MDP Project: Water, Sanitation and Hygiene in East Sumba

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Abstract

This research aims to identify the key stakeholders, explain factors that influence water, sanitation, and hygiene (WASH) behaviours, determine the chance of bacterial contamination in water, and hygiene and sanitary practises in East Sumba. The interview results show that DinKes (health agency), PAMSIMAS (rural water company), and the village board are the key players that connect the upper administrative units to the local communities. The data obtained also show that the root causes that influence the WASH condition are low education level, upbringing/norms, weak economy, and geography. The water quality testing results show that in terms of *E. coli* 14% and 12% of the respondents had a high chance of contamination in their water source and household respectively. These numbers are 25% and 29% in terms of total coliforms. Approximately 59% respondents still use poor sanitation facilities, which includes open defecation (33%) and unimproved latrines (26%). The other 14% respondents are listed under limited sanitation service, and 27% of the respondents had their own toilet, however, it is difficult to conclude if these people fall under the basic or safely managed category of sanitation services.

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1 Introduction

Universal access to drinking water is a global challenge. In 2015, approximately 1.2 billion people still have difficulties in accessing safely managed drinking water services and 844 million still lacks basic drinking water service [1]. Safe drinking water service is defined as drinking water services which are located at home, available when needed, and free from contamination [2]. Contamination of water sources in low-income countries is more common than in countries with higher income, especially in the rural areas [3]. This condition results in high rates of waterborne diseases, such as diarrhea and cholera. Waterborne diseases caused the deaths of 1.3 million people in 2015, most of them are children under the age of 5 who are living in developing countries [3].

Nusa Tenggara Timur (NTT) or East Nusa Tenggara is one of the poorest provinces in Indonesia with the most difficult access to water [4]. The survey results in 2018 revealed that only about 15% of the population in NTT had access to water from the piping system [5]. Nearly 40% of the population draws water from unprotected sources including wells and from surface water including springs and rivers, where the quality is uncertain [5]. In 2015, only one in five people used basic sanitation facilities at home, while 18% practiced open defecation, which certainly adds to health risks [4]. This conclusively has a negative impact on health, especially in children. Sumba island, specifically in East Sumba Regency, is gaining special attention in this study because this region is gaining popularity due to tourism, but the percentage of improved drinking water services in East Sumba is only roughly 50% and the improved sanitation is only 35% in 2018 [5].

The condition in East Sumba leads to the curiosity of how the locals manage their water, including their sanitary practises. A previous study suggested that most households in developing countries tend not to treat their drinking water consistently, which will subsequently endanger their health [6]. Both social and economic factors are affecting this habit. Further, indigenous people of East Sumba are divided into different social classes (caste) and part of them profess to domestic religion of Marapu which affects the way its followers are handling water [7]. There is uncertainty whether or not people in East Sumba realise the health risk they are facing due to their water consumption pattern. Even if the people understand the risk, other problems will arise, which are whether or not they want to change their drinking water and sanitary practises habits. Their ability to get safer water is still an open question.

Our client, Ir. Daniel Sihombing, a PhD student from TU Delft, aims to investigate the factors responsible for the Water, Sanitation, and Hygiene (WASH) conditions and practises in the area. The project aims to explain the players influencing WASH program, underlying causes that inhibits WASH practises, and quantifying the chances of water contamination. In order to do this, stakeholder, causal, and Bayesian Belief Network (BBN) analysis are used.

This report will first provide background information about the study area in chapter 2. Further, research questions are described in chapter 3. A literature review regarding stakeholder analysis, WASH conditions, sanitary inspection risk assessment, and BBN are presented in chapter 4. Following this, chapter 5 explains the methodologies used for data collection, stakeholder analysis, sanitary inspection, water quality and risk analysis. Chapter 6 elaborates the information from the interviews and the results of the stakeholder and water quality analysis. Finally, in chapter 7 conclusions, limitations, and recommendations for future research are presented.

2 Background

This chapter defines the scope of the project. First, the project background is described and the problem areas are identified. After a complete overview of the problem being obtained, sub-problems are identified. Each of these sub-problems is addressed by a different problem solving approach that is discussed in section 3.

2.1 Geographical Location and Climate Condition

Indonesia is a country with population of around 270 million people and it is divided in 4 administrative units. The national government (level 0) is the upper level and below it, the country is divided into 34 provinces (level 1). The study area belongs to East Nusa Tenggara province which is on the southeastern part of Indonesia. Provinces consist of districts or regencies (in Indonesia "kabupaten") (level 2) so that the allocation and administration of resources is smoother, and East Nusa Tenggara has 22 of those.

Sumba island is an island located in the southeastern part of Indonesian archipelago. Sumba island settles between Sumbawa and Flores island, approximately 700 km from the famous Bali island. Sumba is one of the largest islands in Nusa Tenggara Timur province. The island is divided into three regencies, namely West Sumba, Central Sumba, and East Sumba. East Sumba Regency is where the study area is located. Districts are divided as well into "sub-districts" (in Indonesian "kecamatan"). The last layer of administrative units is the village.

Table 1: The villages of the study area and the sub-districts to which they belong (*Palindi Tana Bara is a sub village that will separate from the main village 'Kuta' in the future - in this report both names are used interchangeably)

Kecamatan (Sub-district)	**Desa (Village)**
Kanatang	Mondu
	Hamba Praing
	Palindi Tana Bara (Kuta)*
Nggaha Ori Angu	Mangamenggit
	Pulu Panjang
Kuta Waingapu	Pambontanjara
	Mbatakapidou
Pandawai	Kawangu
	Palakahembi

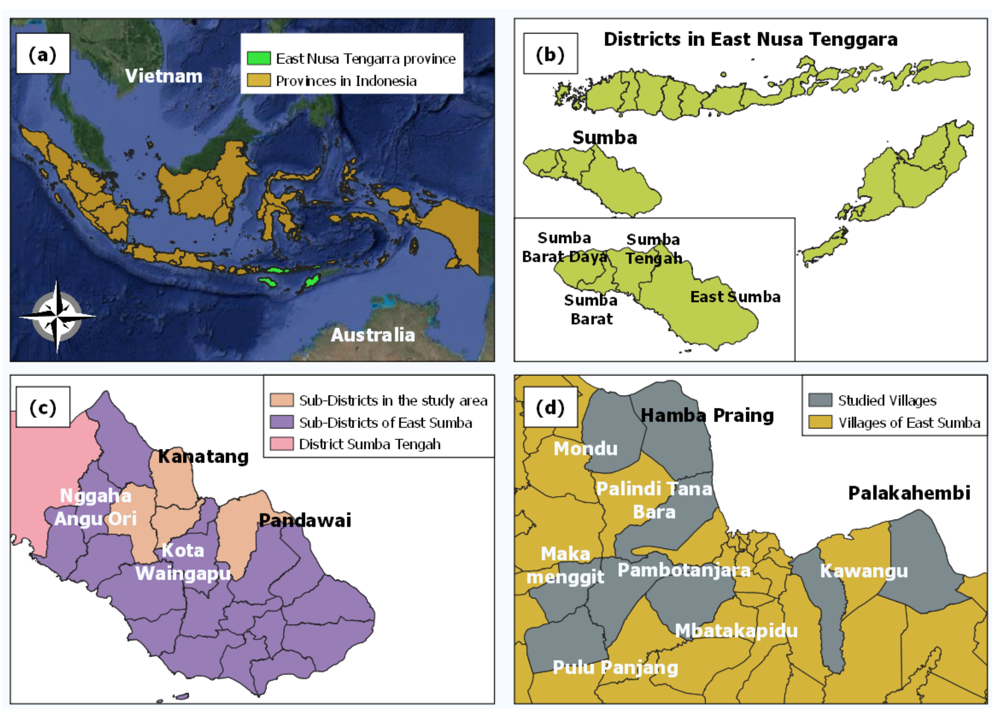


Figure 1: Administrative units to which the study area belongs

In 2015, the lowest humidity in East Sumba was 67% in October with the highest being 83% in March [8]. East Sumba has rather warm climate all year, with an average temperature of 27 degree Celcius. The lowest and highest temperatures recorded in 2015 were 17.4 and 35.8 degrees Celcius, respectively. There are only two seasons in East Sumba: a dry and a rainy season. The dry season takes place from May until November whereas the rainy season takes place from December until April. On average, East Sumba has 83 days of raining in a year with a total rainfall of 765 mm/year [8].

2.2 Water, Sanitation, and Health Conditions

Different kinds of water sources are used in East Sumba Regency. Until 2018, the majority of residents relied on unprotected water sources, including wells (11%), springs (23%), and other surface waters (2%)[5]. Approximately only 18% residents are connected to piped water system. The government also attempted to improve the access to sanitation in East Sumba, and they managed to increase the access to sanitation from only 14% in 2014 into 35% in 2018 [5]. The number of diarrhea and cholera patients can be seen in Table 2. The number of cases is a good indicator of the WASH practice in the area. Diarrhea and cholera are more prominent outside of the city (sub-district of Kanatang, Pandawai, and Nggaha Ori Angu). Other than diarrhea and cholera, the most occurring diseases in East Sumba Regency include acute respiratory infections and malaria [9].

2.3 Economic Situation

Table 2 shows the break down of GDP and current public health situations for the four sub-districts visited. Most of the GDP are centralized in the district capital of Waingapu. One million IDR is equivalent to around 65 EUR, and Waingapu GDP is around 41 million EUR. The five main contributors to the GDP are agricultural products, construction, education, trade, and government spending.

Table 2: Health and economic statistics of Kota Waingapu, Kanatang, Pandawai, and Nggaha Ori Angu sub-district [10, 11, 12, 13].

Kecamatan (sub-district)	Kota Waingapu	Kanatang	Pandawai	Nggaha Ori Angu
Diarrhea and cholera patient year 2017 (persons (% of total patients))	63 (2.72%)	281 (4.26%)	438 (6.77%)	364 (2.89%)
Total population (2017)	39,239	10,311	16,256	9,755
Diarrhea and cholera patient % of Total population	0.16%	2.73%	2.69%	3.73%
Regional GDP (million IDR, year 2014 except Kanatang (2013))	629,910.0	56,037.8	231,644.8	115,904.8
GDP - Agriculture, Forestry, and Fishing (million IDR)	48,573.1	26,270.0	63,709.8	43,635.2
GDP - Construction (million IDR)	62,730.9	4,624.7	29,177.9	16,568.4
GDP - Education (million IDR)	73,718.2	-	39,516.8	34,671.2
GDP - Trade (million IDR)	138,132.4	11,305.7	24,549.2	14,730.7
GDP - Government Administration, Defense, and Welfare (million IDR)	77,662.6	6,981.9	22,255.5	18,778.1

2.4 Culture

There is an indigenous belief in Sumba, called Marapu. Marapu embraces animism, which is worship of ancestral spirits. According to etymologists, the word Marapu is taken from the words 'ma' that means 'which', and 'rappu' which means 'worship'. Therefore, 'marapu' can be interpreted as 'the ones who are worshiped' [14]. Marapu belief is very influential in the daily life of Sumbanese people. The traditional house of Sumba (Figure 2) is designed based on this belief. The house consists of three levels, in which the upper level is designated for Gods and the ancestral spirits, the medium level is for humans, and the lower level is for the domestic animals. Therefore, it is very common for Sumbanese people to live closely with domestic animals, especially pigs, buffalos, horses, and chickens. Some people also practise open defecation because the lack of toilet, and the faeces are eaten by the pigs. In addition to that, Marapu also affects the way its followers are handling water, including for ceremonial activities [7].

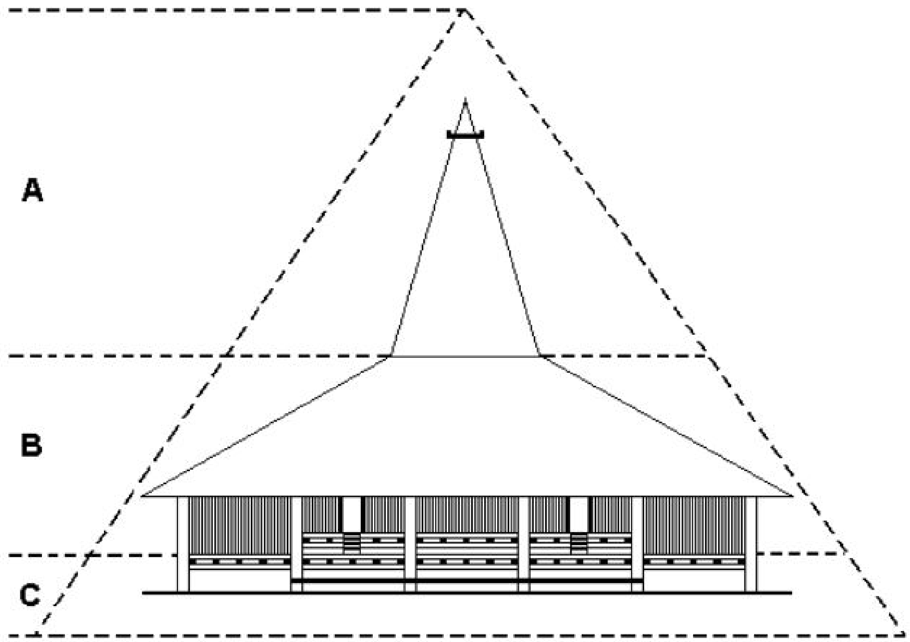


Figure 2: Traditional house of Marapu [7]

3 Research Question

Based on the introduction and background information provided in the previous sections, the main research question is:

"What are the factors affecting Water, Sanitation, and Hygiene (WASH) conditions and practises in East Sumba?"

To answer the main research questions, the following sub-research questions were formulated.

- Who are the main stakeholders and what are their interests and influences regarding the WASH conditions in East Sumba?
- What root cause might influence Water, Sanitation, and Hygiene (WASH) behaviours of the inhabitants in East Sumba?
- What are the chances of bacterial contaminations in water source and drinking water in East Sumba?
- What are the hygiene and sanitary practises conditions in the rural area of East Sumba?

4 Literature Review

4.1 Stakeholders Analysis

Stakeholders can be defined as the individuals, groups and organisations who are involved in a system and can influence its progress or even vice versa [15]. Stakeholders analysis is a process which is usually executed before the main project and has a vital importance for its success since ignoring the desires of a powerful stakeholder can derail the project. Some of the reasons which lead to project failure are related to poor stakeholder management and communication [16].

It is impossible that only one authority or group is involved in a project or problem since the interrelationships among different stakeholders are ever increasing and more and more groups, institutions and individuals are

Table 3: Methods of stakeholders analysis based on their type and their phase at which they are executed

	Phase of Stakeholders Analysis		
	Identification of Stakeholders	Stakeholders Categorization	Stakeholders Relationships
Focus Groups	x		
Semi-structured Interviews	x		
Snow-ball Sampling	x		
Interest-Influence Matrix		x	
Card-Sorting		x	
Bases of Power-Directions of interest diagrams		x	
Actor Linkage Matrix			x
Knowledge Mapping			x

influenced by or influence the course of a project/problem. However, the large number of stakeholders creates problems in identifying the most influential ones, therefore the use of criteria is imperative. Some of these criteria are: power, interest, urgency, role, responsibility, experience, knowledge, legitimacy (how the actions of a stakeholder comply with a given system of norms), training skills, risk, managerial abilities, education background, self-esteem and instability (how a stakeholder can overcome some obstacles and make progress) [17].

The stakeholder analysis can be separated into three steps: identification of stakeholders, categorisation, and searching for the interrelationships among them for possible cooperation and conflicts [18]. Table 3 summarises some available methods which can be applied based on the categories mentioned above. Focus group and semi-structured interviews were used for identification of stakeholders, interest-influence matrix for their categorisation and social network analysis for investigation of their interrelationships. The reasons why these methods were selected are mentioned below in the summary.

4.1.1 Stakeholder Identification (step 1)

The first tool which can be used is focus group, where a small group of participants (e.g. researchers, stakeholders) identifies the stakeholders after a thorough discussion; their interests and influences are analysed as well. The main disadvantage of this approach is that some critical stakeholders may not be identified if the focus group consists of researchers who may not be aware of the whole situation [19].

A more interactive approach is a semi-structured interview which is like a discussion where the questions have been determined beforehand and it does not have a strict structure. They are useful when the topic is quite complex and can help in revealing unknown issues. Also, there is more flexibility during the interview since it is logical that the interviewee may digress from the topic. In addition, other stakeholders may be revealed from the semi-structured interviews. On the other hand, there are some drawbacks such as the "interviewer effect" which is defined as the fact that the presence of interviewer influences the answers of the interviewee [20]. Another point is that, more training for the interviewer is required compared to structured interviews. Also, the interviewer may not be competent enough to get all the information (some information may not be verbal but it is transferred by body language). This is why interviewer's experience is significant and novice interviewers need practice before the real interview. Also, the generalisation of the interviews is tricky since the questions can vary when more than one interviewer perform the interviews.

Snow-ball sampling can be used for stakeholders' identification where interviewer asks stakeholders to identify other ones. The second group of stakeholders may identify more stakeholders and this process ends when there is no extra stakeholder which has not been interviewed. This approach is easily applicable and no prior experience is required. This process can be enhanced by the addition of a questionnaire which is used in all interviews and maximises the contribution to the stakeholders' identification [19].

4.1.2 Stakeholders Categorisation (step 2)

One of the most common tools for it is interest-influence matrix where the researcher places the stakeholders in a matrix at which the axes are interest and influence (there are no figures on the axes) since this analysis is qualitative (it is based on researcher's judgement). Stakeholders can be categorised into key players which have high interest and influence; context settlers (high influence and low interest) whose opinion matters and can change the course of the project; subjects which have low influence and high interest and the last category is the crowd which has less interest and influence [21]. The interest-influence matrix can be expanded using an extra attribute such as the support of the project. In that way, clusters of stakeholders with specific characteristics can be identified which can be useful for further analysis if need be. Furthermore, card-sorting is used for stakeholders categorisation where stakeholders sort the other stakeholders according to their own principles, beliefs and interests which are not the same with those of the project manager and other stakeholders as well [22]. In this way, the stakeholders are categorised into groups. The origin of this method comes from psychology in clinics but it has been applied successfully in water management as well [22].

4.1.3 Stakeholders Relationships (step 3)

Actor linkage matrix is one of the tool which can be used which is a table with two dimensions (the stakeholders are in both of those, first row and column respectively) and the degree of connection or of knowledge among them is described in the rest cells [23]. The degree of communication is often determined based on a few classes (e.g. weak, medium, strong). It is worth mentioning that the cells which correspond in the same stakeholder in rows and columns show the inherent communication or flow knowledge for the stakeholder itself.Actor Linkage Matrix is a rapid way of identifying the interrelationships among stakeholders.

Bases of power-directions of interest diagrams can also be used for the determination of stakeholders' relationships. This method indicates the power, interests and goals of the stakeholders but to a higher detail compared to interest-influence matrix. The origins of power and if power changes under certain circumstances are investigated. The researcher tries to see the aspirations and desires of the stakeholder from its point of view and after that patterns can be identified by comparing the bases of power–directions of interest diagrams (or star diagrams) [21].This method is mostly used for the influential stakeholders. The 2 main advantages of bases of power are [24]:

- The researcher gains an insight about the stakeholders and will identify similarities which can be quite helpful for categorisation
- A common baseline can be used for the evaluation of key stakeholders

A quantitative method which shows the relationships of the stakeholders (both sign and power) is social network analysis (SNA). The sign refers to the state of relationship between stakeholders, one example of this is trust and distrust [25]. Power of a stakeholder can be determined by looking at their ability to give punishment, provide rewards, and ability to manipulate beliefs towards other stakeholders (condign, compensatory, and conditioning power respectively) [18]. Another way to estimate power is by looking at the connection of a stakeholder to other powerful stakeholders, however, this depends on the situation of each case. There are some situations that can increase the power by association to powerful players and vice versa [26]. Using SNA, central stakeholders (those with connection with many others) can be identified and their relationships ought to be maintained. Networks with central stakeholders are considered vulnerable because any disruption in the communication may lead to information loss as there is no alternative ways for transferring the information [18]. On the other hand, a more distributed network offers flexibility and stability compared to the previous one. Also, the recognition of weak ties between stakeholders is especially useful since the project manager can take the required measures to enforce them in advance. The lack of trustfulness is a common reason for not successful communication. In order to identify which players are in a more central position centrality indices can be used [27]. There are three centrality indices such as, degree, betweenness, and closeness centrality. Degree centrality measures the number of connection a node has. Betwenness centrality identify which node lie within the shortest path of any two nodes. Lastly, closeness centrality uses the inverse of the distance of a node to all other nodes to determine the most central node [28].

Last but not least, knowledge mapping reveals which stakeholders have knowledge which is required for the accomplishment of the project. Also, the communication among the stakeholders for the exchange of knowledge is investigated, so the possible interactions among stakeholders are identified. Knowing what kind of knowledge is known by which stakeholder by a visual method can provide a quick overview to the project manager. Also, knowledge can sometimes be transferred only between a specific couple of stakeholders which makes them important and project manager can design his \her schedule respectively so that this can ensure that this communication will not be hindered [18]. Finally, this map is dynamic and changes happen as the project progresses.

