POLITECNICO DI TORINO - ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

MASTER THESIS

WOMEN CARRYING WATER IN RURAL NEPAL: HEALTH IMPLICATIONS AND A STRATEGY FOR IMPROVED WATER SUPPLY

A CROSS-SECTIONAL STUDY IN NEPAL

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NOVEMBER 2020

Acknowledgement

I would first like to thank my supervisor, Regula Meierhofer, whose expertise was invaluable in formulating the research questions and methodology. The feedback pushed me to sharpen my thinking and brought my work to a higher level.
I would like to acknowledge my Italian supervisor, Professor Alberto Tiraferri for the patient support and the useful insights which clarified crucial points when elaborating this project.
A special thank to Professor Fulvio Boano for the help in the Water Scheme design, your comments and corrections were fundamental for the achievement of this part of the thesis.
I would also like to thank my Supervisor from the EPFL, Professor Urs Von Gunten, who has been very patient in the correction and reading of my paper.
A general thank to my department of Politecnico di Torino (DIATI), you all contributed to providing me with the tools that I needed to choose the right direction and successfully complete my work.
In addition, I would like to thank my parents, my grandmothers and my brother for their wise counsel and for accompanying me along this whole path. You are always there for me.
Finally, I could not have completed this dissertation without the support of my friends, which are too many to be listed. But, Irene, Julien, Mathias, Denis, Jael and Nora, you definitely helped me with stimulating discussions as well as happy distractions to rest my mind outside of my studies.

Contents

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Glossary

CIs Confidence Intervals. 15, 16

GEE Generalized Estimating Equation. 4, 15, 17, 18, 37, 43

GLM Generalized Linear Model. 18

NSI Non Standardized Index. 20

OR Odd Ratio. 15–18, 35, 51–58

PCA Principal Component Analysis. 19

PE Polyethylene. 27, 47, 59

PN Nominal Pressure. 59

Rs Rupees. 49

SDGs Sustainable Development Goals. 11

SPSS Statistical Package for Social Science. 16, 19

UN United Nations. 11

UP Uterine Prolapse. iii, 15, 18, 38, 53, 57, 58

VAT Value Added Tax. 33, 60

WASH Water Sanitation and Hygiene. 1, 7

WHO World Health Organization. 59

WI Wealth Index. 20, 21, 51

WSS Water Supply System. ii, iii, 4–6, 12, 23, 28, 32, 33, 47, 49, 59–62

Abstract

Background: Women in Nepal, especially in rural areas, are submitted every day to strenuous activities for household maintenance and children care, such as water fetching. This is a result of a a male-dominated society where women, despite developments in recent years, still struggle to achieve gender rights and equality, thus having important effects on both physical and mental health.
The aim of this project was to find relevant risk factors (both water carrying related and not) over the health of a female sample (1200 participants were interviewed). The project focused on the relationship between the risk factors and certain health outcomes, chosen on the basis of their medical and social relevance: pain at the ankles, head, neck, back and uterine prolapse (UP). Head, neck and back pain, with UP were included in the analyses since previous studies have already highlighted their association with water carrying.
Once the water carrying related risk factors were identified, a strategy for the design of Water Supply System WSS in one hamlet of Bolde district was developed.
Method: This project used data from a cross-sectional study conducted in 2019 during the dry season in the Kavrepalanchowk and Sindhupalanchowk districts of Nepal. Quantitative data were collected during face-to-face interviews with women, physical examinations were carried out and observations were collected through questionnaires.
Statistical Analysis tools such as Regression model generation through Generalized Estimating Equation (GEE) adjusted for age and accounting for clusters were used to find relevant health risk factors.
As first step, a frequency analysis was carried out to get information about the degree of health problems among women carrying water.
Since pain at the ankles was found to be the location where women currently or previously involved in water carrying had more pain, compared to those never involved, the first GEE was performed to find water fetching related factors for the pain at the ankles.
The second GEE was conducted only for women involved in water collection at the time of the survey, in order to find current water-carrying-related factors.
The third GEE was done for the whole sample, to try to identify both water-carrying and daily habits related factors which are potentially associated to health issues.
Three prevision models were generated on the basis of the GEEs results, including the relevant risk factors.
For the WSS design, references to previous projects and hydraulic guidelines were used. The scheme was divided into the following parts: catchment, transmission, water-tank, distribution and pipe-to-house connection. The available data (e.g. water demand per day, morphology of the site and type of ground) were used to calculate the unknown diameter of the entire system. Once the technical aspects had been designed, the overall cost was estimated. The final step was to evaluate the sustainability of the system.
Result: A first demographic statistical analysis revealed that 78,5% of the sample population carried water regularly at the time of the survey and 76,0% of women had general pain. Among women currently involved in water carrying the mean of the intensity of pain at the head, neck and back are higher than in women never involved in water collection, but lower than in women involved in the past.
The first model suggested water load (kg) as a risk factor for ankle pain among women who have been involved in water transportation in the past (OR = 1,039; p-value = 0,002 and CI95% = 1,014; 1,064).
The second model revealed several water-carrying-related factors associated with various health outcomes of women currently involved in water collection.

