustain home water treatment: Insights from the Malawi antenatal care program. *Soc. Sci. Med.* 75, 634–642. doi:10.1016/j.socscimed.2011.09.018.

World Health Organization (2011). *Guidelines for drinking-water quality*. 4th ed. Geneva, Switzerland: World Health Organization doi:10.1016/S1462-0758(00)00006-6.

Wright, J., Gundry, S., and Conroy, R. (2004). Household drinking water in developing countries: A systematic review of microbiological contamination between source and point-of-use. *Trop. Med. Int. Heal.* 9, 106–117. doi:10.1046/j.1365-3156.2003.01160.x.

WWAP (United Nations World Water Assessment Programme)/UN-Water (2018). The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. Paris Available at: www.unesco.org/open-access/.

WWAP (United Nations World Water Assessment Programme) (2015). *The United Nations World Water Development Report 2015: Water for a Sustainable World*. Paris: UNESCO.

WWF (2006). *Living waters : conserving the source of life : thirsty crops : our food and clothes: eating up nature and wearing out he environment?*. Zeist, The Netherlands: WWF International Available at: https://www.ircwash.org/sites/default/files/WWF-1986-Living.pdf.

Zabinski, J. W., Pieper, K. J., and Gibson, J. M. (2018). A Bayesian Belief Network Model Assessing the Risk to Wastewater Workers of Contracting Ebola Virus Disease During an Outbreak. *Risk Anal.* 38, 376–391. doi:10.1111/risa.12827.

Zhang, Z., and Zhang, J. (2017). Perceived residential environment of neighborhood and subjective well-being among the elderly in China: A mediating role of sense of community. *J. Environ. Psychol.* 51, 82–94. doi:10.1016/j.jenvp.2017.03.004.

Zimmer, D., Van Hofwegen, P., and Toubkiss, J. (2006). Costing MDG Target 10 on Water Supply and Sanitation: Comparative Analysis, Obstacles and Recommendations. *World Water Concil*, 1–71.

Acknowledgements

Names that play roles in this PhD study

“A friend loves at all time, and a brother is born for adversity”

- Proverbs 17:17 -

I have only one official name in all my legal documents: Daniel. This practice is quite common in my country, Indonesia. There are many conversations that I had with new people are often started by discussing my name. But the problem arose when I need to submit my first scientific journal: I had to write the first and second name. I came up with “D. Daniel”, i.e. use “D.” in front of my name, which was inspired by the Japanese comic “One Piece”. I interpret it as a person who seeks and found freedom: the freedom to dream, freedom to achieve those dreams, and freedom to express themselves. Thanks to people who help me carrying the name of “D” (LOL! ☺) and enjoying this freedom during my PhD.

First of all, I would like to thank my daily supervisor, Dr. Saket Pande, for all his guidance during my PhD research. In the beginning, it was quite tough for me adjusting to your style or approach of “mentorship”. I think that “learning by doing” and “do it as soon as possible” may describe your approach. But, after one and a half years, I could see the benefits of it. Almost all plans were done as planned. I am also grateful because you always support everything that can benefit me and never think too much for giving your approval. From you, I learn how to draw a strong research implication, to bring the issue to a higher level, and see it from a bigger perspective. You open my mind-set to think “globally” and not on a small scale.

I am also thankful for my promotor, Prof. Luuk Rietveld. I would say that you are kind of opposite of Saket. You give depth tough on everything and very careful when deciding something. You are very precise in writing, i.e. picky about words or terms used in the draft. Another thing that I learn from you is that never show any weakness in my manuscript. I am really grateful to have both sides of the mentorship style in my PhD research.

Sometimes I think that I am an alien in the Sanitary engineering section where most of the people do “engineering stuff”, while I am more a “socio-civil engineering”. It is quite difficult to find a person to talk with about my topic in this group. But luckily, there are still some people who can understand “my language”, i.e., socio-civil engineering stuff: Diana and Anne-Marie, because they do the same thing; and Kajol, because he has a lot of field experience in rural areas. I thank them for all the positive feedback on my field study.

I also want to thank in particular to some people who help me in such a way during my PhD life and have some effort to create me as a scientist and: (1) Dr. Sara J. Marks, you are one of the first scientific mentors that I have and inspire me a lot to work in the WASH issue. By the way, I never thought that we are still collaborating until now; (2) Arnt Diener, a truly amazing mentor that teach me how do collect data in a field, using a sketch in presentation, and inspire me making a video of the fieldwork; (3) Dr. Doris van Halem, thank you for the lab-in-a-suitcase so I could do my water quality testing in my fieldwork. I am happy that I could contribute to the TU Delft Global Drinking Water community; (4) Mariska, the best department secretary in the world who makes all bureaucracy things easier in this very complicated TU Delft environment: You solve one-fifth of my PhD problems (!).

I want to thank also colleagues for the great atmosphere in our section here: Hong Xiao, Shuo, Ka Leung, Mingliang, Bin Lin, Lihua, Max, Liangfu, Javier, Bruno, Anjana, Saqr, Victor, Carina, Antonella, Emiel, Adrian, Marieke, Irene, Pamela, Lenno, Risalat, and Sara. Wish you all the best in your future career.