4.1.4 Summary

At this part, the reasons why some methods were applied and others not are mentioned. A survey was applied for the locals since we wanted to be sure that the opinion of many villagers will be heard. Villagers who live at different part of the village would probably have different opinions about WASH behaviour. Regarding stakeholder identification, snowball sampling was not used since it would take more time and staying in Indonesia was limited. Thus, focus group and semi-structured interviews were used. As for stakeholder categorisation, card-sorting was not used as it was deemed too difficult because of the high illiteracy of the locals. Card sorting requires an iterative comparison, so the respondent should know what each card shows. Last but not least, regarding stakeholder relationships, SNA was selected since it can provide the overview of the stakeholders' relationships very quickly compared to Actor Linkage Matrix. Also, the bases of Power-directions of interest diagrams provides a lot of details which are not required for the objective of this research; the general overview is more important in this study.

Some other important remarks are highlighted. The qualitative methods lack precision because the subjectivity is high but this may not be a problem as long as it is in line with the goal of the project. On the other hand, qualitative approaches are much faster compared to quantitative which require high computational cost. A disadvantage for quantitative methods is that they have a large dependence on experts which makes them not easily applicable if the researcher does not have sufficient knowledge regarding the topic. Hence, decrease of experts' participation using automated methods is imperative; in that way, the manual process which is time-consuming will be diminished considerably [17].

4.1.5 Open Data Kit (ODK)

Open Data Kit (ODK) is a recent development which has empowered residents of developing countries to collect data which has not been gathered by State Agencies. Due to financial problems, developing countries lack of data in many different fields (not only regarding water management) and as a result, even if developed countries want to help them, they cannot because of the absence of data. This gap is covered by ODK which is capable of hosting forms and aggregating all the answers. Thus, interviews and collection of data can be realised rapidly and the same holds for the process of data.

It was decided to use ODK for this project. It can record the coordinates of the mobile device if satellite-to-site visibility is sufficient. Cellular data is not required for filling in the forms but it is necessary when the data is sent to the server. The user can take photos which is of great importance especially for measurements. It is quite common for a local inhabitant to take a wrong measurement misinterpreting the scale but taking a photo and checking afterwards by the researcher guarantees the quality of the measurements. Furthermore, it makes data processing much easier because of how the result table is configured. Lastly, questions can be modified easily, which helps the iterative process mentioned in section 5.2.1.

4.2 Water, Sanitation, and Hygiene (WASH)

Water, Sanitation, and Hygiene (WASH) are three topics that have become a concern of WHO and UNICEF since 1990. Universal, affordable, and sustainable access to WASH is a core of public health issue in global progress and is one of the goals of Sustainable Development Goals No. 6 [1]. Even though these three issues have differences, they are grouped as one because of their dependencies towards one another. For instance, water sources become polluted without safely managed toilets; and basic hygiene practises cannot be done without clean water [29].

4.2.1 Health Risks from Inadequate WASH

The absence of hygiene and prevalent open defecation practise resulted in an increasing concern about the sustainability of water resources and water quality, as this will lead to the occurrence of waterborne diseases [30]. Inadequate WASH is an important risk factor of diseases, especially in low income countries [31]. Poor WASH leads to the faecal contamination of drinking water, which is one of the causes of diarrhea [3, 32]. Diarrhea continues to be one of the most crucial health problems [33]. Exposure to faecal-contaminated drinking water resulted in severe diarrhea and deaths, especially in children [32]. Lack in WASH also promotes the occurrence of other water-related diseases, including gastrointestinal illnesses, typhoid, and cholera [34, 35].

4.2.2 Microbial Drinking Water Quality Analysis

The idea of using microorganisms such as *E. coli* as indicators of faecal contamination is a well-known practice in the evaluation of microbial drinking water quality. *E. coli* has been used conventionally to control drinking water quality, and it prevails as a significant parameter in drinking water quality monitoring as part of verification or surveillance. WHO suggested *E.coli* as faecal indicator, but it is more accurate to state that the presence of *E.coli* is an indicator of the potential presence of enteric pathogens than the absence of *E.coli* is equal to the absence of enteric pathogens. On the other hand, total coliforms can be used as indicator for cleanliness and stability of distribution systems, but they are not favored as faecal indicator. Water which is designated for human consumption should not contain any faecal indicator organisms [36, 37]. Table 4 shows the guideline values for verification of microbial quality [37].

Table 4: Guideline values for verification of microbial drinking water quality [37]

E. coli count (CFU/100 mL)	Classification
>100	Very high risk: urgent action required
11-100	High risk: higher action priority
1-10	Intermediate risk: low action priority
0	Low risk: no action required

There are many available techniques that can be used for microbial drinking water quality analysis. There are two techniques that are generally used for detection of total coliform and faecal coliform (including *E. coli*). The first is the "multiple fermentation tube" or also often called "most probable number (MPN)" technique. In this method, certain volumes of water sample are put in test-tubes containing a culture medium. The tubes are then incubated for a standard time under a standard temperature. The standard time and temperature differ based on the type of culture mediums used and the purposes of the analysis. The second technique is "membrane filter" technique, in which a measured volume of sample is passed through a membrane filter that retains bacteria, which has 47 mm diameter and 0.45 μm pore size. The filter is then placed on culture medium and incubated [38, 39, 36]. There are many advantages of membrane filtration technique compared to MPN technique, as it is found to be more accurate and precise; more rapid; require less labour, glassware, and culture medium; cheaper; and it can be readily adapted to be used in the field [38, 40].

There are many culture methods for total coliforms and *E. coli*. They are based on the expression of the

β-galactosidase enzyme for total coliforms and the β-glucuronidase enzyme for *E. coli*. Both liquid culture-based and culture on solid media techniques are applicable [41]. Considering water analysis in rural and remote areas, it is important to use a medium which is easy to carry and easy to store [42]. Compact-Dry plate (CDP) is one of the alternatives that offers those benefits. It is made using chromogenic substrates and redox indicators, which is able to give different colours for coliforms bacteria (red) and *E. coli* (blue) [43]. Previous study has proven that enumeration and direct counting of *E. coli* using CDP resulted in no significance difference with MPN method [44].

4.3 Risk Assessment using Sanitary Inspection

Risk assessment is a crucial component of the Stockholm Framework. It is adapted in all water-related WHO guidelines. For drinking water systems, risk assessment is an essential part of developing and implementing Water Safety Plans (WSPs). The aims of the risk assessment are to analyse and evaluate the health risks related to the water supply, to figure out if the health hazards are sufficiently controlled, to inform the operation and management of the water supply, and to determine if any necessary developments to guarantee safely managed drinking water are needed. Health hazards can be pathogenic microorganisms, chemicals, or radioactive substances in specific concentrations that have disadvantageous health impacts [37].

Sanitary inspection (SI) is one of the approaches to do risk assessment [45]. It can be done by inspecting the apparent causes of contamination that may introduce the hazards entering the water system; observing the possible occurrence of hazardous situations; and how these are regulated. Sanitary inspections are regularly used for point sources (e.g. wells, springs), concentrating on the close proximity to the source and the status of the infrastructures. Sanitary inspections can also deal with the storage tanks/reservoirs and, under certain circumstances, distribution and treatment systems. Sanitary inspection generally consists of standardised "sanitary inspection forms", which contains systematic questions. These questions focus on the most basic and typical factors that may lead to contamination of the water systems. Sanitary inspection is a powerful and generally relevant method for the risk assessment of water supply systems. It is commonly used in small water supply locations to assist the identification and management of high-priority risk factors. [37].

4.4 Prediction of microbial drinking water contamination

Sanitary inspection and water quality data can be combined to identify the most important source of contamination. For example, it can be used to assess whether on-site or off-site sanitation corresponds to the contamination of drinking water, because the remedial actions required to tackle either source of contamination varies. Combined analysis of sanitary inspection and water quality data is principally beneficial in assessing household water management systems [36]. The idea of combining sanitary inspection with water quality data yields a useful information because they support the determination of the risk factors that are presumably linked to health risks [37]. Therefore, sanitary inspection and water quality data can be combined to predict the chance of water contamination.

In this study, a Bayesian Belief Network (BBN) is used to model the chance of microbial drinking water contamination in water source and household level, based on sanitary inspection and microbial water quality data. A BBN is a graphical model that embodies probabilistic relationships among variables of interest and it is formed based on probabilistic inference mechanisms according to the Bayesian rule [46]. A BBN's structure is described by directional linkages, or called 'arcs' in BBN, that indicates the dependence and conditional independence expectations, for example relationships between random variables. In BBN, the variables are named 'nodes'. These nodes in turn influence what information is needed to establish the collective probability distribution between the random variables of a network [47]. The factors that contribute to a certain result are called the 'parent' nodes, whereas the consequences are called the 'child' nodes. The advantage of BBN is that it works both ways around. This means that BBN can be used to calculate the probability distribution of children given the values of their parents as well as vice versa [48]. This means for this project, when the practices that lead to a certain chance of contamination are known, it can be deduced which practices need to be changed to obtain a lower contamination risk.

BBNs have an intelligent statistical foundation and can be coupled conveniently with progressive statistical techniques, e.g. machine learning. Machine learning of BBN consists of two types: structure and parameter learning. Structure learning covers the finding of the optimal directional linkages, while parameter learning specifies the conditional probability distributions [49]. This feature of BBN can be useful for health surveillance and environmental modelling [50], as it is able to analyse the data obtained from the survey and learn parameters from the available data. BBNs are able to be trained to in such a way that the parameters of the network are optimised to match the data, however, it undergoes overfitting when there is insufficient data [49]. Machine learning technique is not always consistent in achieving good accuracy compared to the real condition when learning the probability tables entries or parameters. Therefore, it is commonly accepted that integrating expert judgements can improve the learning process of BBNs [51].

5 Methodology

5.1 Stakeholder Analysis

5.2 Stakeholder Identification

At the start of the project, some of the key stakeholders were identified such as village government, health agency, locals, etc using focus group consisting of the members of our group. In order to incorporate newly encountered stakeholders semi-structured interviews were used. Once identified, the criteria used to categorise these stakeholders were influence and interest. The values for the influence and interest were obtained through interviews.

Furthermore, the connection between stakeholders was determined using the social network diagram, the information was also obtained through the interviews. The sign and power of the relationships link were not incorporated in the diagram as there was not enough information obtained to quantify those numbers. The connections are defined by whether the stakeholders know and interact with one another. The diagram is indexed using betweenness centrality. It was chosen compared to the other indexing method as it shows the stakeholders that connect the most nodes under the shortest paths possible [27]. This provides insight to which a stakeholder acts as a bridge for all the other stakeholders.

Finally the information gathered from the interviews and surveys was used to create a conceptual model of what contributes to the WASH practices in the area. Possible causes that affect the increase or decrease of WASH practices were put into one map and connected using qualitative analysis. From the diagram, root causes were then determined.

5.2.1 Interviews and Surveys

In this project, regarding the interviews, a mixed-methods approach was used. Semi-structured interviews were done for all the stakeholders (one interview for each stakeholder) except the locals; for those we used a survey with 334 respondents. At the beginning, before formulating the survey, 15 exploratory semi-structured interviews for locals (five interviews in each village) were completed in three villages (Hamba Praing, Pambotandjara and Makamenggit). It was necessary to understand their mindset, desires, goals and behaviours. Due to time limitations, it was not possible to do semi-structured interviews in all nine villages. The above-mentioned three villages were selected since they have some differences regarding access to water and thus considered to represent the whole study area. The asked questions of these semi-structured were about their drinking water source, water treatment, WASH behaviour, and stakeholders relationships (see Appendix A). These questions were selected after a discussion between the group and the client who was aware of the local conditions and Sumbanese norms. The result of these interviews were used to construct the survey questions (see Appendix A).

Based on the semi-structured interview answers of the inhabitants of these villages, the questions of the survey which used for all villages were created. The survey was separated in three sections (institutions, economy, and habits) so that the analysis in the following phase can be more effective. The questionnaire was modified since some questions were not formulated well and locals were not able to understand them (their answers were quite abstract). Thus, an iterative process took place until the point at which the questions were understandable. Questions regarding sensitive topics such as religion and traditions were asked by having taken advice from local acquaintances and testing the questions with a few locals.

In addition, the questions were not followed strictly but the interviewer followed the flow of conversation and ask questions depending on how the interview was developed. The structure was used to ensure that all key points were covered within this conversation. The aim of the semi-structured interviews was to find insights that might have been missed. The interview and survey questions can be found in Appendix A.

5.2.2 Open Data Kit (ODK)

It was decided to use ODK for recording the answers of the survey. It can record the coordinates of the mobile device if satellite-to-site visibility is sufficient. Cellular data is not required for filling in the forms but it is necessary when the data is sent to the server. The user can take photos which is of great importance especially for measurements. It is quite common for a local inhabitant to take a wrong measurement misinterpreting the scale but taking a photo and checking afterwards by the researcher guarantees the quality of the measurements. Furthermore, it makes data processing much easier because of how the result table is configured. Lastly, questions can be modified easily, which helps the iterative process mentioned in section 5.2.1.

5.3 Sanitary Inspection

Sanitary inspection was done by proposing a set of questions referring to the pilot of sanitary inspection (SI) packages by WHO in 2018. The pilot SI packages by WHO is an improvement of the 1997 SI packages. The new SI packages are revised to provide better compatibility with WSP data, to incorporate most relevant and scientifically valid risk factors, and to include the most applicable technologies [52]. SI was collected using ODK as what has been explained in section 5.2.2. The SI was adjusted so that it could be applied to different types of water source and household practices. The SI consisted of 11 sections, namely household information; water source data; inspection of water source; water transport and collection; water storage after collection; household water treatment; water storage after treatment; handwashing practises, inspection to sanitation facilities; inspection to environmental cleanliness; and general remarks about the weather, date, and time. The complete questions list of the SI can be found in Appendix C.

5.4 Water Quality Analysis

Monitoring the actual water quality in the study area is an important factor to get an insight in the relationship between WASH-practises and drinking water quality. This insight can be of important value when working towards an intervention solution. As what has been explained in section 4.3, combining water quality data and sanitary inspection is beneficial to identify source of contamination and analyse household water management system.

Data from 336 respondents were collected in this study, with total 325 samples from household levels (drinking water which is ready to drink) and 276 samples from water sources. Some samples could not be taken from household level due to unavailability of water at the moment of sampling, the water was just recently boiled, or because they consume commercial potable water (gallon water) which is not relevant for this study. Some households shared the same water source (e.g. community well or public tap), therefore the number of samples from water sources were less. The quality of the drinking water sources as well as the water in

the homes of the locals was analysed. Water samples were taken on site in sterile 100 mL Whirl-Pak® bags. The samples were then stored in thermos containers (without ice) in order to prevent external factors such as UV or temperature changes from influencing the samples [53, 42]. The thermos containers were used to transport the samples to a mini portable lab in the village, where the they were processed. This was done by pipetting 1 mL of sample directly onto the center of a Compact Dry™ EC plate (Nissui Pharmaceutical Co. Ltd, Japan), a ready-to-use test method recommended for the isolation and enumeration of total coliforms and *Escherichia coli*. The plates were transported insulated at their original temperature in a non-heated field incubator (Letz, Germany). This step was necessary because of the lack of electricity in the villages. All samples were processed as fast as possible, but at most within six hours. Back at the base camp, the plates were placed in an electric portable incubator (Hartmann, Germany) at ± 37.5 °C for 24 hours. The exact temperature graphs can be found in Appendix D. After incubation, total coliforms and *Escherichia coli* colonies were counted. For all samples that resulted in too numerous to count (TNTC), all colony counts were assumed to be 150, following the early research that used 150 to describe TNTC in petri film disk [54]. One producer of EC plate (Hardy Diagnostics, USA) suggested 100 CFU/mL as TNTC [55], but Nissui Pharmaceutical Co. Ltd, Japan suggested that the sample must be diluted if TNTC is detected [56]. However, due to field limitations, the dilution of the sample was unfeasible and hence it was decided to use 150 as TNTC.

5.5 Bayesian Belief Network

As explained in section 4.4, a BBN model was used to integrate SI and microbial drinking water quality analysis data to predict the chance of contamination in water source and household level. The BBN was modelled used GeNie 2.4 software by BayesFusion LLC. The model was constructed using a data-based approach [57]. The outer nodes are filled with the data obtained from the sanitary inspection (SI) and the inner nodes are filled with the water quality data. The water quality data were therefore categorised in low, medium, and high. The categories for *E. coli* are adapted from the data in the WHO guidelines [36]. The low level for total coliforms is categorised based on data from Canada and the data for the high was based on samples not passing the test for groundwater, as no data for standard of total coliforms in drinking water could be found.

Table 5: Microbial water quality categories

	E. coli CFU/ml	Coliform CFU/ml
Low	0 [36]	<0.1 [58]
Medium	<=1 [36]	0.1 - 99
High	>1 [36]	>99 [59]

Because of the large number of data in the outer nodes, it was chosen to add intermediate nodes for a better overview. These nodes were filled using a knowledge-based approach [57]. This was done by giving the variables (number of variables = n) from the parent nodes a suitable score (0 for low chance of contamination, n-1 for high chance of contamination) and adding them up. Based on their cumulative score, the values were again categorised in low, medium and high chances of contamination to fill the intermediate node.

The relationship between the nodes, conditional probability, was derived from the empirical data of this fieldwork. The model learns these relationships using the EM algorithm [60, 61] which can learn parameters from data sets with missing values, making it suitable for field work, where this is often the case. The Randomize function with random seed 1 was used. Relevance was disabled, which slows down the algorithm but gives a better results [62]. A sensitivity analysis of the model was conducted to determine the nodes which are likely to give different outcomes when small changes in the parameters are applied [63]. The brighter red a node is, the more sensitive it is to slight changes that propagate into the target node. The target node itself is naturally the brightest red. Two different version of the same model were constructed. One in which the water quality risk was fed to the model based on *E. coli* data, and one based on total coliform data. The SI data that was fed to the outer nodes remained unchanged for both version.

6 Results & Discussions

This chapter describes the results obtained from the research. Firstly, all of the stakeholders are introduced in section 6.1. It is important to explains all terminologies and stakeholders in this section, because they will be mentioned in the following sections as well. Secondly, the results of the interviews are presented in section 6.2. Thirdly, the water quality and sanitation are elaborated in section 6.3. Finally, section 6.4 discusses the overall results and strategies that can be made to improve the WASH conditions and practises.

6.1 Stakeholder Analysis

6.1.1 Stakeholders Identification

The stakeholders of this study are: Village Board, Village Council, BAPPEDA (Regional development Agency), DinKes (Health Agency), PUSKESMAS (Health Clinic), Posyandu (Health Post), DinPU (Public Work Agency), Kecamatan (Sub-District Board), Water Board, PAMSIMAS, Non Governmental Organisation (NGO) and Social Agency. Their role and responsibilities are analysed below.

Village Government and village council are two administrative bodies which play a catalytic role in the construction of infrastructures regarding water management, promotion of WASH and locals' mindset change in general. They are the closest in the management hierarchy to the locals compared to the other administrative units. Thus, the role of both bodies is of great importance since any breakdown here can easily derail projects stemming from higher levels.

The members of those bodies are elected with two different elections and are not selected by higher authorities. Each village is divided into sub-villages and a specific number of candidates can be nominated by each sub-village. Only a fixed subset of the candidates will be elected which is different in each village (it depends on the population of the village). The elections for the village board and village council take place every 6 years. The main responsibility of the village council is to monitor the actions of the village board. It is worth mentioning that nobles or wealthy villagers who own a lot of arable land are usually nominated for participating in these bodies. The political competition requires significant financial resources which only these villagers can afford.

BAPPEDA (Regional development Agency) is a critical actor not only for the planning of infrastructure, but also for the assessment taking into account the official technical guidelines which have been legislated. Also, it is responsible for the planning process and the evaluation of the programs regarding regional planning. It cooperates with villages directly but also with the administrative units above them. Its WASH related spending is limited as it mostly focuses on building infrastructure (roads and bridges) setting aside water related infrastructures. Another point is that the majority of its budget comes from the national budget and the rest from its own earnings.

DinKes (Health Agency) is a governmental health agency which oversees the implementation of WASH program in the area. It collects health and sanitation data such as diarrhea and conducts research in the area. Further, it manages PUSKESMAS and Posyandu and provides them with doctors, nurses, and supplies. PUSKESMAS is a health clinic which is responsible for care of patients and promotion of healthy lifestyle and hygiene. It also covers health issues regarding mothers who have given birth recently and regarding children [64]. It follows the guidelines of the health agency and is in charge of the sub-district level. Indonesia is not very urbanized which means that health clinics need to be scattered so as to cover the majority of the inhabitants who live at remote areas. Similar to PUSKESMAS, another stakeholder is Posyandu (Health Post) but it is focused on health promotion and does not take patients.

DinPU (Public Work Agency) is responsible for the construction of projects and cooperates a lot with BAPPEDA. It used to install pumps in the rural environment to service the remote villages but now it mostly focuses on constructing roads and bridges as BAPPEDA does.