- For head ache intensity the following risk factors were outlined: distance (OR = 0,990; P-value = 0,000; 95%CI = 0,056; 0,919), up hill or down hill type of path (OR = 0,226; P-value = 0,038; 95%CI = 0,056; 0,919), water carrying related risk score (OR = 1,031; P-value = 0,000; 95%CI = 1,017 ; 1,044) and help in water carrying (OR = 72,814; P-value = 0,001; 95%CI = 5,326 ; 995,471).

- For neck intensity no significant predictors were found.
- For back pain intensity, the help in water collecting by other members of the family resulted to be the only predictor (OR = 0,357; P-value = 0,000; 95%CI = 0,233;0,547).
- For uterine prolapse, the waist loading mode was detected as a risk factor (OR = 2,780; P-value = 0,003; 95%CI = 1,432 ; 5,396).

The third model has pointed out potential risk factors, both water-carrying-related or not:

- Head ache intensity appeared to be associated with: transport in the three previous months (OR=0,158 and P-value=0,000;95%CI=0,076; 0,330), age of marriage (OR=0,825; P-value= 0,007; 95%CI=0,708 ;0,962), mean value of water load in rainy season (OR=0,986 P-value=0,04; 95%CI=0,708 ; 0,962), distance (OR=0,998 and P-value=0,000; 95%CI=0,997 ; 0,998) and number of births (OR=3,469 ;P-value=0,020; 95%CI=1,060 ; 11,359).
- For the neck pain intensity, the resulting risk factors are: employment in agriculture (OR= 58,898; P-value=0,001; 95%CI=1,878; 1434,131), age since which they have lifted heavy loads (OR=0,620; P-value=0,001; 95%CI=0,466; 0,826), frequency of lifting heavy loads in rainy season (OR=0,055 and P-value=0,000; 95%CI=0,003 ; 0,996), help in water carrying (OR=83,690; P-value=0,023; 95%CI=0,074 ; 6519,211), difference in altitude between water source and household (OR=0,956; P-value=0,023; 95%CI=0,920 ; 0,994) and education (OR=1,839; P-value=0,017; 95%CI=1,050 ; 3,221).
- For the back pain intensity: loading mode on the head (OR=1447,480; P-value=0,000; 95%CI=195,826; 10699,305), help in lifting loads during pregnancy (OR=2,335; P-value= 0,038; 95%CI=0,913; 5,974), current pregnancy (OR=2,658; P-value=0,035; 95%CI=1,070; 6,604), number of collection trips in rainy season (OR=1,259; P-value=0,001; 95%CI=1,104; 1,436), number of pregnancies (OR=2,042; P-value=0,005; 95%CI= 1,246;3,347), difference in altitude (OR=1,025; P-value=0,029; 95%CI=0,999; 1,051) and carrying during pregnancy (OR=0,651; P-value=0,036; 95%CI=0,435; 0,972).
- Uterine prolapse potential risk factors were found: history of water collection (OR=7,722; P-value=0,000; 95%CI= 2,812; 21,204), help in water carrying during pregnancy (OR=0,145; P-value=0,049; 95%CI=0,021; 0,989), education (OR=0,619; P-value=0,017; 95%CI=0,418; 0,918), number of trips per day in rainy season (OR=0,898; P-value=0,040; 95%CI=0,810; 0,995), distance (OR=0,995; P-value=0,030; 95%CI=0,991; 1,000) and type of main source in dry season (OR=1,389; P-value=0,034; 95%CI=0,975; 1,979).