Special thanks to these people: Miktha, Dennis, Widya, Ariel, Fahreza, Wicak, Dias, Arifin, and all Indonesian PhDs in Delft; also to my spiritual family in Full Gospel Mission Church (FMC) Delft: Pap Victor, Mom Vivie, Bung Andri, mas Rudi, mas Randi, Ko Timo, Bang Patar, and other CARE and church members; and to mbak Nur and mbak Ningsih for treating me as a family member. I could not mention all your name but please accept my deepest thanks for all your support and hospitality during my study.

I want to express my gratitude to my PhD sponsor: Indonesia Endowment Fund for Education (LPDP). I will “payback” everything by contributing to our country's development. You would be proud to have an awardee like me ☺.

I must mention my family in Indonesia: Bapa, mama, and Dian; and all the big family members of Sihombing and Pakpahan. Thank you for helping me through all the difficult moments and support me with your prayer. Also, I want to thank Patricia Amanda Tjanda Candrasa (Cia) for being a true friend and partner for the last seven years. You are my special supporter!

Last but not least, super thanks to the Lord for everything that you have given me. I could not have done it without You. All are from, by, and for You. To God be the glory.

Curriculum Vitae

About author

“Life is like riding a bicycle. To keep your balance you must keep moving”

- Albert Einstein –

Name : Daniel (D.Daniel)

Date of Birth : Bandung, May 1st 1990

Nationality : Indonesia

E-mail : danielhombing@gmail.com

Education

1. 2008-2012 Institut Teknologi Bandung, Indonesia (B.Sc. Chemistry)
2. 2013-2015 IHE Delft, Netherlands (M.Sc. Environmental science and technology)
3. 2016-2021 Delft University of Technology, Netherlands (on-going PhD in Water Management)

Publications

Daniel, D., Marks, S. J., Pande, S., & Rietveld, L. (2018). *Socio-environmental drivers of sustainable adoption of household water treatment in developing countries*. Npj Clean Water.

Daniel, D., Diener, A., Pande, S., Jansen, S., Marks, SJ., Meierhofer, R., Bhatta, M., & Rietveld, L. (2019). *Understanding the effect of socio-economic characteristics and psycho-social factors on household water treatment practices in rural Nepal using Bayesian Belief Networks*. International Journal of Hygiene and Environmental Health.

Daniel, D., Diener, A., Bhatta, M., Van de Vossenberg, J., Marks, SJ. (2019). *Assessing drinking water quality at point of collection and point of use in remote rural Nepal*. International Journal of Environmental Research and Public Health.

Daniel, D., Pande, S., & Rietveld, L. (2020). *The effect of socio-economic characteristics on the use of household water treatment via psychosocial factors: a mediation analysis*. Hydrological Sciences Journal.

Daniel, D., Pande, S., Iswarani, W. P., & Rietveld, L. (2020). *A Bayesian Belief Network Model to Link Sanitary Inspection Data to Drinking Water Quality in a Medium Resource Setting in Rural Indonesia*. Scientific Reports.

Daniel, D., Sirait, M., & Pande, S. (2020). *A Hierarchical Bayesian Belief Network Model of Household Water Treatment Behaviour in a Suburban Area: A Case Study of Palu - Indonesia*. PLoS ONE.

Daniel, D., Gaicugi, J., King, R., Marks, S. J., & Ferrero, G. (2020). *Combining sanitary inspection and water quality data in Western Uganda: Lessons learned from a field trial of original and revised sanitary inspection forms*. Sustainability

Daniel, D., Djohan, D., & Nastiti, A. *Interaction of Factors Influencing the Sustainability of Water, Sanitation, and Hygiene (WASH) Services in Rural Indonesia*. Water.

Daniel, D., Pande, S., & Rietveld, L. *Socio-economic and Psychological Determinants for Household Water Treatment Practices in Indigenous - Rural Indonesia*. Under review.

Daniel, D., Djohan, D., Machairas, I., Pande, S., Arifin, A., Djono, T. P. Al, & Rietveld, L. *Identifying factors that contribute to the sustainability of water supply, sanitation, and hygiene services in indigenous - rural Indonesia*. Under review.

Daniel, D., Pande, S., & Rietveld, L. *Endogeneity in water-related behavioural analysis: a meta-analysis of household water treatment adoption in developing countries*. Under review.

Daniel, D., Prawira, J., Al Djono, T.P., Subandriyo, S., Rezagama, A., & Purwanto, A. *A System Dynamics Model of the Community-based Rural Drinking Water Supply Program (PAMSIMAS) in Indonesia*. Under review.

Klessens, T. M. A., Daniel, D., Jiang, Y., van Breukelen, B. M., Scholten, L., & Pande, S. *Public Willingness to Conserve Groundwater in Vietnamese Mekong Delta: Combining Water Resources, Socio-environmental, and Psychological Factors*. Under review.

Conferences

Time	Institution / organizer	Event name
2016	RWSN	7th Rural water supply network
2017	European Geosciences Union (EGU)	European Geosciences Union General Assembly 2017
2018	EGU	European Geosciences Union General Assembly 2017
2018	International Water Association (IWA)	World water congress & exhibition
2019	EGU	European Geosciences Union General Assembly 2019
2019	IWA	Water and Development Congress & Exhibition
2020	University of Colorado Boulder	Colorado WASH symposium
2020	American Geophysical Union (AGU)	AGU Fall meeting 2020
2020	LIPI, ALMI, NOW, Nuffic, the Dutch embassy	Week of Indonesia-Netherlands Education and Research