Kecamatan (Sub-District Board) is the administrative unit which is above the village and below the district level. It follows the guidelines of the district and its primary goal is to facilitate the communication between the upper layer of hierarchy with the lower ones. The elections for Kecamatan take place every 5 years.

Water Board consists of at least 3 members (president, treasurer and the secretary) and some technicians who work voluntarily. The main concern of the water board is the maintenance of the drinking water network after its construction. Also, it manages the money which is collected by locals for repairs regarding the drinking network. It is common for these members to be quite old. If they try to retire, nobody wants to take this responsibility due to lack of incentives or there is no one with sufficient qualification. As a result, they continue having their posts despite their age. It is not an official institution, so there is no statute about its function and its main responsibilities. It is usually established when a pipe network is built by PAMSIMAS.

PAMSIMAS is an organisation which is mainly funded by the World Bank and the national government. Its primary concern is to enhance the sanitation and to construct relevant infrastructures for better access to drinking water. It has a close collaboration with the board of the village where the infrastructure is built. The majority of PAMSIMAS projects took place for two to five years, but only the first year is funded by PAMSIMAS. In the second year, villagers and the village government need to contribute financially to the project. In this way, the feeling of ownership is greater and locals tend to feel more accountable for the project as a result. In some cases, locals may contribute by working during the construction phase. However, in many cases, locals were reluctant to support the continuation of the project using their own funds and many projects have failed. For instance, in one village where PAMSIMAS was active, its pipe network project was successful for about two years until the solar panel for the pumping was stolen. The village fund was not sufficient for purchasing a new panel and the villagers did not want to give money for it. This problem has not been solved yet and many households do not have quick access to water and locals walk long distances to bring potable water in their households on a regular basis. Additionally, PAMSIMAS does not build the pipe network all the way to the households, they only install public taps.

Different NGOs are the main partners of UNDP (United Nations Development Programme) branch which is active in Indonesia and their role is arguably significant. According to our research, there are many NGOs which are active in the area but their focus varies (it was related to drinking water treatment in the past). The majority of them are about irrigation and protection of children. The NGOs which have contributed to WASH promotion in the past were KOPPESDA and SIDe. NGOs take funds from a donor of international scale which wants to achieve a specific goal in a specific geographic location. Therefore, the focus of these NGOs changes depending on where the money is obtained. Moreover, the desires of the donor may change the following period, thus a follow project may not be feasible. Also, the donor does not accept any extensions. If the NGO requests extra time for planning at the beginning of the project, it is considered as an indication of ineffectiveness and the possibility for the NGO to take the funding reduces dramatically. Also, the cooperation of the NGO with other stakeholders depends on donor's guidelines. Thus, the dependency of the NGO to the donor is obvious and its initiatives are limited. KOPPESDA gave a remark that due to the time limitation they were not able to properly know and build up rapport with the locals. They think that it is an important step of the process that is often missing in this kind of project.

Social Agency is another stakeholder and its main concern is the protection of the poor providing them with necessities. It had a relationship with Kecamatan in the past and the first one delayed the delivery of subsidies for the locals if the locals continued to practise open defecation and not use the toilet. Thus, it had an influence on WASH practices but this collaboration is not active anymore. Therefore, in the following analysis this stakeholder will not be included.

6.1.2 Locals' perspective towards institutions

A part of the survey was devoted to the institutions which are present in the study area and critical information about their help towards locals were derived by locals' perspectives. In all villages except Hamba Praing, at least 60% believes that the help by government or village board is not sufficient (see Table 7). The lowest satisfaction is noticed in Palakahembi, Pambotandjara and Pulu Panjang whereas Mbatakapidu and Mondu have considerably higher values. As can be seen in Table 2, Kanatang (the sub-district to which Hamba Praing, Mondu and Palindi Tana Bara belong to), is the poorest sub-district (lowest GDP) compared to the other ones, so it is possible that locals of these villages receive more help from local authorities and are more satisfied regarding it (their percentages are 71.8, 37.5 and 28.6% respectively).

Another important institution is the water board which is not present in half of the villages. One of the questions in the survey was about the awareness of locals in regard to the existence of the water board. It is surprising that only in two villages more than 50% of the respondents know that it exists in the village. These two villages are Hamba Praing and Mondu which are neighbours and their percentages are not that high (66.7% and 60.0% accordingly) which means that locals ignore about it since they may reckon that it is not an important body. In Palindi Tana Bara, all the respondents are unaware of the Water Board but this result may be a bit misleading due to the small sample size in that specific village. In general, in the villages where there is no water board, the percentages of awareness are considerably lower. One more question regarding how well locals are informed about water projects was asked. Again, the citizens of Hamba Praing and Mondu are well-informed and know whether there is or there was any kind of water supply project by any actor (such as ProAir, PAMSIMAS and NGO) in their village. Nonetheless, in six out of nine villages, the majority is uninformed which is an important obstacle which hinders any concerted action by the locals. Pulu Panjang has the lowest percentage of informed citizens and it may be related to its location.

6.1.3 Stakeholders Categorization

Before analysing the potential collaboration and conflicts among stakeholders, it is worth presenting the interest-influence matrix. Only one influence-interest matrix (Figure 3) was created rather than two separate ones (for the villages which have a water board and those who do not) since the water board is not a

Table 6: Survey using polar questions regarding institutions for all villages and locals' habits (The answers are percentages which answered positively to these questions

	Hamba Praing	Kawangu	Palindi Tana Bara	Makamenggit	Mbatakapidu	Mondu	Palakahembi	Pambotandjara	Pulu Panjang
Institutions									
Does the government or village provide help in funding water projects?	71.8	22.5	28.6	30.0	41.8	37.5	11.1	15.9	11.4
Do you know if there is water board in the village to manage water infrastructure?	66.7	20.0	0.0	35.0	34.5	60.0	22.2	34.1	11.4
Do you know if PROAIR/PAMSIMAS/other NGO/government has/had a water supply project in the village?	92.3	27.5	21.4	37.5	65.5	80.0	29.6	43.2	14.3
Every time you go to the hospital or health post, do the doctor or nurse ALWAYS ask you whether you treat your drinking water or not?	66.7	65.0	92.9	70.0	58.2	60.0	48.1	81.8	34.3
Habits									
Do you think teething causes diarrhea?	43.6	35.0	92.9	70.0	56.4	50.0	40.7	70.5	51.4
Do you think water quality affects diarrhea?	64.1	60.0	85.7	70.0	58.2	55.0	55.6	63.6	57.1
Do you think that taste is the reason for you not treat or treat your drinking water?	74.4	62.5	85.7	77.5	69.1	77.5	70.4	79.5	65.7
Do you think that health is the reason for you not treat or treat your drinking water?	69.2	62.5	85.7	70.0	61.8	60.0	63.0	70.5	68.6
Do you think that your parents' teaching/habit is the reason for you not treat or treat your drinking water?	59.0	50.0	64.3	65.0	45.5	37.5	48.1	31.8	62.9
Is convenience the reason you do not treat the water?	43.6	27.5	42.9	10.0	20.0	30.0	25.9	25.0	25.7

key stakeholder and whether it exists or how active it is cannot considerably influence the other stakeholders. Also, this analysis is qualitative and diving into detail without having quantitative data make it more difficult and prone to inaccurate comparisons.

This matrix represents the average influence and interest of each institution for the 9 studied villages. Some of the stakeholders vary more than others per village. For instance, Dinkes (health agency) applies the same policy in the whole district, so the changes among these villages are subtle. For this majority of stakeholders, their position in the interrest-influence matrix does not change per village and this is the reason why only one interest-influence matrix was created and stakeholders can be categorised into four groups. On the other hand, some stakeholders are unstable such as the village board which is dependent on the village head personality and ambition.

Village board (which is mainly represented by the village head) is the most important stakeholder and its influence is almost the same as its interest. Another interesting comparison is about Dinkes and PUSKESMAS. Both of them have a high interest since not promoting of WASH can lead indirectly to many diseases. However, they try to counter some other fatal diseases which are dominant in the area such as malaria and dengue fever so their interest does not have a maximum value. However, Dinkes has higher influence since its decisions and guidelines can influence the institutions which are at a lower level in hierarchy.

PUSKESMAS has a high interest but not a high influence since it cannot change the behaviour of locals so that locals protect the drinking network if it exists in their village. On the contrary, DinPU has a lot of power to influence the current situation regarding WASH by building water related infrastructure but its focus is different as was mentioned above.

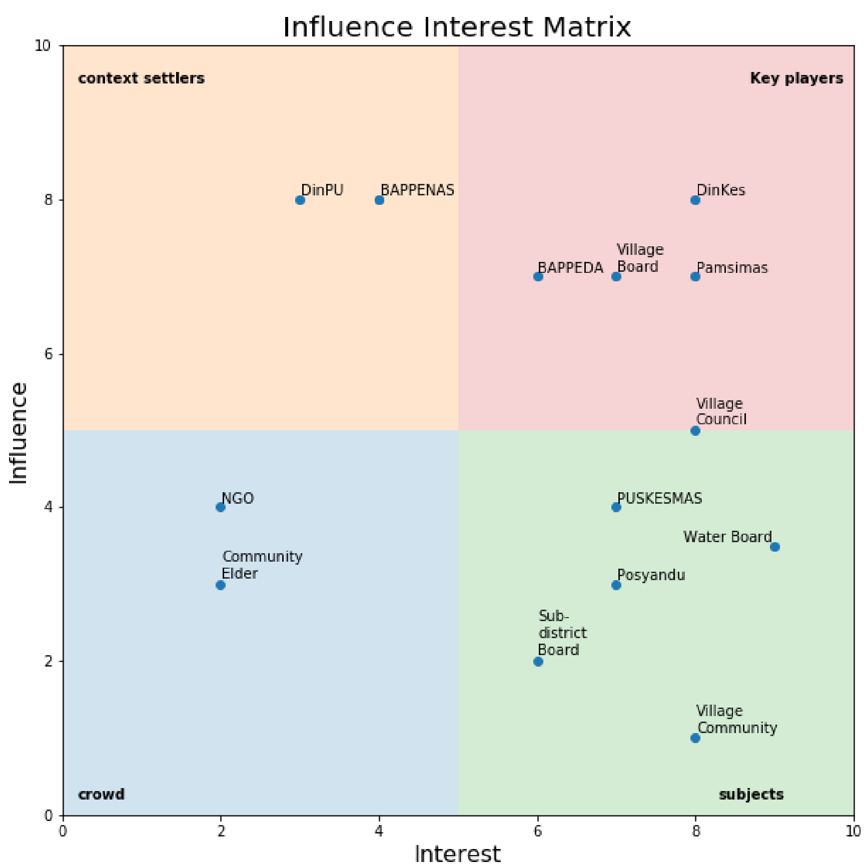


Figure 3: Influence-Interest-Matrix for all stakeholders in the study area

6.1.4 Stakeholder Relationships

The relationships between stakeholders are analyzed by making a conceptual social network. Figure 4 shows the overview of stakeholder relationship in East Sumba and 5 shows the diagram indexed using betweenness centrality. The arrows indicate the knowledge of one stakeholder towards another, they also include the flow of information, goods, and money between stakeholders. However, they are not weighted and mainly serve to show the connection between stakeholders. Betweenness centrality was chosen as a method for indexing as it considers only the shortest path possible and the strength of each connection is not taken into account. It shows the most important stakeholders that act as a bridge for the others. In this case PAMSIMAS (rural water agency) is the most crucial, followed by DinKes (health agency), Waingapu hospital, BAPPEDA (planning agency, and some of the village governments. PAMSIMAS is involved with most governmental agencies and some of the water boards, however, it is not present at all in the village yet. Similarly, DinKes presence can be felt at all villages and most governmental agencies collaborate with it. These two institutions are crucial to act as a bridge between the government and the local communities. One thing to note from the graph is that it does not show the importance of village heads. There is still lingering feudal sentimentality in the area, which caused the locals to see the head as the main voice of authority. During our interviews, DinKes, PAMSIMAS, and NGOs mentioned that to reach the locals they need to first approach the village heads and gain their support. Figure 4 shows the overview of non-indexed stakeholders. It shows that the majority of players need to go through the village head (village government) to reach the locals. Currently, there is an established connection between DinKes and the locals through the health post. Similarly, PAMSIMAS is also working with the water board of some villages and can reach the locals. However, it is believed that village head endorsement is still the key piece to strengthen that connection. Therefore, while PAMSIMAS and DinKes are the central players for WASH project in East Sumba the village governments are the crucial player to reach the locals.

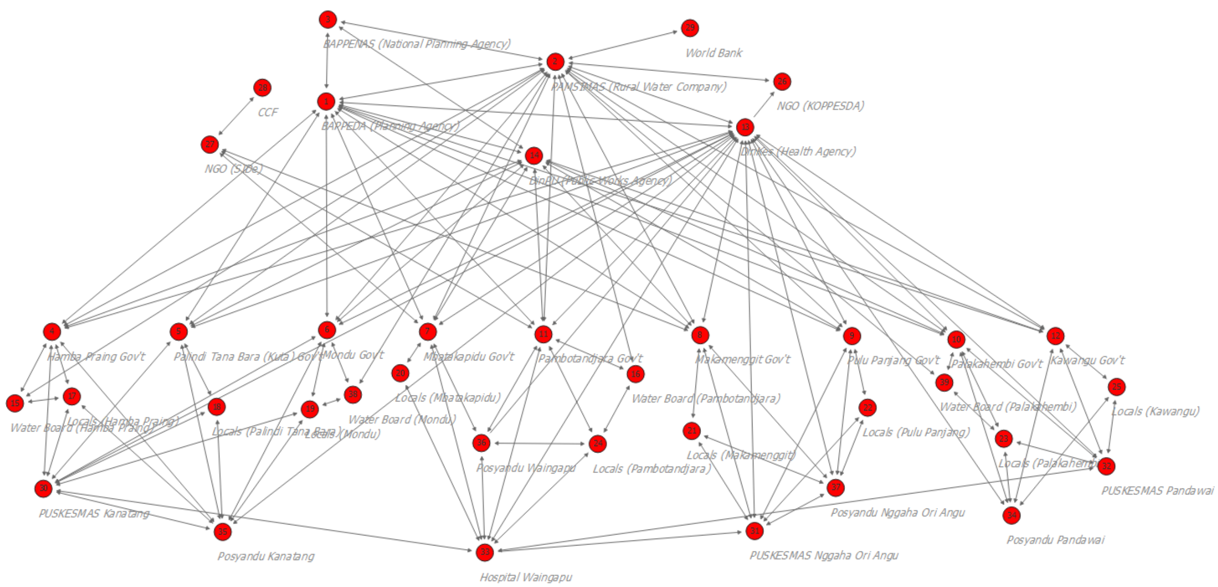


Figure 4: Social network for stakeholders in Sumba.

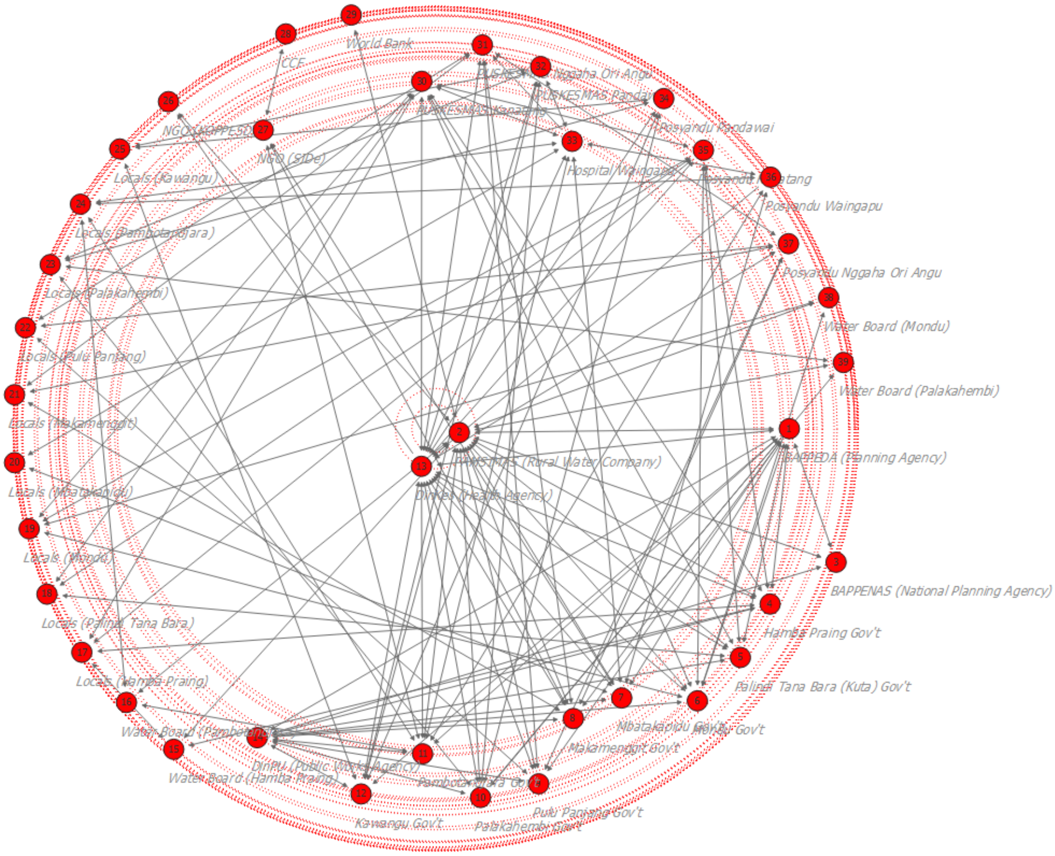


Figure 5: Social network for stakeholders in Sumba, indexed using betweenness centrality.

6.1.5 Possible collaboration and conflicts among stakeholders

Based on the previous results, collaboration of some stakeholders can facilitate the locals' acceptance of WASH behaviour. There are no conflicts among stakeholders, and different stakeholders have different priorities in this study.

The village board is the main stakeholder and its cooperation with the local water board can be effective only if the state institutions have provided the required resources. Also, the water board tends to care more about the creation of a drinking network and less about promoting WASH behaviour. Thus, this collaboration will not be as influential as the relationship of the village board and local PUSKESMAS. Both of them may host more events endorsing WASH, and this can be more influential but it requires more time. Based on the interviews with PAMSIMAS representatives, they are open to this kind of events but they wait for village initiative. Even if they want to inform locals, it is not allowed without the approval of the village head.

Also, based on figure 5, DinKes and PAMSIMAS are stakeholders of great importance and their collaboration with the village board ought to be strengthened. Last but not least, it is worth highlighting that during the semi-structured interviews, most of the locals did not suggest any specific collaboration among stakeholders, so most possible recommendations were extracted by the meetings with national agencies.

6.2 Interview and Survey Results

6.2.1 Drinking Water Source, Water Board, and Toilet Availability

The existence of a water board, the main water drinking source of the village and whether locals sign a binding contract for the construction of toilets are tabulated in Table 7. Half of the villages have a water board and there is no pattern (these villages are not clustered to a specific region). Regarding the drinking water source, there is heterogeneity (Mondu and Hamba Praing use public taps whereas wells is another popular source which Kawangu, Mbatakapidu, Palakahembi, Pulu Panjang and Hamba Praing use primarily). In the first group of villages, there are also private wells. In Makamenggit, Palakahembi, Palindi Tana Bara and Pambotanjara the pipe network is not functional but it used to work periodically. Therefore all these villages use trucks for water services to a different degree. Mbatakapidu is the only village where locals enjoy private taps and the locals do not need to go to public spots for taking water, however they are not available everywhere. Furthermore, another point is that locals switch water sources throughout the year due to high variability of water resources. A detailed record of how the water source changes over the year is required before coming up with a solution.

Regarding the construction of toilets, the local governments have a program where they provide materials free of charge to households as long as they use it to build a toilet. Only Mondu and Palakahembi apply fines to locals who have not built the toilet after being provided with the materials. Locals sign contracts in both villages and the village board monitors the toilet construction. Once built, the village board will also come by every certain period of time to check whether people are using the toilet. The results show that there are toilets that are not used because they are not functional.

Table 7: Drinking water-related data (existence of water board, main drinking water source, and signing of a binding contract regarding the toilet construction between local and village committee)

	Water Board			
Village	**Yes**	**No**	**Main Drinking Water Source**	**contract**
Kawangu		x	private wells	no
Makamenggit		x	trucks and rain harvesting in summer	no
Mbatakapidu		x	private taps and private wells	no
Mondu	x		public taps	yes
Palakahembi	x		public taps, wells and trucks	yes
Palindi Tana Bara		x	trucks and springs	no
Pulu Panjang		x	springs and wells	no
Pambotanjara	x		public taps and trucks	no
Hamba Praing	x		wells and public taps	no

The main water source which each village uses can be explained by the river network of the study area. As seen in Figure 6, there is no river in Palindi Tana Bara, Pambotandjara, and Palakahembi (in the last one; there is a small river on the south part of the village but its contribution is minimal), so there is a lack of surface water resources implying indirectly that the the ground water is deep as well. Hence, locals resort to trucks for water service since the other approaches are not feasible. In Makamenggit, trucks are used partially even though the origins of River Matawai Pariwana are within the village boundaries. On the other hand, Kawangu is located downstream and the river Kambanirou goes through it to discharge its water in the sea. Thus, the groundwater table is shallower compared to the above-mentioned villages which is the reason why most of its inhabitants own their own private well.