Diameter of 20 mm were calculated in the WSS design both in the transmission and distribution pipelines. A water tank storage of 40 m^3, located at 660 m altitude, was obtained to cover the hamlet demand (14900 l/d). Pre-excavation conditions to estimate system reactions to operational stresses were validated as well as service conditions (e.g. minimum and maximum water velocity requested in hydraulic schemes). The total cost of the project with a depreciation and amortization rate of 5% each, provided a final water cost of 215,8 Rs/month per household. This value was compared to the minimum suggested water tariff (110 Rs/month) and possible financial solutions were described.

Conclusions: Health risks factors were found to be affecting health of women in rural Eastern Nepal. Studying water collection risk factors together with other factors provided more conclusive insights to understand life patterns impacting women's health.

For this reason the project, with additional research, could be a reference for the design of an action plan.

To deal with the water collection issue a Water Supply Scheme WSS could be planned, thus shortening distances women have to walk every day to the source. Interventions should be well addressed to deal with non-water-carrying-related factors and habits that were found to be affecting health of woman, such as lifting other heavy load, the age of marriage, the help in water carrying, the education and some other social indicators. For instance, national health services, NGOs and volunteers could undertake education campaigns where women would be informed and taught about the effects of such habits. With a clearer idea of what the strongest health risk factors are, investments could be better addressed, thus accelerating an improvement of the quality of life. Despite assumptions were necessary in the WSS design, values that were obtained in the dimensioning of the scheme respected the pre-excavation and service conditions. Strategies to make the system affordable to local users were proposed. Limitations and recommendations were defined in order to work on weaknesses of the project and finally guarantee access to water to people.

1 Introduction

1.1 Background and Literature Review

1.1.1 Drinking water access - a critical theme

Worldwide access to drinking water was 91% in 2015. This means 9% – nearly one-in-ten – did not have access to it [13].
95% of households now have access to drinking water sources in Nepal, which is a good achievement compared to the numbers in 2001-2005 of 71,6%-75,5% respectively and 46% in 1990 [6][17](Table 1).
This data are dealing with drinking water only; the Sustainable Development Goal of the United Nations set important targets for safe managed drinking water (see Paragraph 1.1.3), which is defined as "Drinking water from an improved source that is located on premises, available when needed and free from faecal and priority chemical contamination." [6].
Access to close drinking water sources is very important for the following reasons: health problems due to carrying water, loss of economic productivity due to less time available, higher levels of water contamination if the water source is located further away, lower amount of water is transported and consequently lower hygiene in household [48].

62% of households are now using sanitation facilities, while the percentage went from only 6% in 1990 to 20% in 2001 to 46,2% in 2005 [6][17] (Table 1).
The quality of water is still poor, with 71% of all water sources contaminated with Escherichia coli bacteria.
The functionality of the water supply system is also quite limited: only 25% of it is reported to be properly functioning.
Building wells, water networks and irrigation canals is much easier in the flat areas rather than in the mountainous areas, where only transporting material and technical personnel becomes a considerable undertaking. For this reason, the costs of pumping water from the acquifers sources to the villages located in higher areas require technologies and economic investments [10].
In rural areas most of piped water stands are found in the public places nearby houses. The piped water connection to houses or personal premises is less common in rural areas. Only some well-off households are able to have piped water connection to their houses in their own efforts. It is also evident that 35 percent of richest households have access to piped water in courtyard or home. But households from poorest quintiles are less likely to have piped water connection in their home [10].
Available data indicates that there is a disparity in accessing and using piped water between rich and poor (see Table 2).
Another important issue is Open Defecation (ODF), 16% of the population in Nepal still practices it [64].