It is worth highlighting that in this map, only 195 households had been mapped and not the whole dataset since the GPS did not work all the time and the steep terrain obstructed the smooth transfer of signal between satellite and mobile device. Also, there are some overlapping points since they are clustered in nearby locations.

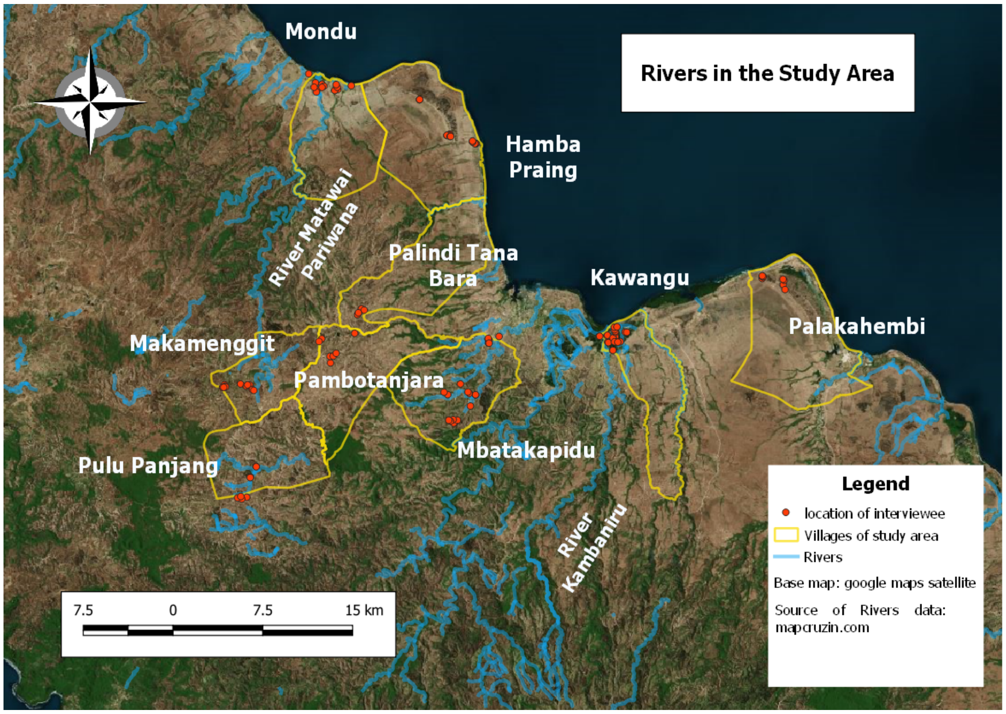


Figure 6: River network of the study area in combination with locations of interviewees' households

6.2.2 Finance

In general, the questions about willingness to pay for service are delicate and the interviewers articulated them carefully. If the interviewer asks the interviewee what the minimum amount of money he\she can afford for water services, there is a high probability that the respondent will choose the lowest amount out of the list. Therefore, we formulated the questions differently. We predefined specific levels of money and asked the locals if they are willing to pay that amount; those levels were 5,000, 10,000, 25,000 and 50,000 IDR/person/month. The questions were asked in ascending order.

Table 8 shows the percentage of villagers who can afford to pay these specific quantities of money. Only three villages have the majority of their inhabitants who are willing to pay 5,000 IDR/person/month; 5,000 IDR is almost half the price of a meal. Pulu Panjang is the village at which most locals cannot afford 5,000 IDR and the opposite applies for Makamenggit. As regards 10,000 IDR, the changes in percentages were subtle and the maximum decrease was 5% for Mondu and Kawangu. However, a considerable drop occured when the locals were asked about 25,000 IDR and Palakahembi was the village with the least locals who were willing to pay that amount of money. Makamenggit was the village that are most willing to pay having only a decrease of 10% of its initial percentage of 5,000 IDR. Finally, 50,000 IDR was considered too expensive for water services and no one in Palakahembi is willing to pay for it. The percentages of all villages had decreased substantially except Makamenggit and Pambotandjara which are just below 50%. By looking at table 7 one can explain the reason behind this. The three most willing villages (Makamenggit, Pambotandjara, and Palindi Tana Bara) have trucks as their main water source. Trucks are by far the most expensive water source. In these villages people often pay 300,000-400,000 IDR per month for their water. These percentages are compared with the tax realization of the villages from 2017 in table 9. The tax realization is the ratio of actual over expected tax revenue, it shows that most of the locals are still unwilling to pay taxes as most of the values are about 50% and below. This behavior is similar to what is observed in table 8. However percentage of people willing to pay for the water does not seem to be correlated to the tax realization. More data is needed to learn more if there is any connection between the two.

Another question was asked about their preference between purchasing gallon water (7,000 IDR) and boiling their own water. In all villages, the percentage which is in favor of the gallon water did not go above

40%. Makamenggit had the highest percentage which was just below 40%. On the other hand, Mondu and Palakahembi had the lowest values and their results are in line with the "willingness to pay" questions (see Table 7). The reason why a large percentage in these villages chose boiling the water is probably not because that they like it but it is because the gallon water is seen as being unaffordable. In general, the willingness to pay shows the combination of how affluent the locals are and whether they want to support water utilities in the village.

Lastly, the village budget can be seen in table 9. Overall the villages have a similar annual budget. However, the percentage for WASH varies. Pambotandjara, Hamba Praing, and Palakahembi spend more for WASH compared to the other villages. The criteria for a fund to be considered a WASH fund are: toilet/healthy house fund, water, sanitation, health staff, water pumps, and construction for new related buildings. Most of the budget is spent on infrastructure and local business.

Table 8: The percentages of inhabitants who are willing to pay for water services in all villages of the study area

Village	**5k IDR** [%]	**10k IDR** [%]	**25k IDR** [%]	**50k IDR** [%]
Hamba Praing	33.33	30.77	10.26	7.69
Kawangu	35.00	30.00	25.00	25.00
Makamenggit	67.50	67.50	57.50	47.50
Mbatakapidu	30.91	30.91	14.55	12.73
Mondu	30.00	25.00	5.00	2.50
Palakahembi	33.33	22.22	7.41	0.00
Palindi Tana Bara	57.14	57.14	42.86	35.71
Pambotandjara	61.36	61.36	50.00	43.18
Pulu Panjang	28.57	28.57	8.57	2.86

Table 9: Village tax realization 2017 [10, 11, 12, 13], budget, and its percentage going towards WASH project.

Kecamatan (Sub-district)	**Desa (Village)**	**Tax Realization from Target** (%)	**Village Budget (million IDR)**	**Percentage of Budget Going to WASH** (%)
Kota Waingapu	Mbatakapidu	55.56%	1,208.10	7.42%
	Pambotandjara	57.37%	1,246.90	15.02%
Kanatang	Hamba Praing	34.93%	1,235.90	15.86%
	Mondu	29.81%	1,551.40	4.99%
	Palindi Tana Bara	22.94%	1,271.70	5.46%
Pandawai	Kawangu	52.87%	-	-
	Palakahembi	33.71%	1,454.00	18.43%
Nggaha Ori Angu	Makamenggit	32.82%	1,327.80	6.73%
	Pulu Panjang	50.87%	1,336.20	4.98%

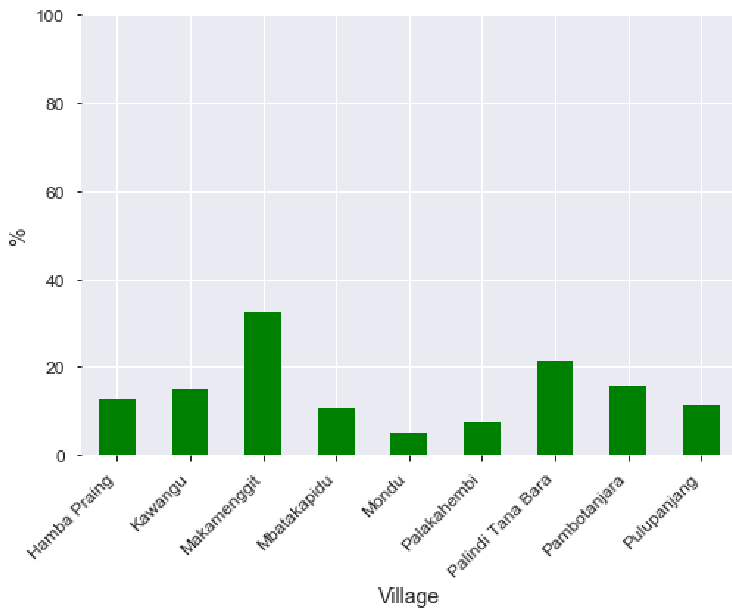


Figure 7: Locals who prefer to pay 7,000 rupiah for a gallon of treated water compared to boiled water

6.2.3 Social and Culture

6.2.3.1 Tradition and Animals Animals are an integral part of Sumbanese lifestyle and attempts of separating them for locals have not been made. More specifically, out of all animals, pigs are very important since they are used as sacrifices and are quite expensive. One of our interviewees, Ahas, is researching the culture and religion in East Sumba. He mentioned that "the religion is less important than the tradition, so they will follow their traditions even though it has conflicts with their religious beliefs". The fear of punishment from their ancestors makes people follow it passionately and embracing a habit which is not in agreement with the tradition is very unusual. The outcry of local community and the fear of stigma are some other deterrents of habit changes. He believes that changes of mindset starting from the school is the only solution. Only changes in that level can bring the desired outcome compared to the other quick-fix solutions which are superficial and not effective.

Tradition and locals' habits are arguably parameters of great importance and it is not possible to be omitted of this analysis.

6.2.4 Water Treatment Behaviour

A section of the survey is devoted to locals' habbits and the main goal is to reveal their influence on locals' behaviour and mindset towards water treatment. First of all, the objective of the first questions was to check if the locals are aware of the impact of drinking untreated water on their health. In half of the villages, only around 50% of inhabitants is aware of the fact that poor water quality can cause diarrhea (Table 6). Thus, this is an indication that the health agency or the health posts may not sufficiently inform the locals or the majority of the locals are not willing to join events about health promotion. Palindi Tana Bara is the village with the highest score (around nine out ten inhabitants are well-informed about the reasons of diarrhea) and the opposite holds in Mondu where the percentage is only 55%.

The reasons why locals do not treat the water were investigated using the survey as well. In six out of the nine studied villages, taste is very important and above 70% of the sample size in these villages takes it into consideration regarding the water treatment. For all villages, it is at least 60% and Kawangu has the lowest figure. This is in line with previous research in South India and the reason is related to the pots which they use; many pots have been used for many years and some metal has been leached giving a nasty taste to boiled water or some left-over particles from previous cooking have been remained in the pot which make boiled water having a peculiar taste [65].

A striking finding is that health is less important than taste on the decision of treatment drinking water in all villages except Kawangu, Palindi Tana Bara and Pulu Panjang. Pulu Panjang is the only village at which health is more important but the difference is subtle (less than 3%). A possible explanation for Palindi Tana Bara and Kawangu is that because they are closer to Waingapu, the probability of their inhabitants to visit hospital is higher and as a result they consider health as a top priority.

Also, it was found that inconvenience is not a primary reason in the decision of treating the water. Boiling the water using woods which had been gathered from nearby fields was not considered as a tiresome task by locals and did not influence their decision. The percentage of inhabitants which considered convenience as important was around 25% in most villages. Palindi Tana Bara is one of teh village villages with the highest percentages (42.9%); springs and trucks are main sources of Palindi Tana Bara, so locals need to walk long distances and carry the water back to their household or to pay for trucks and as a result the convenience is important for them. On the contary, Pulu Panjang has a low value and this is related to the fact that springs are very close to interviewees' households (see Fig 6) which means that it is not required for villagers to put a lot of effort to collect water.

Another worthwhile point is the influence of the doctor, village head and relatives on health issues which is depicted in Figure 8. For all villages except Mbatakapidu, the majority of inhabitants trusts the doctor but the percentage is not very high if Palindi Tana Bara is not taken into account (its range is between 56.4-68.3 %). The sample size of this village is quite small, so it is not representative. On the other hand, only in two villages (Kawangu and Mbatakapidu), the village head has some influence but it is limited (under 5%). However, the deep interviews showed that locals can embrace the diversity and they are not oppressive towards friends who select to drink treated or untreated water. For instance, in social events, in Mondu, it is common that the host asks the guests what kind of water they want to drink. However, many locals highlighted that it is not that common a host who drinks raw water offers boiled water to the guest. In general, based on the qualitative interviews, families have the same preference towards the treatment of drinking water. It is rare to see one person in a family that drinks raw water when the rest of the family drink treated water, and vice versa. However, it is a different situation when it is about traditional ceremony. People expect everyone to follow the tradition, this leads the the lower wealth level that will be explained in section 6.2.5.

Figure 9 shows that the percentage of its residents who believe that lack of the water is the reason for not using the toilet ranges from 15-35% and Palakahembi has the lowest percentage. Another interesting finding is that the belief that a son in-law is not allowed to use the same toilet as his in-laws is applicable not only in Sumba but in African countries (Zambia and Ghana) [66], [67].

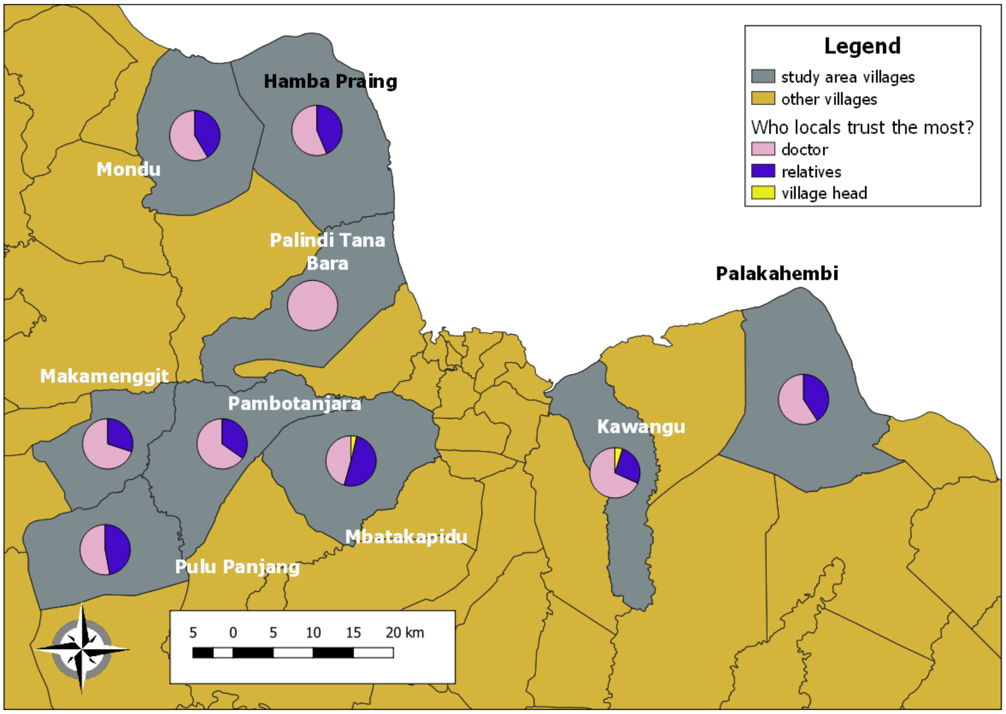


Figure 8: The influence of doctor, village head and relatives on locals regarding health issues according to their own opinion

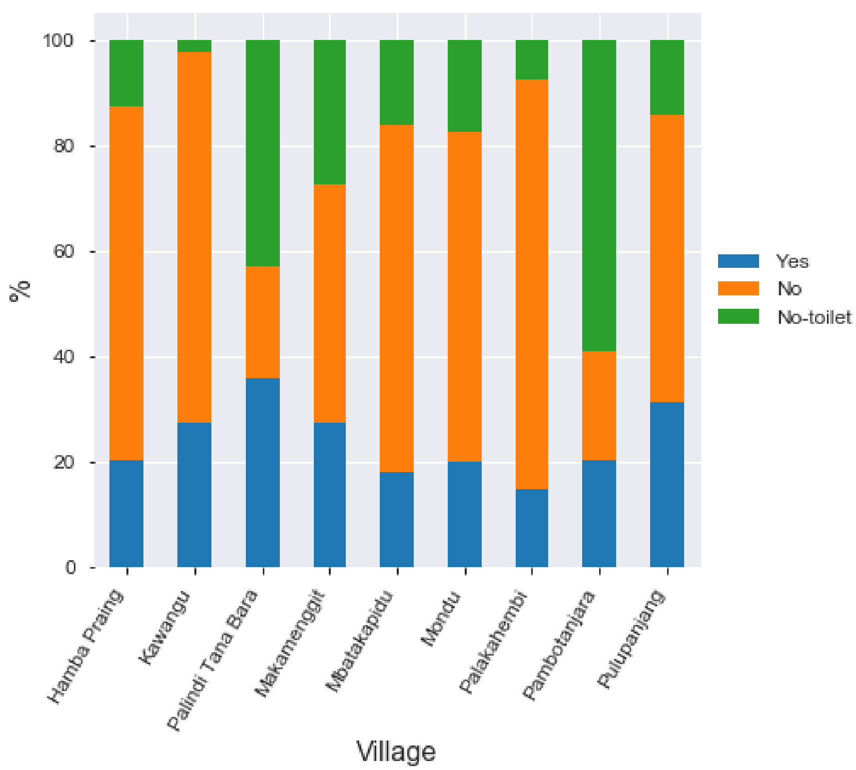


Figure 9: The answers of locals to the question: "Is the lack of water the reason for you not using the toilet for defecation"

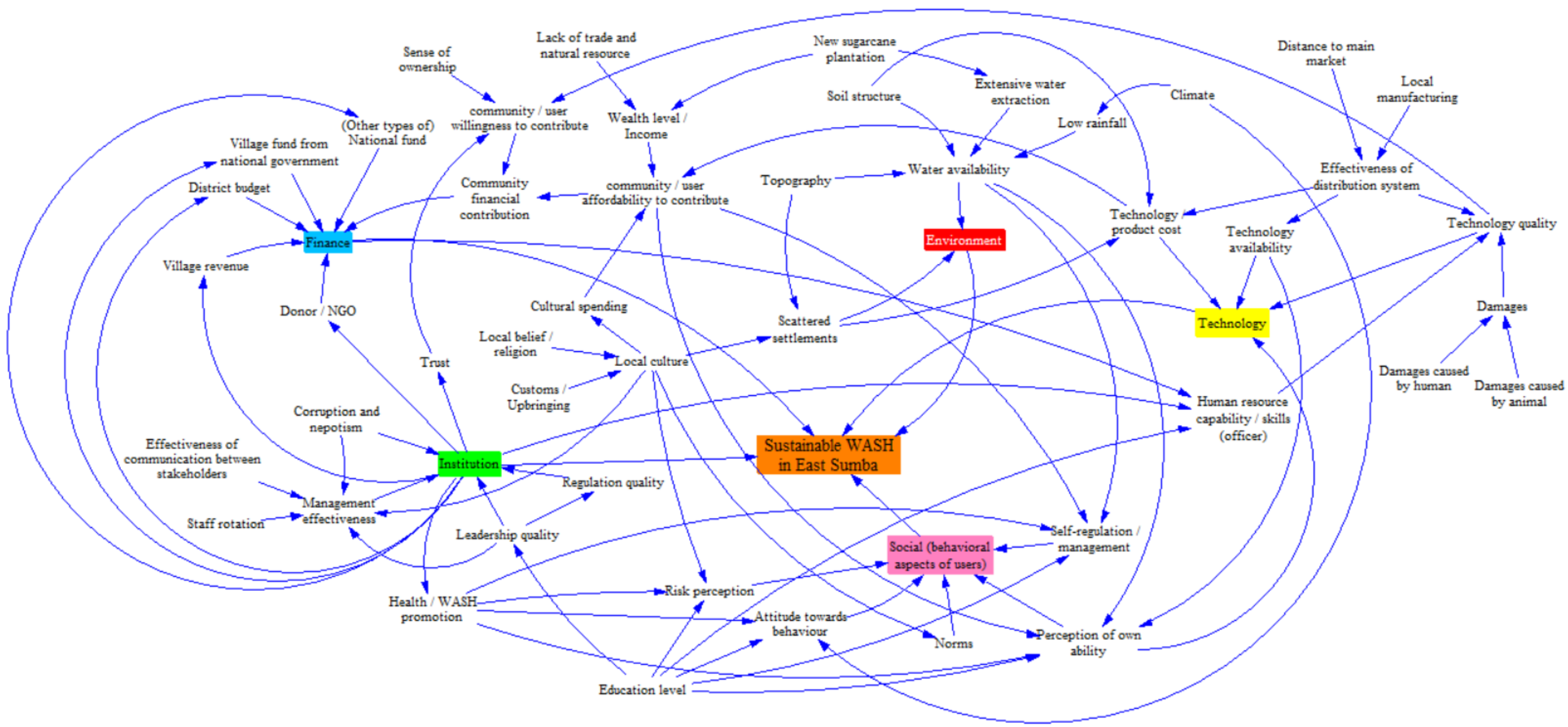


Figure 10: Conceptual diagram for WASH condition in East Sumba. Made in collaboration with Daniel [68].

6.2.5 Concept Diagram of WASH Condition

Figure 10 shows general information about the WASH condition in East Sumba. The links between variables are identified from the information gathered during interviews and discussion with the different stakeholders. Feedback loops are not incorporated in the diagram due to insufficient information. Moreover, the creation of the diagram was not done together with all stakeholders in one place. Connections found were confirmed by asking the stakeholders during interviews. However, the concept diagram is useful to provide information about the general situation in the area.

The sustainability of WASH practice in East Sumba is explained by five main factors, such as financing of the WASH program, institutions that monitor the program, environment in the area, technological options available, and social behaviour of the locals towards the program. The root causes to the situation in Sumba that affect these four factors are believed to be low education level, culture, weak economy, and geography.

First, the low education level reduces the available human resource capability in the area. East Sumba is unable to effectively manage its institutions due to weak leadership and and low skilled staff. This in turn causes weak policy and regulation. Corruption and nepotism are prevalent in the area, which further weaken the institution quality. Moreover, low skilled staff reduces the options of technology available to be used. Lastly, it affects the locals in term of risk perception, attitude, ability, and self-regulation, which hinder the social aspect towards WASH practices.

Second, East Sumbanese customs and religion have a deep influence to the people. Tradition such as mother in-law cannot be in the same room or use the same toilet with the son in-law impede attempts to reduce open defecation. Similarly, upbringing is one of the reasons for refusal to drink treated water. Furthermore, local ceremonies are expensive, especially the burial ceremony. Locals often save money for years and sometimes decades to be able to afford the provisions needed for the ceremony. This is done while the corpse of the deceased is stored in their house throughout the years.

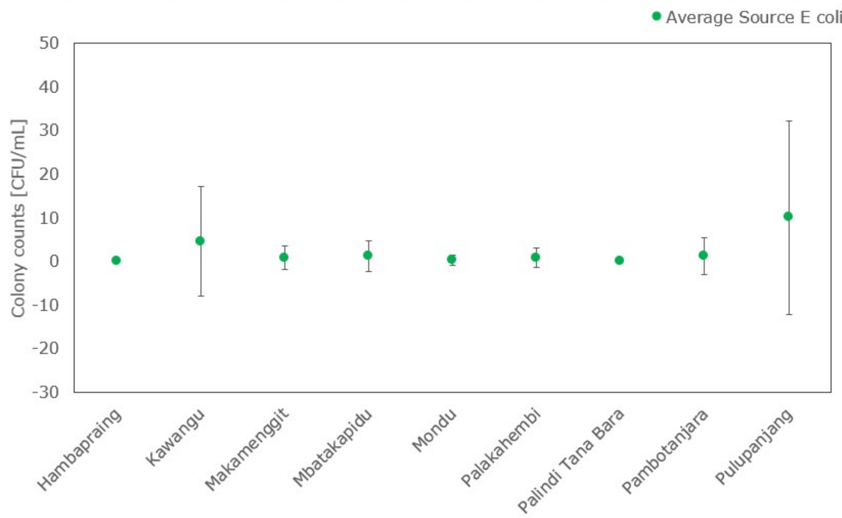
High cultural spending combined with the weak economy further reduces the wealth level of the region. The local government depends on the national government subsidies. The region produces agricultural products, cattle, and traditional clothes. The island has a significant deficit in trade and obtaining products from outside of the island is expensive. Most of the subsidies are allocated for community empowerment in term of creating local business and infrastructures and little is spent towards the WASH project. Contributions from locals are insignificant due to the low wealth level of the region.

Lastly, East Sumba is hilly and dry. In the hills, it is hard to build infrastructures from the water source to the settlements. Furthermore, settlements are spread out. There is a tradition dating back to warring period of the island where their ancestors built houses on top of the hills as it is easily defensible and provides a good view of the area. Unfortunately, these hills are far from rivers and water springs. Moreover, the climate is dry and hot; one of the main reasons the locals do not like boiled water is that they feel it is not refreshing.

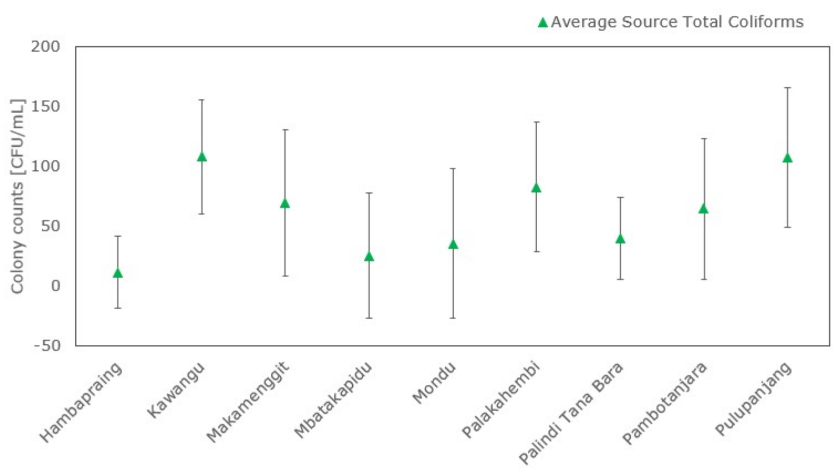
6.3 Water Quality and Sanitation

6.3.1 Microbial water quality

Figure 11a and 11b show the average of water source quality in different villages. In terms of *E. coli*, in average Hamba Praing had the best quality of water source, followed by Palindi Tana Bara and Mondu. The error bars show the standard deviation of the results. In Kawangu and Pulu Panjang, the standard deviations are quite broad. Big standard deviation indicates the huge variance in the data, which implies that the quality of water sources in Kawangu and Pulu Panjang villages differ a lot between the households. It should be highlighted that some households had *E. coli* concentration which is way higher than the average. For example, in Pulu Panjang, one sample had *E. coli* concentration concentration of 68 CFU/mL and in Kawangu, one sample had 63 CFU/mL of *E. coli*. These distinctive results lead to the board standard deviation. Even though the standard deviations showed negative colony counts, of course this does not necessarily mean that there were samples with negative colony counts. It showed that the water sources quality in one village varied. However, the calculated median value (not shown in the Figure) shows that almost all villages have approximately 0 CFU/mL of *E. coli* in their water source, except Kawangu. This result is a good indication that most water sources used by the households in the area of study were not contaminated by *E. coli*.



(a) *E. coli* concentration in water sources in different villages



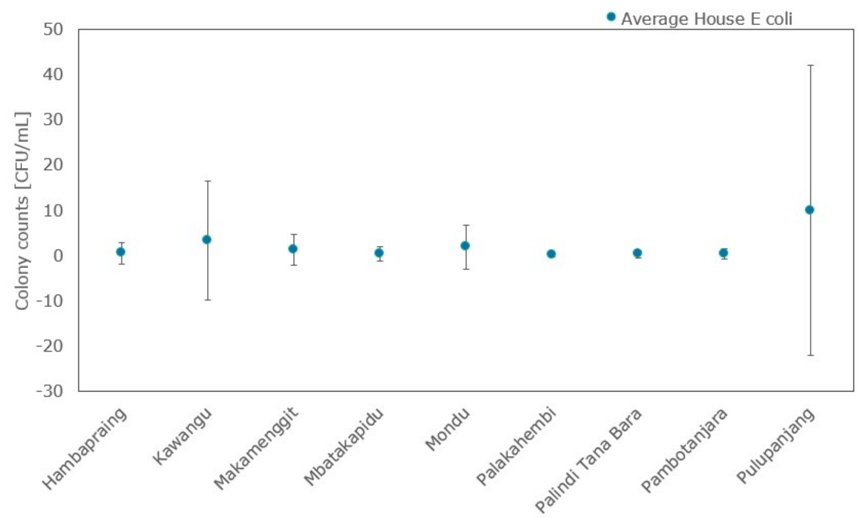
(b) Total coliforms concentration in water sources in different villages

Figure 11: Microbial water quality of water sources

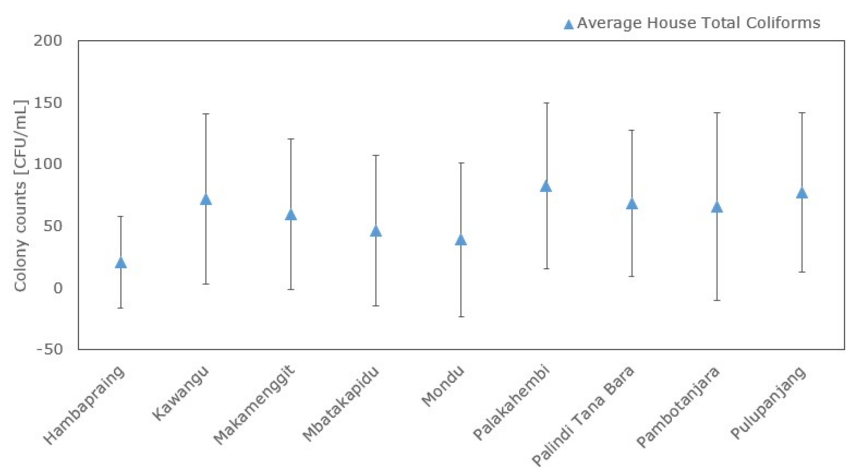
As can be seen from Figure 11b, Hamba Praing was also the best in terms of total coliforms quality, followed by Mbatakapidu and Mondu. These results are interesting, because Mbatakapidu is the water source for the city of Waingapu, yet it turned out not having the best microbial water quality. In comparison to *E. coli*, both average and median values of total coliforms are higher, which indicates that the water source might have contaminated by coliforms bacteria. Despite the fact that total coliforms cannot be used as faecal indicator, the existence of coliforms indicate the uncleanliness of water systems [36], even though total coliforms bacteria are common in the environment and typically not dangerous [69]. However, USEPA suggested that the test for samples containing positive total coliforms must be repeated three times within 24 hours. One repeat sample must be collected from the same tap as the original sample, one repeat sample must be collected from within five service connections upstream, and one repeat sample must be collected from within five service connections downstream. This needs to be done to ensure if the water system is contaminated or not [70]. Nevertheless, because of the time and material restraints, it was impossible to repeat the experiment.

There were 31 out of 276 samples (approximately 11%) that showed too numerous to count (TNTC) in terms of Total Coliforms. As has been described in section 5.4, these samples are described as 150 CFU/mL. The highest average and median values of total coliforms were found in Kawangu and Pulu Panjang villages, that reached up to 108 and 107 CFU/mL in average and 122 and 150 CFU/mL in median of total coliforms bacteria. In general, the worst water source quality was found in Pulu Panjang and Kawangu, both in *E. coli* and total coliforms concentrations.

Figure 12a and 12b shows the results of microbial quality at households level. Surprisingly, microbial water quality at the households level was found to be similar with the quality at the source, even though the water is treated. This is probably caused by the fact that it is not only the treatment of water that affects the microbial water quality at households level, but also the handling during collection and transport, and also cleanliness of the storage [71]. Palakahembi, Palindi Tana Bara, and Pambotandjara had the lowest concentration of *E. coli* at household level, while Hamba Praing, Mondu, and Mbatakapidu had the lowest concentration of total coliforms.



(a) *E. coli* concentration in households level in different villages

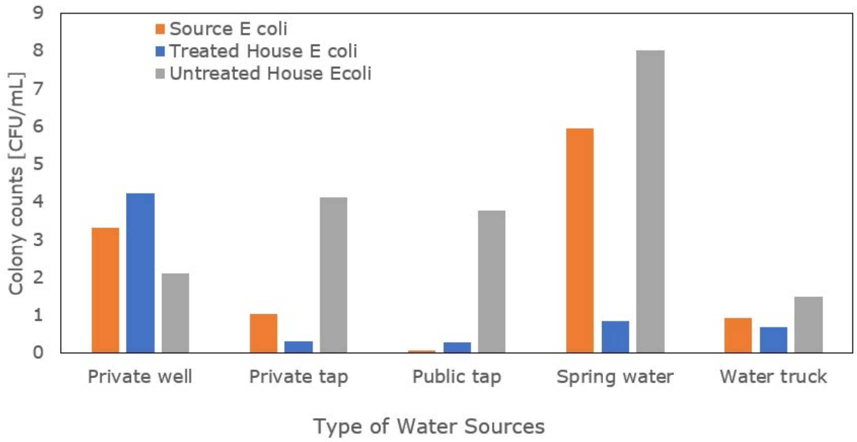


(b) Total coliforms concentration in households level in different villages

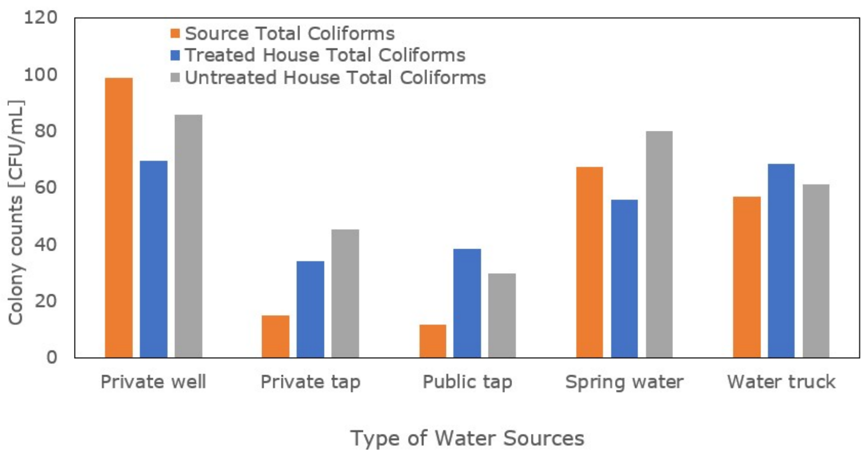
Figure 12: Microbial water quality of households

To better see the different quality between water sources and households level, the plot of microbial water quality from different types of sources and the concentration in houses, both after treatment and without treatment is given in Figure 13a and 13b. It is apparent that public and private taps have the best quality of water compared to other water source types. This also explained why Hamba Praing village has the best water quality. In most cases the concentration of *E. coli* in treated water is lower than in untreated water, with the exception for private well. This indicates that treating water has significant impact in preventing the growth of *E. coli* in water storage at houses. The distinctive result in private well where the concentration of *E. coli* in houses that treated the water is higher than untreated one might be caused by bad practise of household water treatment, for example, when boiling of the water is done using a dirty pan or when the water is stored in uncovered storage. Furthermore, the higher concentration of *E. coli* in houses than in sources shows that there might be contamination that occurred in the houses itself, probably in the water storage tanks. In terms of total coliforms, generally the concentrations in the houses are higher than in the water sources, except for the private well. The difference in the private well may be caused by the fact that the initial concentration of total coliforms in the source was high and some bacteria died during the storage. However, in other sources, when the initial concentration of total coliforms are relatively low, growth may occur in the water storage. The occurrence of total coliforms in water storage can be caused by the growth of biofilms, which is promoted by the presence of organics and nutrients in the water [72, 73]. Biofilms may formed when the water storage is not cleaned regularly, as the interview showed that only approximately 41% respondents cleaned their storage containers oftenly and approximately 54% cleaned using soap oftenly. Another factor that influences the water quality inside the water storage is the duration of water storage days, as previous study revealed that potential health risk increased if the water is stored for more than 3 days [74].

Apart from boiling, another option that can be done to treat water and avoid recontamination in the water storage is by using solar disinfection (SODIS) technique. The SODIS method is suitable for treating drinking water in developing countries. Clear PET bottles are filled with water and exposed to direct sunlight for at least 6 hours. The UV-A rays will kill germs such as viruses, bacteria, and parasites. Studies have proven that the use of PET bottles in the SODIS method is non-toxic. The claim that drinking water stored in PET bottles exposed to sunlight can lead to cancer is not encouraged by any scientific evidence [75, 76]. SODIS bottles were distributed as part of the project, so future research can look into the applicability of SODIS in East Sumba.



(a) *E. coli* concentration in water sources in different villages



(b) Total coliform concentration in water sources in different villages

Figure 13: Water quality of difference water sources and at households level (treated and untreated)

6.3.2 Sampling method

The water samples that were taken had a volume of 1 mL, as described in 5.4 whereas the guideline from WHO is to use a 100 mL filtered sample [36]. In this research, the vacuum and disinfection materials required for filtering were not present. Therefore, limited resources were the reason for choosing this lower volume, as 1 mL can be directly pipetted on the compact dry plate and a filter kit is not needed [56]. In areas where resources are scarce, this method may be the only applicable one. However, the known acceptable number of colonies in a culture plate is ranged between 30-300 CFU [77]. As a consequence, this method is most useful for surveillance monitoring if the majority of samples are known to be contaminated [78]. It is therefore possible that the *E. Coli* samples in this research include some false negatives. This also goes for the total coliforms, but to a lesser extent, as they occur in larger quantities. Approximately 10 % of the samples was triplicated and their standard deviations calculated. The mode, minimum, maximum, and percentage of 0 standard deviation were tabulated. The summary of standard deviation analysis for all triplicates is presented in Table 10. Based on Table 10, standard deviations of *E. coli*, both in source and house, seem better than the standard deviations of total coliform. Nearly 60% of *E. coli* samples have standard deviation of 0. The maximum standard deviation of source *E. coli* is 10.41 CFU/ml and the one at house is 8.38 CFU/ml. However, as is was discussed above, due to expected false negatives these data are not reliable, because errors may propagate through the triplication. On the other hand, the more abundant presence of total coliforms bacteria makes them comply to the condition for which 1 mL samples are accurate:

most samples are known to have positive coliforms. The total coliforms data seem to vary a bit more, as the percentage with a standard deviation of 0 is rather low and the maximum standard deviation is fairly high. However, the total coliforms distribution gives a more realistic indication of the measuring error. The presence of many TNTC plates for total coliforms contribute to this observed error. All in all, despite the small standard deviation in the data for *E. Coli*, they cannot be fully trusted, because of the limitations that occurred during the research. The total coliforms replication thus gives a more realistic view of the standard deviation in the samples. However, whenever possible, it is highly recommended to keep the lower limit of 25 CFU per plate to minimise the error in bacteria counting, which can be done by following WHO guideline [79, 36].

Table 10: Standard deviations of triplicates. The units are in CFU/ml unless stated otherwise.

Standard deviation	**Source E. coli**	**Source Total Coliforms**	**House E. coli**	**House Total Coliforms**
Mode	0	0	0	0
Minimum	0	0	0	0
Maximum	10.41	74.44	8.38	103.24
Occurence of a standard deviation of 0	21	6	22	12
n data	35	35	37	37
% samples with a standard deviation of 0	60	17	59	32

6.3.3 Prediction of chance of microbial drinking water contamination

In order to show a visual representation of the relationship between the source and storage (household level) conditions of drinking water, a Bayesian Belief Network was constructed. The models can be found in Appendix D. This BBN is built with the assumption that contamination in drinking water at house is affected by contamination in storage, contamination in water source, and contamination from household water treatment. This assumption follows the literature which suggest that the quality of drinking water in households in developing countries is affected by the aforementioned factors [36, 74, 71]. The anticipated result is as follows:

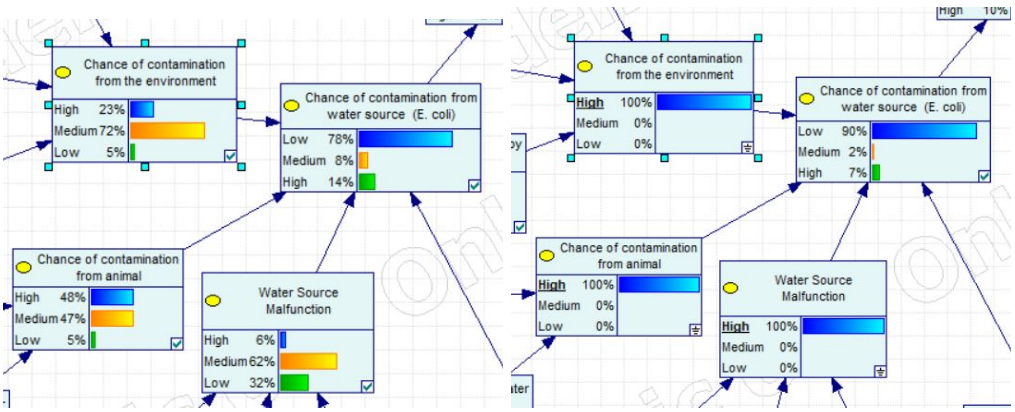
- The worse quality of environment in water source will lead to higher chance of contamination in water source. Eventually, the worse quality of water source, the worse habit in managing the water storage, and the worse practise of household water treatment will result in higher chance of contamination in drinking water.
- The better quality of environment in water source will lead to lower chance of contamination in water source. Eventually, the better quality of water source, the better habit in managing the water storage, and the better practice of household water treatment will result in lower chance of contamination in drinking water.

Two separated BBN models were developed, one using *E. coli* as indicator of drinking water quality and one using total coliforms. As *E. coli* serves as better indicator for microbial drinking water quality [80], that one is discussed first.

E. Coli As can be seen from the BBN model, only 12% of the people who participated in this research had a high chance of microbial contamination of their drinking water and 7% had a medium risk. These numbers do need seem extremely alarming at first sight, but when thinking about it, this shows that almost 20% of people do not have access to drinking water that complies with the WHO guidelines. In addition to this, there is a possibility of false negatives in the water quality information as is discussed in section 6.3.2. This means that in reality, the situation could be worse than what is displayed by the model. In other words, there is possibility that in reality there are more samples that had *E. Coli*, but it was not detected due to the small volume of the samples.

The uncertainty of microbial water quality data becomes clearer when playing with the BBN model. When zooming in to the chance of contamination based on the *E. coli* count in the water source, higher chances of contamination from the environment of the source resulted in lower chance of contamination from water source as illustrated in Figure 14. This goes against both common sense and the WHO guidelines [81].

Hypothetically, when the condition in the environment around the water source favors the chance of contamination in the water source, there will be high chance of contamination in the water source, namely high concentration of *E. coli*. As an example, if the water source is located nearby a latrine and it is found that there are many garbage or excreta around, then the chance of contamination in water source must be high. However, this is not the case as shown in Figure 14.



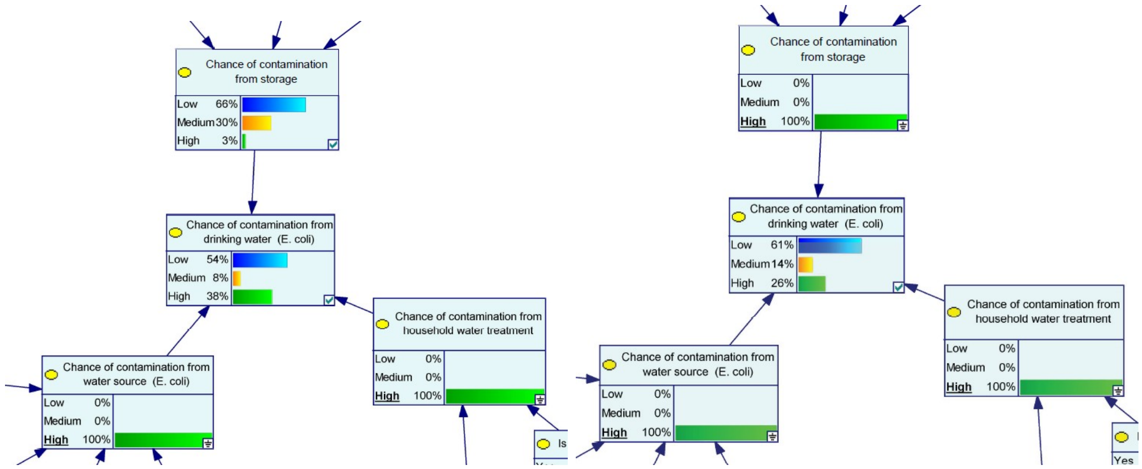
(a) Real results **(b)** Hypothetical (incorrect) model

Figure 14: The model displaying the results directly from sanitary inspection and *E. coli* counts vs the hypothetical (incorrect) display of microbial quality when all parent nodes are manually set to a high chance of contamination

When the chance of contamination from water source and chance of contamination from household water treatment are set to high, the chance of contamination from drinking water also increased. This result is as expected. However, when the chance of contamination from storage is also set as high, the chance of contamination from drinking water decreased. The results are shown in Figure 15 to give clearer idea. It was expected that when all three nodes are subject to "high", the chance of contamination will be higher, but it turned out that the BBN showed different result. This might be caused by the uncertainties of the validity of the microbial water quality analysis due to the small volume of sample that was used (1 mL) and a too high detection limit. BBN worked by learning the input data as described in Section 4.4, however, the real data did not match with the expected results. As an example, one household in Kawangu village reported this information during interview:

- leakage in the water source
- there are some excreta around the water source
- they only clean their water storage occasionally
- the water sample taken from the house was not treated at that time

With this information, it was predicted that the water quality at both source and house would contain numerous amount of *E. coli*, but it turned out that both showed 0 CFU/mL. These mismatch data resulted in such a delicate model.



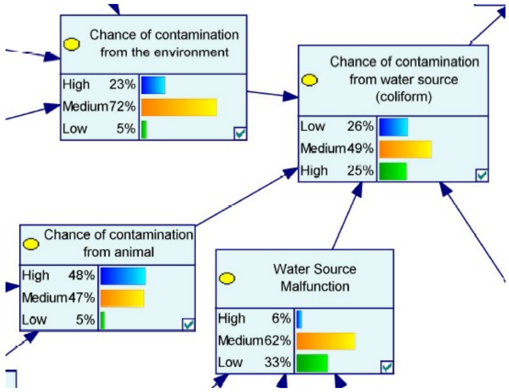
(a) Result when chance of contamination from water source and household water treatment are set to high

(b) Result when chance of contamination from water source, household water treatment, and storage are set to high

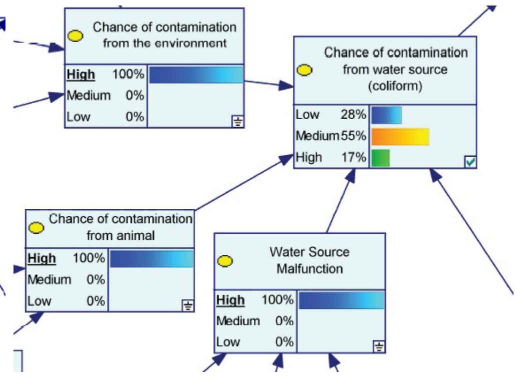
Figure 15: The model displaying the results when some nodes are modified into high chance of contamination. The result in (a) goes with the expectation, but (b) is peculiar

The BBN model using *E. coli* as an indicator organism has shown some weaknesses. What can still be seen from the model is the percentage of people that lack basic protection measures for their source, collection, and storage for drinking water. This is the case, because the probability table in the outer nodes are based directly on the SI. The arrows between the nodes still indicate which nodes are influenced by these outer nodes, but the calculated relationship between the two are incorrect.

Total Coliforms As total coliforms bacteria were more abundant in the water that was sampled, it is not suffering as much from the detection limit of the testing method. Even though total coliforms are less suitable as indicator of faecal contamination, it is still useful as indicator for cleanliness of water distribution system [36]. This was the motivation to create a BBN model using coliform bacteria. As can be seen from the BBN model in D in Figure 32, 29% households were in high chance of contamination and 54% were in medium. It is substantially higher chances of contamination compared to the *E. coli* one, which is obvious, because more samples were positive in coliforms. To ensure that the model works properly, some manipulations were done to the model. The similar settings as done to the *E. coli* model were applied. The results are given in Figure 16. Surprisingly, the chance of contamination of water source went down when the chances of contamination from the environment, animal, and water source malfunction were set to "high". This result is similar with what attained in *E. coli* model. The error in this model can also be explained with the reasons mentioned in *E. coli* section. Once more, the model was manipulated to see how the model behaves if the chances of contamination from water source, storage, and household water treatment were set to "high". The results are given in Figure 17. It seems that the model of using total coliforms worked better than *E. coli* model. When chances of contamination in water source and household water treatment are set to high, the chance of contamination from drinking water increased into 61% high chance. Similar trend is achieved when chances of contamination from water source, household water treatment, and storage are set to high, as the chance of contamination from drinking water increased even more into 81% high chance. These results are in line with the expectation, and it is evident to conclude that BBN using total coliforms worked better. Unfortunately, the data from household water treatment node tend to give inconsistent results. This means that also this model still contains flaws and is not usable as a predictor for intervention measures.

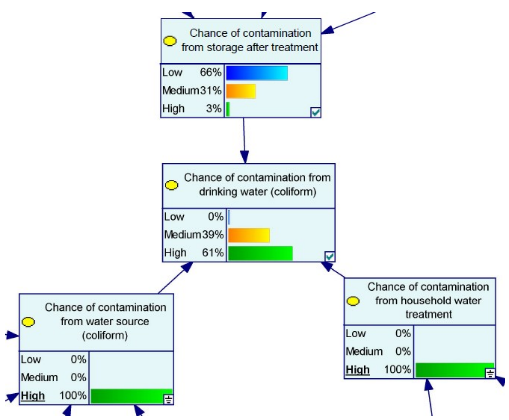


(a) Real results

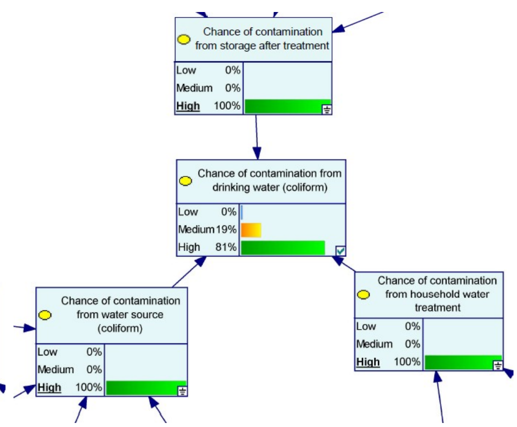


(b) Results when chances of contamination in water source are set to high

Figure 16: The model displaying the results directly from sanitary inspection and total coliforms counts vs the manipulated model when chances of contamination in water source are set to high



(a) Result when chances of contamination from water source and household water treatment are set to high



(b) Result when chances of contamination from water source, household water treatment, and storage are set to high

Figure 17: The model displaying the results when some nodes are modified into high chance of contamination. Both (a) and (b) show the expected results

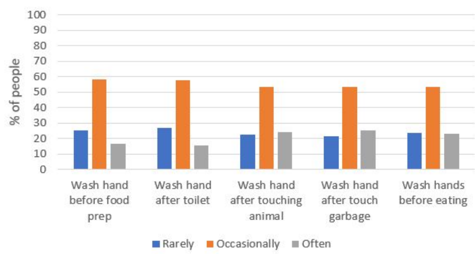
Even though the BBN using total coliforms still resulted in some distinctive results that can hardly be explained, it is preferred as it can better explain the relationship between the nodes. Furthermore, this BBN can also show the general overview about the condition of drinking water quality and factors affecting it in the study area. Some improvements must be done to boost the validity of the BBN. This can be done by using filtration method for microbial water quality analysis, taking more sample or increase the number of triplicates to improve the reliability of the data, and incorporating expert judgement to the BBN.

Sensitivity Analysis BBN can also be used to do sensitivity analysis of the model to see the most sensitive variables to the final target variable. In this study, the final target variable is the chance of contamination from drinking water node, both for the BBN using *E. coli* and total coliforms. The result of sensitivity analysis for BBN using *E. Coli* is given in Appendix D in Figure 31, and the one for total coliforms is given in Figure 33. In general, both of the BBNs have similar results in sensitivity analysis. Chance of contamination from storage, type of water source, and whether the water is treated or not are found to be the most sensitive variables. However, because some of the data were inconsistent, the sensitivity analysis is also not very accurate.

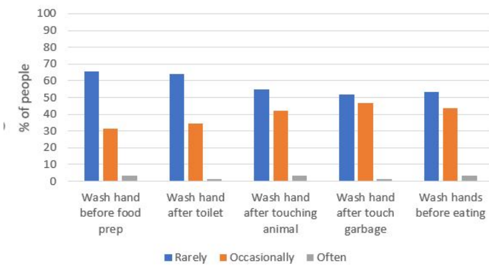
6.3.4 Sanitation and Hygiene Practises

The government of Indonesia has set the goal of Universal Access goal as stated in Indonesia's national midterm development plan. The Universal Access goals, commonly known as 100-0-100 goals, set that by 2019 there should be 100% access to safe drinking water, 0 slum area, and 100% access to sanitation in Indonesia to support the SDGs [82]. It should be highlighted that this goal is quite ambitious, known the fact that the improvement of sanitation in Indonesia is delayed, according to the achievement of MDGs[83].

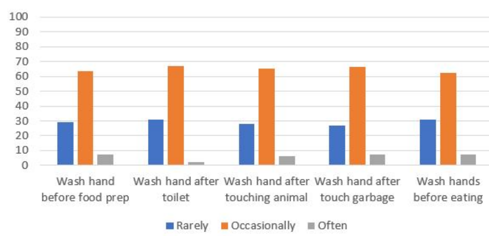
The sanitary inspection shows that in East Sumba Regency, many sanitary facilities are still lacking. To start of with handwashing facilities; almost 20% of respondents did not have any handwashing facilities. 43% only had access to water and 37% had acces to both water and soap. Figure 18 shows how the lack or presence of certain facilities influences how often people wash their hand before or after certain activities such as using the toilet. Of course it is easier to wash your hands if you have facilities to do so. This is clearly visible in the behaviour of people with different facilities. The lack of these facilities thus contributes to poor hygiene and thus higher chances of waterborne diseases.



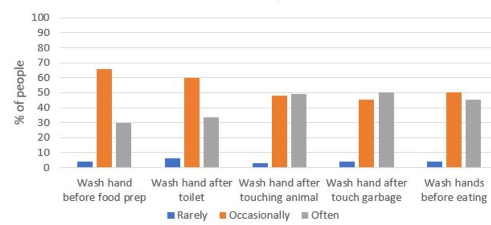
(a) General handwashing frequency



(b) Handwashing frequency among people with no handwashing facilities



(c) Handwashing frequency among people with water only



(d) Handwashing frequency among people with water and soap

Figure 18: Handwashing frequency among people with different facilities

Figure 19 shows the types of toilet owned by the respondents. Approximately 59% respondents still use poor sanitation facilities, which includes open defecation (33%) and unimproved latrines (25%). The other 14% use shared toilet, which is categorised as limited sanitation service by WHO and UNICEF [2]. Only 27% of the respondents have their own toilet. The attained result is in line with the study by Indonesian Statistical Centre (BPS) which stated only 35% residents of East Sumba have access to improved sanitation. The basic sanitation service level is defined as the use of improved facilities that are owned by each household; meanwhile the improved or the safely managed sanitation is defined as the use of improved facilities that are owned by each household, where excreta are safely disposed [2]. Of those 27% of the respondents have their own toilet, it was noticed that they do have septic tank, however, there is uncertainty if the septic tank was built correctly or not. Therefore, it is difficult to conclude if these people fall under the basic or safely managed category of sanitation services. 22% of people with their own toilet do not have water available at their toilet.

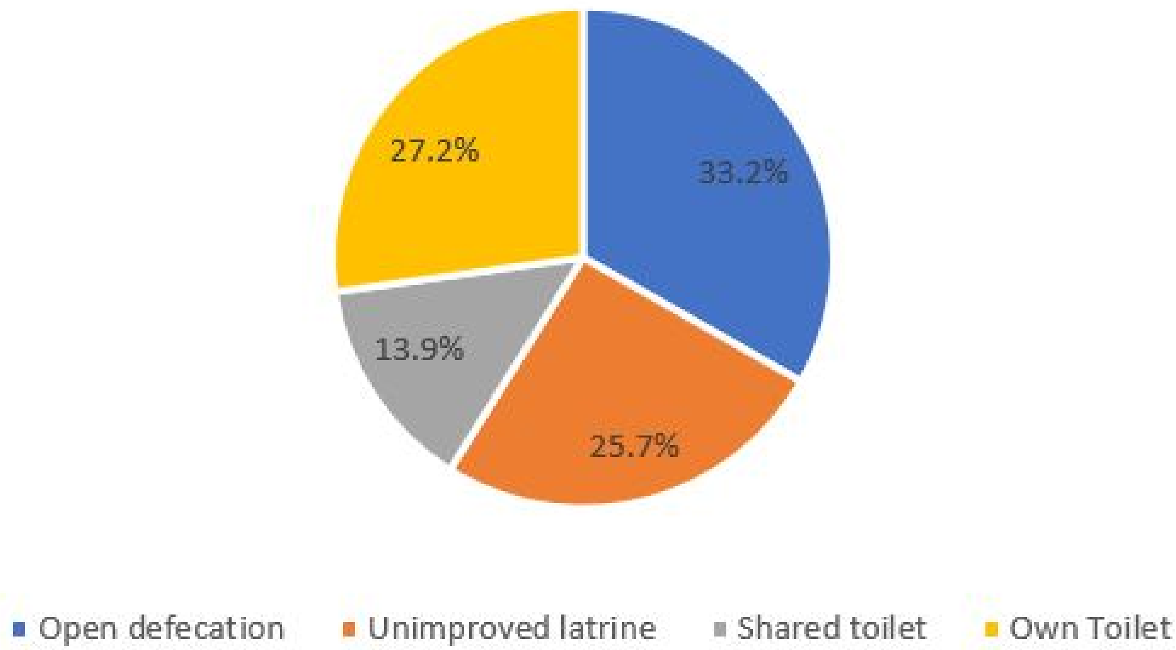


Figure 19: Toilet types

6.3.5 Distance to water source

Another factor that plays a role in hygiene and sanitation is not only the microbial quality and possibilities of contamination of the source or storage, but also the distance to the water source. Some respondents stated that their water sources are located too far, hence sampling in water source could not be done. Far away distance from water source, e.g. more than 30 minutes round trip walking, is considered equal to not having access to drinking water [36]. Those people are likely to have a very high public health risk from poor hygiene (as explained in section 6.3.4) and their basic consumption of drinking water may be compromised. The basic level of drinking water supply service, household water treatment, safe storage, and hygiene education should be prioritised to be given to households in the area [36]. Furthermore, Indonesian Government has set a goal to achieve universal 100% access to safe drinking water [84], and this study revealed that this goal has not been reached. It is also worth to mention that some respondents shared the same water sources with their neighbours (e.g. community well, spring river, and river). This implies that they do not have water services at their home, and this is contrary to the definition of safely managed drinking water [36].

6.4 Integrated Discussion

The stakeholder- and water quality analysis combined are used to explain the factors influencing WASH conditions and practices in East Sumba. The stakeholder analysis and concept diagram are used to evaluate the large-scale factors. For example, the stakeholder analysis identified the three key players (DinKes, PAMSIMAS, and village heads) that are important to maintain the continuation of the WASH program. Lastly, the subsequent water quality analysis is used to evaluate the small-scale factors that influence drinking water quality in each household such as household water treatment, water storage, and water source.

To elaborate, the three key players are important to improve the WASH conditions. For example, DinKes is responsible to promote the household water treatment and sanitary and hygiene practises in Posyandu and PUSKESMAS. DinKes can also include the promotion that keeping the storage container clean is important to maintain the good quality of drinking water. Secondly, PAMSIMAS designs and installs water distribution network for rural areas. Furthermore, village heads are respected by the locals, thus the village heads words can determine whether the locals will follow the promotions done by the DinKes and the plans made by PAMSIMAS. Village heads also interact with water boards and governments to work on maintaining the quality of water sources, because the quality of water sources contribute to the quality of drinking water at household level. The concept diagram was formulated to track the root factors such as low education, culture, weak economy, and geography. The low education blurs the perception of risk of untreated water in the eyes of the locals. The weak economy and high cultural spending reduces people's capacity to afford treated water and toilet. Moreover, geography causes the spread of settlements and increase the difficulties in building water and sanitary infrastructures.

7 Conclusions & Limitations

7.1 Conclusions

From this study, several conclusions can be derived. Based on data obtained from the interviews, stakeholders were identified, categorised, and their relationship determined. The influence interest matrix shows that DinKes, PAMSIMAS, BAPPEDA, and the village board are the key players. Similarly, the social network diagram shows that DinKes and PAMSIMAS are the central players as they connect the maximum amount of nodes for the shortest path possible between stakeholders. However, it is good to note that the village head (village government) is one of the crucial elements to maintain the connection between DinKes, PAMSIMAS, and the locals. This is because the locals are still adhering to the village head's words.

The information from the interviews can also be used to create a conceptual diagram that explains possible causes which contribute to WASH practises in East Sumba. From this diagram, it can be inferred that the four root causes of the inhibition of the WASH practises are: the low education level, weak economy, cultural or upbringing, and geographical conditions. To improve the WASH condition on the long-term basis, these four factors must be handled, especially education and culture. However, in the short-term, the application of boiling water, SODIS, and more promotion for health and sanitary practises can be done to increase WASH practises.

The chances of bacterial contamination were investigated using *E. coli* and total coliforms as indicators. In terms of *E. coli*, 14% and 12% of respondents have a high chance of contamination in their water sources and drinking water at household levels, respectively. Higher chances of contamination were detected in total coliforms, in which 25% and 29% high chances of contamination were documented in water sources and drinking water at household levels, accordingly. Household water treatment such as boiling seems to have a positive effect on the reduction of *E.coli* in the treated water, but not for total coliforms. This could indicate that treatment is not carried out effectively or that recontamination happens inside the storage tanks.

Regarding hygiene practises, approximately 20% of respondents did not have any hand washing facilities. Roughly 43% only had access to water and 37% had access to both water and soap. The study revealed that the lack or presence of certain facilities influences the frequency of hand washing activities. With respect to sanitary practise, approximately 59% respondents still use poor sanitation facilities, which include open defecation (33%) and unimproved latrines (26%). The other 14% respondents are listed under limited sanitation service due to the use of a shared toilet and 27% of the respondents have their own toilet, however, it is difficult to conclude if these people fall under the basic or safely managed category of sanitation services.

7.2 Limitations and Future Research

As mentioned in section 6 This research has limitations. For the stakeholders, many locals were unaware with the term "stakeholders", so the interviewers needed to give some examples of stakeholders before they were able to answer the question. This was suspected to affect their answers. For example, people tended to answer questions such as what do you think is the most important stakeholder by using one of the first examples given to them. In addition, more research can be done to obtain the weights of the connection between stakeholders. Moreover, a workshop with the stakeholders would be able to improve the accuracy of both the influence interest matrix and social network diagram. Further study can be done to determine the positive and negative causal link and the feedbacks between variables. Similarly to the previous point, a more extensive collaboration with the stakeholders can also be done to create a more representative causal diagram.

For microbial water quality analysis, one of the main issues in this research was the inability to follow WHO guidelines to do the sampling using 100 mL sample and membrane filtration technique. Low volume of sample may increases the errors in microbial water quality analysis, which influences the integration of sanitary inspection and microbial water quality data to predict the chance of drinking water contamination. Therefore, some improvements must be done to boost the validity of the BBN. Further research should be done by using filtration method for microbial water quality analysis, taking more sample or increase the number of triplicates to improve the reliability of the data, and incorporating expert judgement to the BBN. In addition to that, future research should fully investigate the condition of the toilet so the sanitation condition can be better categorised.

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A Questionnaires

A.1 Questionnaire of Semi-structured Deep Interviews for locals

Date:
Name of Interviewee:
Location:
X-coordinate:
y-coordinate:
Respondent's information (this part is specifically for household's respondent)
Location (village/sub-village):
Respondent's Name:
Household's head name:
Gender:
Age:
Occupation:
Religion:
Highest education:
No. of children:
Diarrhoea problem in the past two weeks:

General Questions

- If you have children, do your children go to school? How many of your children have graduated from secondary school?
- How many goats/cows do you have?
- How many fields/ how much land area do you have and what kind of crops?

Open Questions regarding the drinking water source

- What is your main drinking water source?
- Is it private or public (public well, private well, river)?
- Do you take the water from somebody else (water company, municipality)?
- For which uses do you consume domestic water and in what percentage?
- How much do you pay?
- Is your water resource reliable?
- How do you judge the quality of your water source and/or your drinking water?
- If the water deteriorates, what do you do?
- Who in your house decides on where to get the water supply?
- Who is responsible to bring drinking water to the household?
- Who do you think can influence and make a change in the drinking water quality in your region?

Water Treatment

- Are you satisfied with the current water quality?
- Who do you think in your house is in charge or responsible for the water quality that you have?
- Do you treat the water?

- If yes, how?
  - Is your method reliable?
  - Are there any problems related to the method which you use?
- If not:
  - Why don't you treat your water?
  - Can you think of any factor, such as culture, religion, that influence your decision not to treat the water?
- Is it expensive to treat the water?
- How much money are you willing to pay for treating drinking water?
- Do you boil your water?
- If yes?
  - What is your opinion of boiled drinking water?
  - Do you like the taste of boiled water?
  - Is it difficult to get all the resources which are needed to boil your drinking water?

Sanitation-WASH

- Are you satisfied with your hygiene situation?
- What kind of challenges do you face to do proper WASH behaviour?
- Who is the person (stakeholder) that can influence your WASH or drinking water habit?
- How often do you wash your hands?
- Have you ever got sick from the bad water quality ?
  - Are doctors or NGOs active to help in this case?
- Are you satisfied with the doctors services?
- Do you take advice about what to drink or not by the doctors?
- How important is the doctor's opinion for you on influencing your WASH behaviour?

Stakeholders Relationship

- Who is helping you most regarding water problems (doctors, municipality, water company, NGO)?
- Do you cooperate effectively with other stakeholders?
- Are you satisfied with the water service from the village?
- Do you know any NGO which is active in the village ?
  - If yes, do you think that NGO and health agency collaborate or they act independently?
  - Do you think that there is a smooth cooperation between local authorities (village head) and NGOs?
- Do you believe that all related stakeholders have similar goals or conflicting interests?
- Who do think is the most important stakeholder related to water resources/water management in this region?
- How could the problems regarding water be solved?
- Could you think some possible cooperation among stakeholders in the future?
- What changes would you like to apply in your region regarding water sanitation and drinking water?

A.2 Survey for locals

General Info
Date:
Name of interviewer:
The code of the house:
Name of person interviewed:
Name of the village:

Institutions

- Do you know if PROAIR/PAMSIMAS/other NGO/government has/had a water supply project in the village? [Yes/No]
- Do you know if water board exists in the village to manage water infrastructure? [Yes/No]
- Does the government or village provide help in funding water projects? [Yes/No]
- Every time you go to the hospital or health post, do the doctor or nurse ALWAYS ask you whether you treat your drinking water or not? [Yes/No]
- Who do you trust most in relation to health issue? [doctor/religious leader/village head]

Economy

- Are you willing to pay 5,000 rupiah per month for water? [Yes/No]
- Are you willing to pay 10,000 rupiah per month for water? [Yes/No]
- Are you willing to pay 25,000 rupiah per month for water? [Yes/No]
- Are you willing to pay 50,000 rupiah per month for water? [Yes/No]
- If it is easy to get, would you prefer to pay 7000 for a gallon of TREATED water compared to boiling your own water? [Yes/No]

Habits

- Do you think teething causes diarrhea? [Yes/No]
- Do you think water quality affects diarrhea? [yes/No]
- Is the lack of water the reason for you not using your toilet for defecation? [Yes/No/No toilet]
- If the government can help you, which one do you choose: water supply or education? [Water Supply/Education]
- Do you think that taste is the reason for you not treat or treat your drinking water? [Yes/No]
- Do you think that health is the reason for you not treat or treat your drinking water? [Yes/No]
- Do you think that your parents' teaching/habit is the reason for you not treat or treat your drinking water? [Yes/No]
- Is convenience the reason you do not treat the water? [Yes/No]

B Stakeholders Analysis

C Sanitary Inspection Questionnaire

A - Household's information
The code of the house:
Name of the person interviewed:
Household's head name:
Name of village:
Name of subvillage:
GPS:

B - Water Source

- What type of water source do you use for drinking water purpose?
- Which source do you use for drinking water purpose right now ?
- Do you take water sample at source?

C - Water Source Inspection

- Is there any chance for water/contaminants to enter the system/source ?
- Is there any leakage in the system/source (tap/piped/well/rainwater tank, etc.) ?
- Are there any damages/cracks in the system/source (tap/piped/well/rainwater tank, etc.) ?
- Is there livestock near the point of collection (POC), 10 m?
- Is there proper fencing or a barrier around the well to prevent contact with animals?
- Has the water supply been continuous over the past 10 days?
- Is excreta or garbage found within 10 m of the tap stand/water source?
- How often does the water supply not flow?
- Distance to nearest latrine (m)
- Is the area uphill from the source visibly eroded or prone to erosion?
- Water visual: clear or unclear?
- Water odor: unpleasant odor?

D - Water Transport or Collection

- How many containers do they have?
- How many times do you use this collection/transport container (in average)?
- How many of the collection/transport container are cracked?
- How many container that have unclean condition inside?
- How often do you clean the transport container?
- How often do you clean the container with soap?
- How many of the container are being covered (at that time)?
- When not in use, is the storage container kept in a place where it may become contaminated?

- Are the water storage containers kept above ground level/floor?
- Do you transfer the water after collection before treatment/boiling or before consumption?

E - Water storage after collection (before treatment or before consumption)

- How many containers do they have?
- How many of the collection/transport container are cracked?
- How many container that have unclean condition inside?
- How often do you clean the transport container?
- How often do you clean the container with soap?
- How many of the container are being covered (at that time)?
- When not in use, is the storage container kept in a place where it may become contaminated?
- Are the water storage containers kept above ground level/floor?
- Do you transfer the water after collection before treatment/boiling or before consumption?

F - Household water treatment

- Do you always treat your drinking water?
- Can you explain how do you usually treat your water / perform HWT / boil water?
- Is there evidence that treatment is being carried out ineffectively?
- What kind of evidence is there to indicate that treatment is carried out ineffectively?
- Do you transfer the water after treatment/boiling?
- Do you use different/specific storage than transport/collection storage, after doing water treatment?
- How often you drink untreated/unboiled water?

G - Water storage after treatment

- Is the collection/transport container cracked ?
- Is the inside of container clean?
- How often do you clean the container?
- How often do you clean the container with soap?
- Is the water storage being covered (at that time)?
- When not in use, is the storage container kept in a place where it may become contaminated?
- Is the drinking water storage container kept above ground level/floor?

H - Handwashing

- How often do you wash your hand with soap at this situation: After using toilet?
- How often do you wash your hands with soap at this situation: Cleaning child's bottom ?
- How often do you wash your hand with soap at this situation: After touching an animal?
- How often do you wash your hand with soap at this situation?: Touching garbage

- How often do you wash your hand with soap at these situation: Before eating?
- What kind of handwashing facilities does the household have?
- How clean are the parents nails?
- How clean are the child's nails?

I - Sanitation

- What types of toilet do you have?
- Does the toilet always have water?
- How is the cleanliness of the toilet/latrine?

J - Environmental Cleanliness

- Could you see flies around or on the water storage container?
- Is there livestock close to the house?
- Is there human or animal feces in the yard (or even inside the house)?
- How often do you eat raw food (especially vegetables and meat/fish)?
- How do they store the cooked food?
- How is the cleanliness of the house floor?
- Is there garbage around house?

K - Water Quality Sample: House/Storage

- Date + time (now/when you collect the water)
- Weather: Is it sunny/cloudy?
- Is the water treated?
- When was the water treated?
- How full is the water storage?

D Water Quality

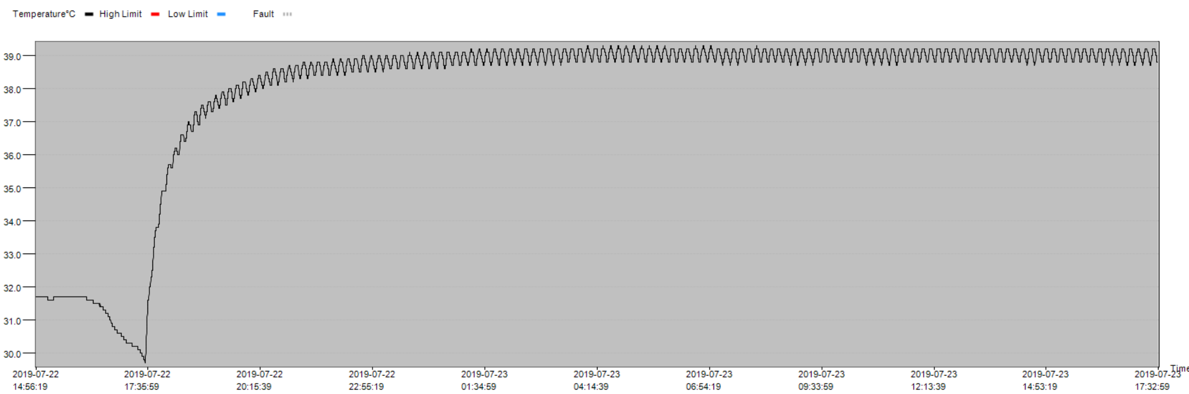

Figure 20: Incubator temperature for samples from Kawangu

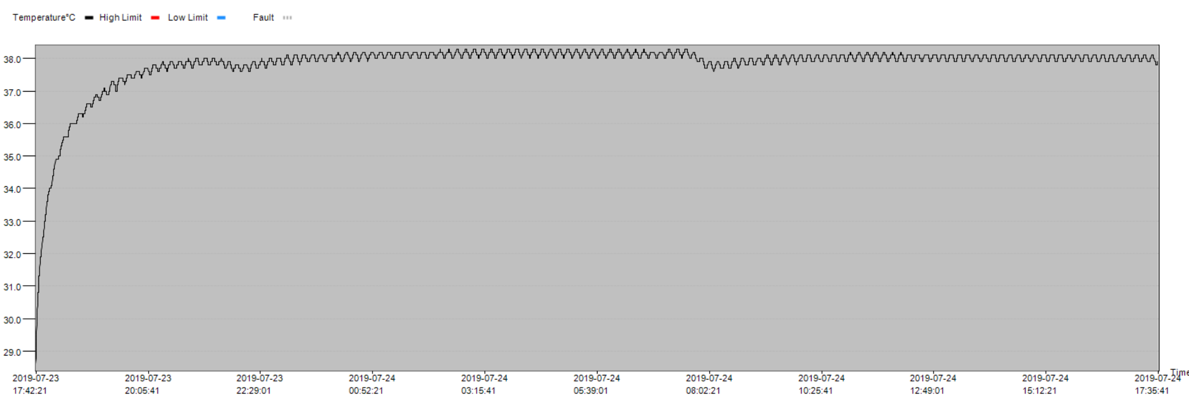

Figure 21: Incubator temperature for samples from Palakahembi

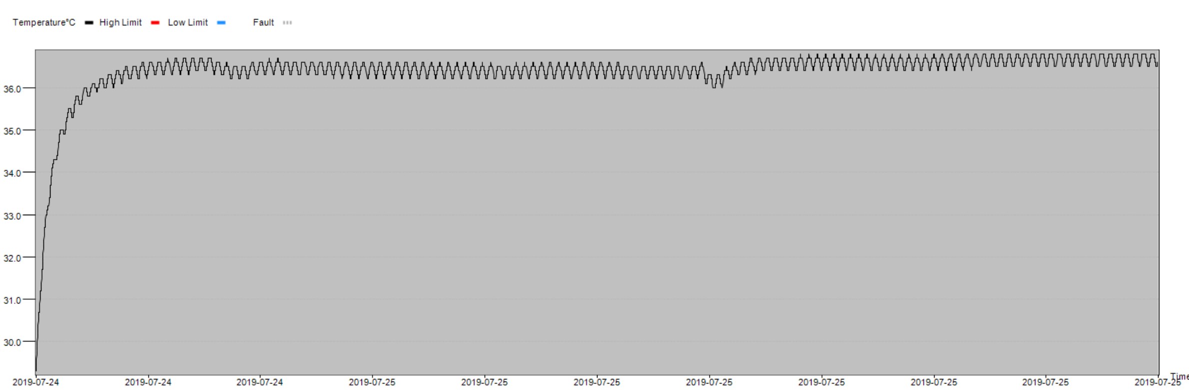

Figure 22: Incubator temperature for samples from Pulu Panjang

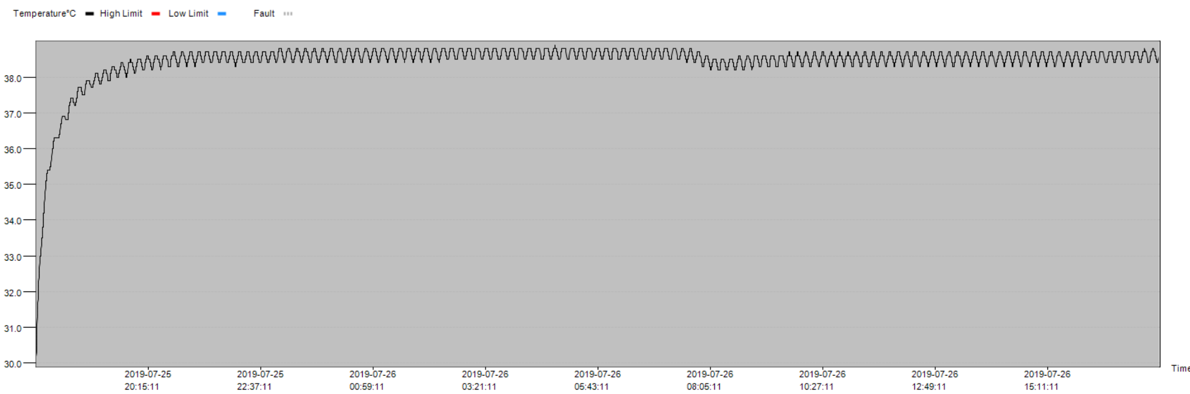

Figure 23: Incubator temperature for samples from Mondu

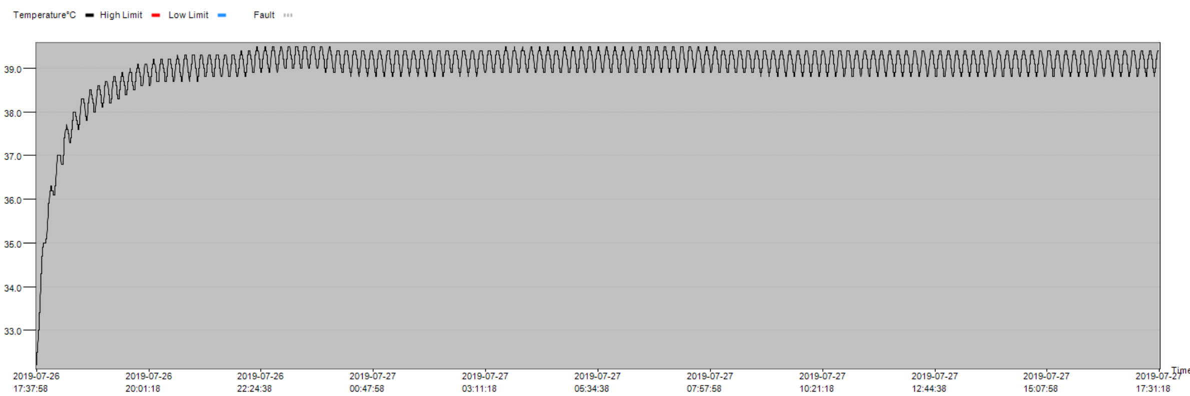

Figure 24: Incubator temperature for samples from Hamba Praing

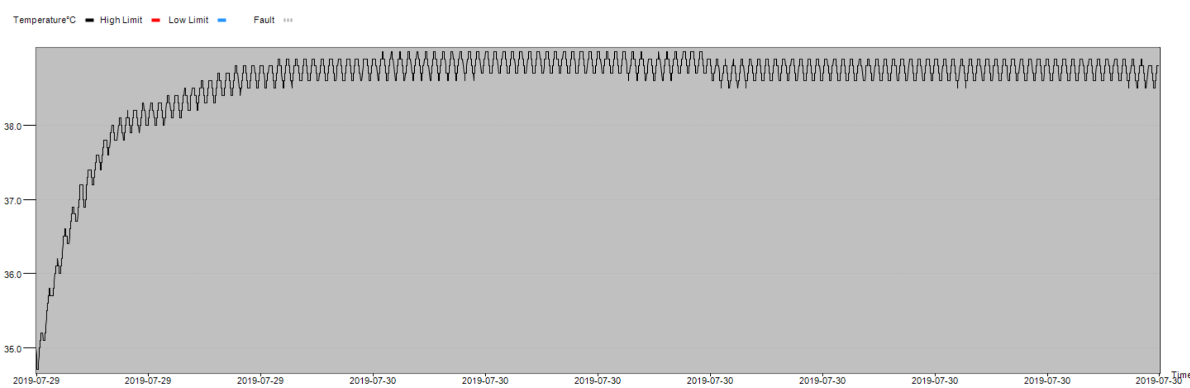

Figure 25: Incubator temperature for samples from Makamenggit)

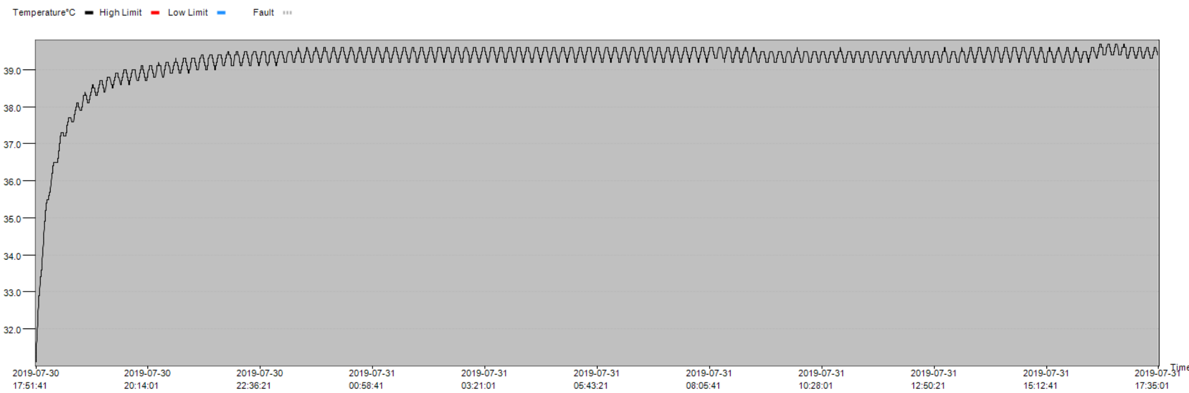

Figure 26: Incubator temperature for samples from Pambotanjara

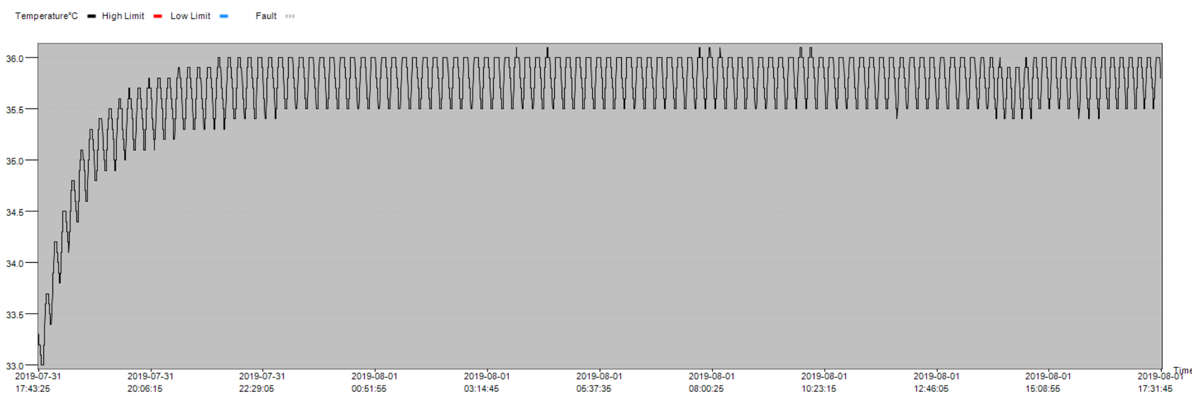

Figure 27: Incubator temperature for samples from Mbatakapidu & Palindi Tana Bara

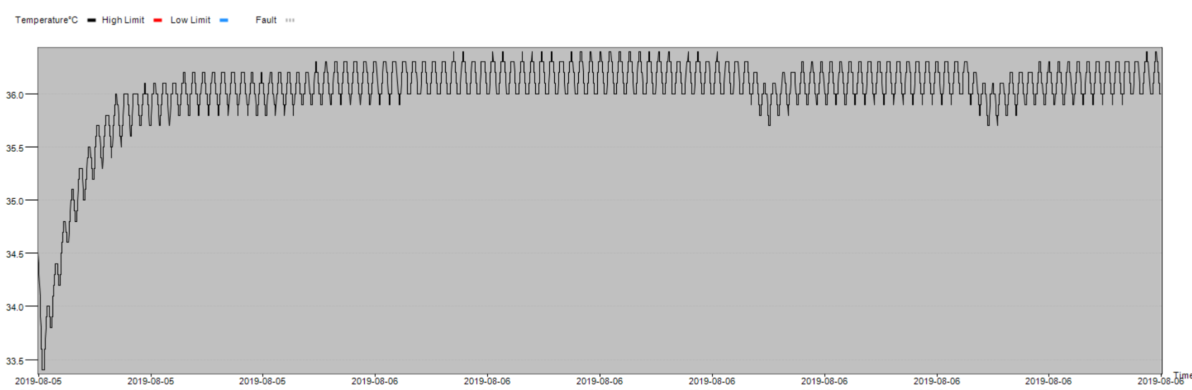

Figure 28: Incubator temperature for samples from Hamba Praing & Mondu

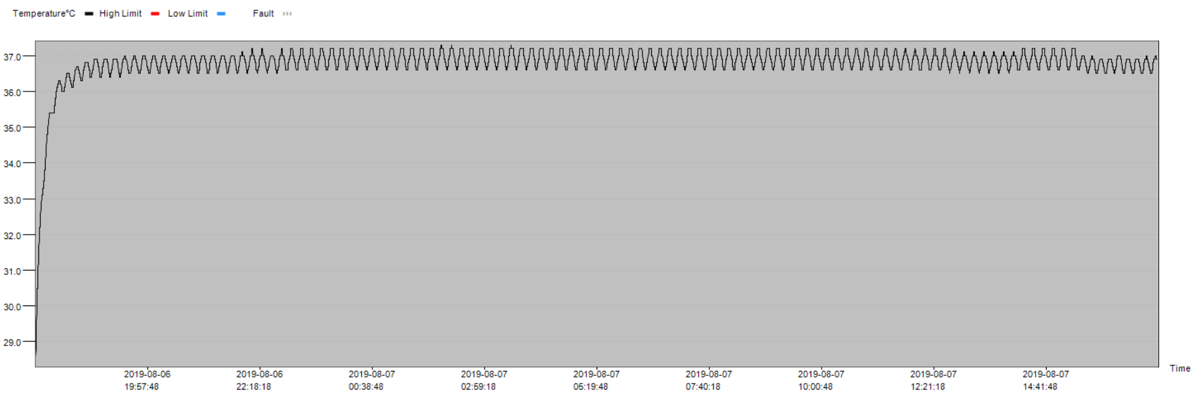

Figure 29: Incubator temperature for samples from Pambotanjara & Makamenggit & Mbatakapidu

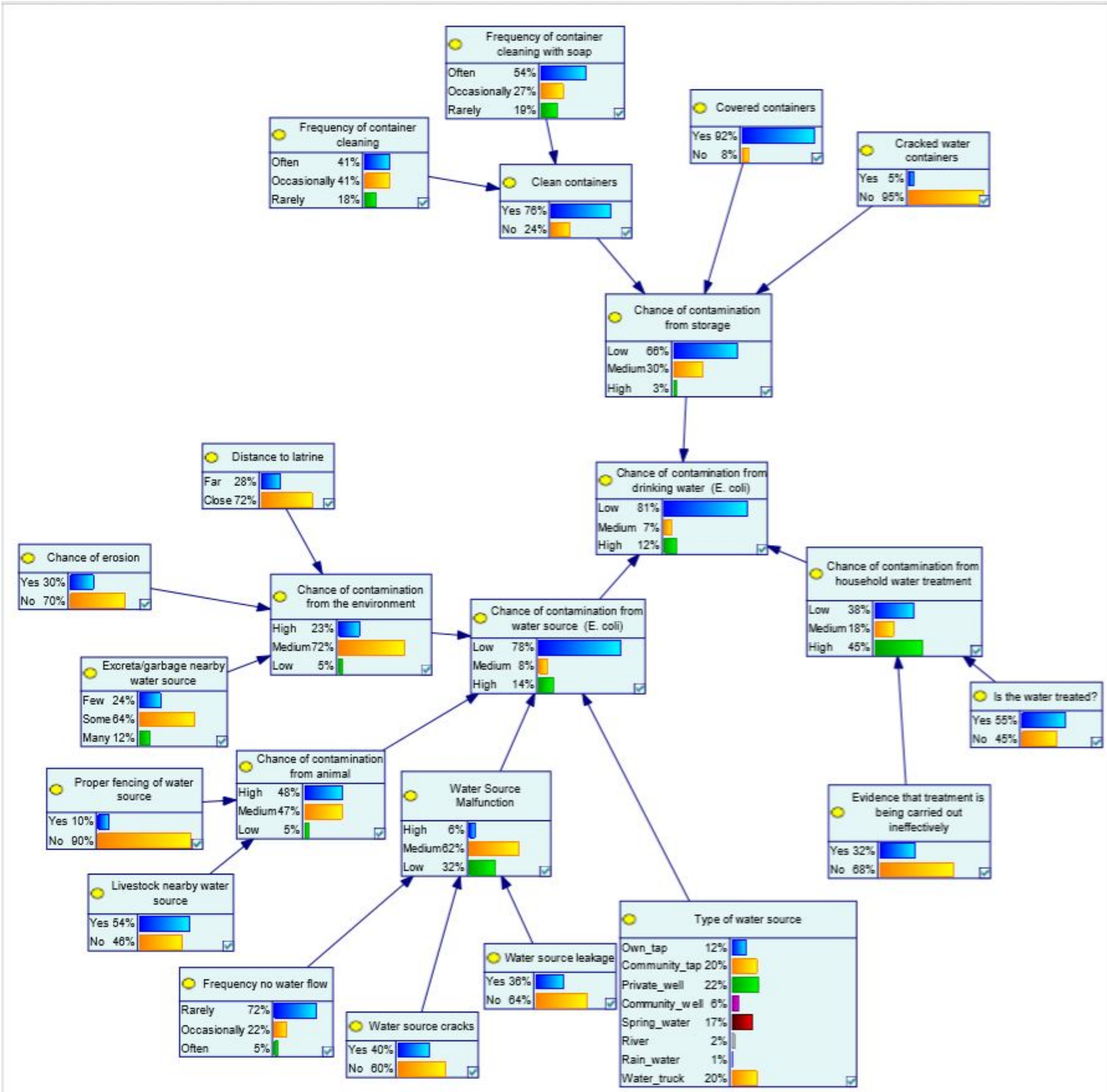

Figure 30: BBN of *E. Coli*

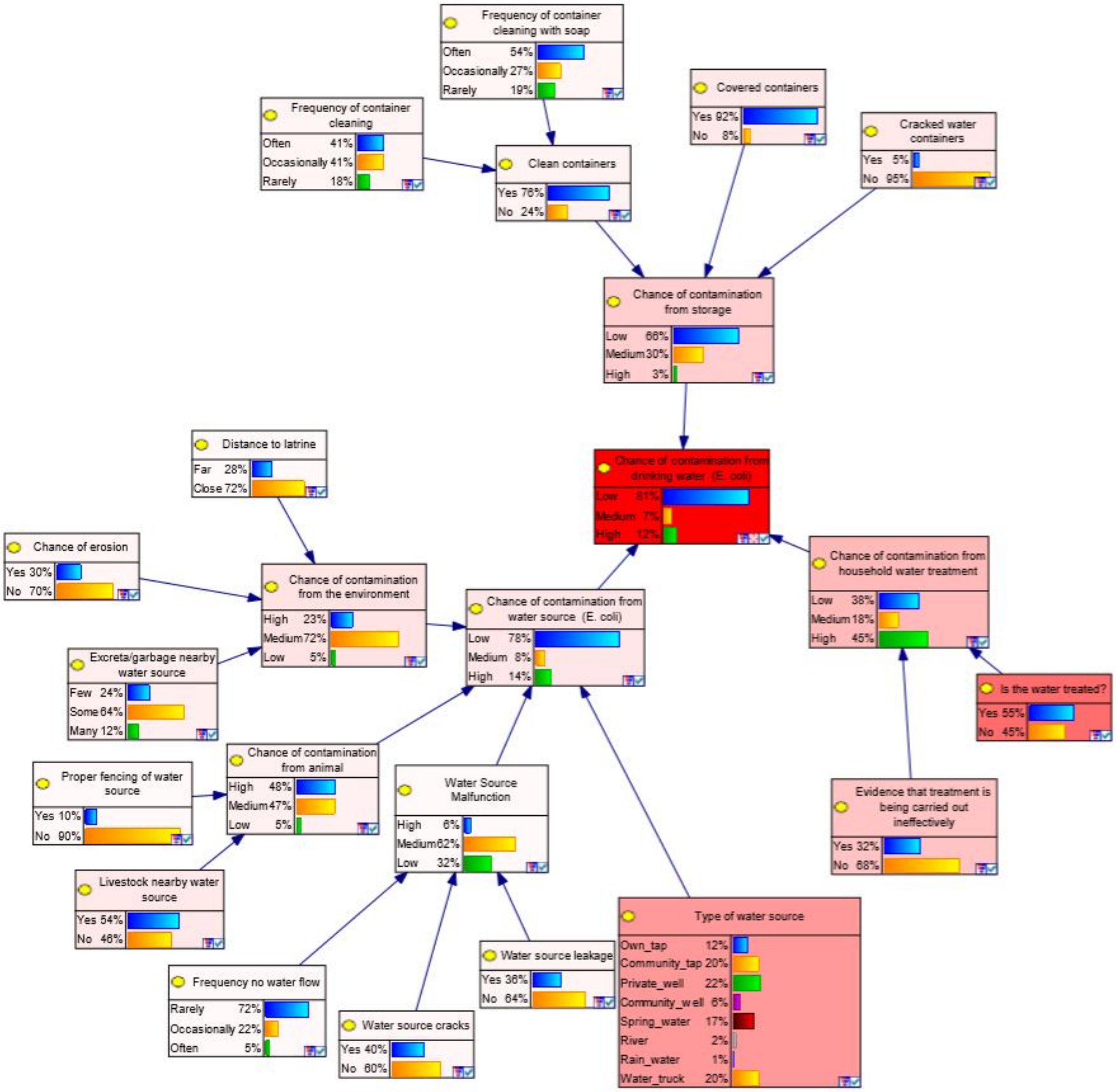

Figure 31: Sensitivity Analysis of BBN using *E. Coli* as indicator bacteria.

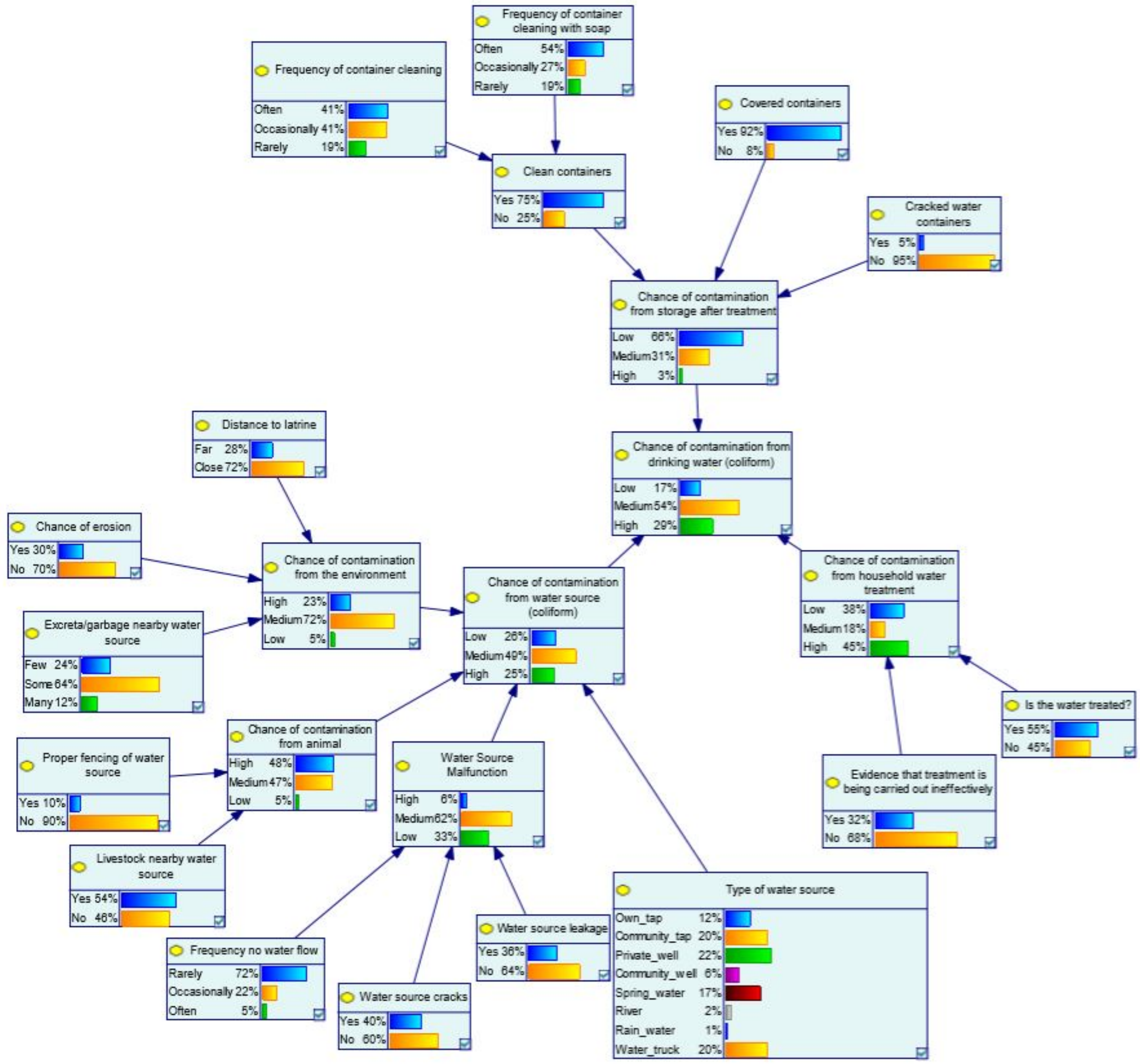

Figure 32: BBN of total coliforms

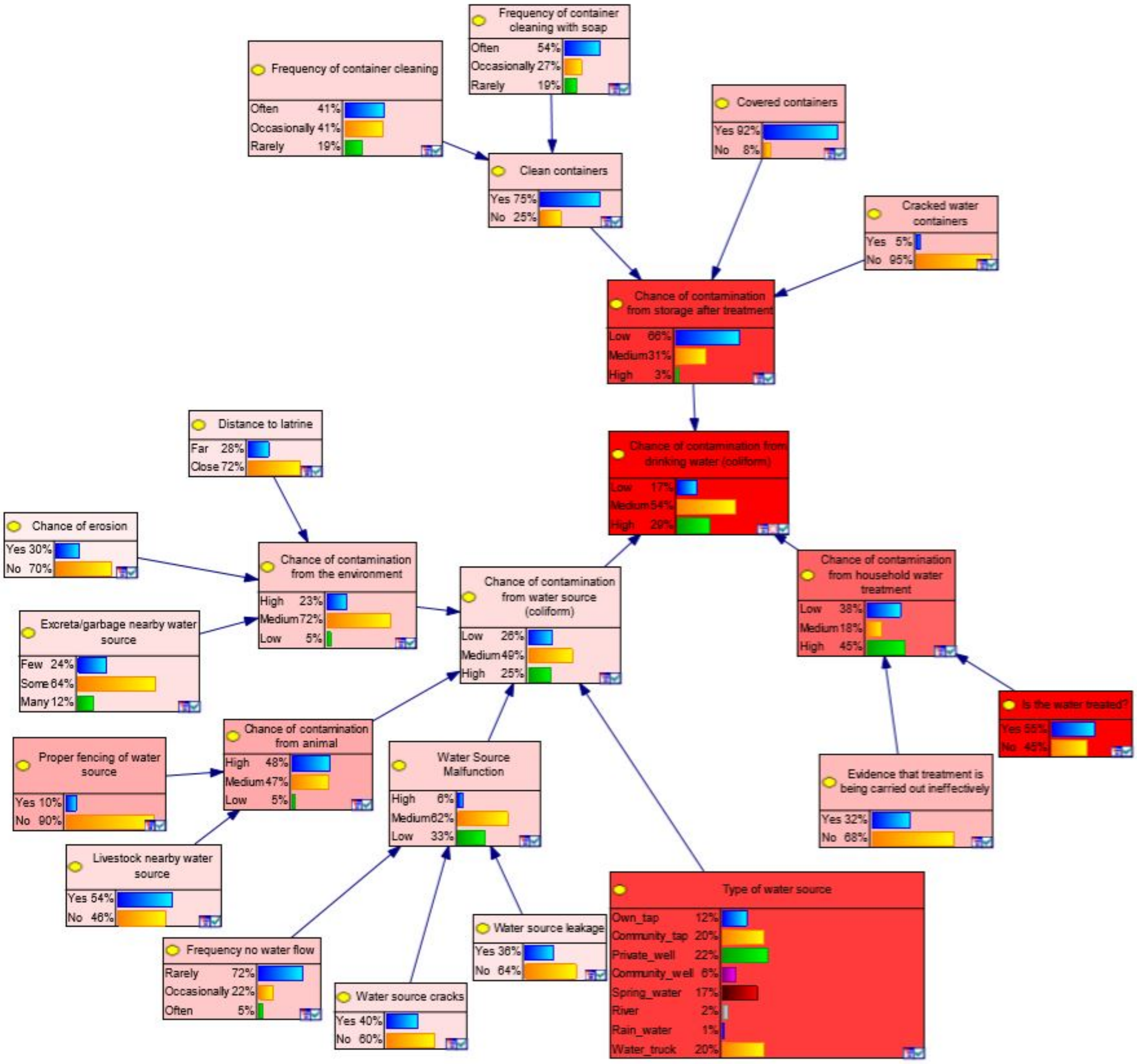

Figure 33: Sensitivity Analysis of BBN using total coliforms as indicator bacteria.

E Sumba Fieldwork

In this part, several photos which were taken during our fieldwork in Sumba are presented.

Figure 34: Traditional Sumbanese House

Figure 35: Sumbanese women are weaving using traditional equipment

Figure 36: Interview with locals

Figure 37: Interview with locals

Figure 38: Water Quality samples

Figure 39: Water Quality samples