WASH services	1990	2001/02	2002/03	2003/04	2004/05	2018
Population with access to drinking water (%)	46	71.6	72.8	73.5	75.5	95
Households with sanitation facility (%)	6	20.0	26.2	39.0	46.2	62

Table 1: Expansion of Water, Sanitation and Hygiene services (WASH) between 1990-2018 [6][17].

Water Supply	Poorest	Second	Middle	Fourth	Richest
Piped water on Premises	10	14	16	17	35
Other improved water	69	82	84	83	64

Unimproved water	21	4	0	0	1

Table 2: Status of water supply by wealth quintiles in Nepal [10].

Besides working for the maintenance of the household, women spend much time and energy each day to collect their water from the spring or public tap and carrying it home, especially during the eight months of dry season [45]. Consequently, women carry a double burden.
Nepalese women, especially in rural areas, are mostly employed in agriculture while men are more likely to be employed in offices or small business, even far away from the village, thus preventing the husband to be home and to provide help for daily duties. Moreover, their working conditions are very poor, sometimes dangerous, insecure and underpaid [5].
Women living in the high mountain regions and in the remote hilly areas are even more economically disadvantaged and have lower food and water accessibility than women living in urban areas or in the plains [20].
To deal with the water shortage, households commit in a series of coping behaviours, such as collecting water from alternative sources, sometimes more distant than those available during the rainy season [45].

The overall situation may often lead women to emotional instability and a low quality of life, in addition to physical strain. Sometimes this even leads to the choice of an "extreme solution" : suicide [5].
Many physical and mental problems have been already studied in association with water -and other heavy loads- lifting; including injury due to extreme fatigue, accumulation of pain, degenerative changes in tissues and bones [34], musculo-sketal disorders [21], lower injury tolerance of the cervical spine [22] .
The research into the women's roles of caring for children and maintaining the household, [11] is not very vast; even if some studies have scientifically demonstrated there are some effects on the health of people having such a role, additional research is missing.
For this reason, the project wanted to make a contribution to expand the knowledge on this crucial topic, as well as to better understand how domestic water carrying is performed, identify potential health risk factors and gain insight into the possible consequences.
Buor Daniel (Geography Section, University of Kumasi) [11] found out that women, who carry the burden of water fetching, suffer from dangerous side effects. Nonetheless, income, education and the non-assistance of their husbands makes a significant additional impact on their health, thus underlying that there are many potential factors -beyond fetching water- that might alter women well-being.
In an investigative study in Ghana [11], an inverse relationship between women health status and hours spent fetching water during scarcity was found. The health status was a ranked variable, based upon the frequency of sickness, being "1" for once in 2 weeks, "2" for once a month, "3" for once in 3 months, and "4" for rarely. It improved when hours spent on fetching water declined.
Another relevant study on this topic has been conducted in South Africa, in the Limpopo province; data has been collected through semi-structured interviews, observations and measurements. Trough the investigation they have highlighted the possible association between spinal pain and water carrying. Particularly, they discovered that typical methods of transporting containers filled with water often produce symptoms of musculo-skeletal disorders and related disability [22].

Uterine prolapse (UP) is a reproductive health problem common in low-income countries like Nepal, it occurs when supportive tissues are too weak and thus cause the uterus to descend, with or without the urinary bladder and bowel, into the vagina.
Heavy lifting has already been detected as one of the potential cause of UP [16][56].
Common symptoms are pelvic pressure, general discomfort, visible bulging, and sexual impairment.

There are four stages of severity in which the disease can appear [16]:

1. The most distal portion of the prolapse is >1 cm above the level of the hymen;
2. The most distal portion of the prolapse is lower than 1 cm proximal or distal to the hymen;
3. The most distal portion of the prolapse is >1 cm below the hymen but protrudes no further than 2 cm less than the total length of the vagina
4. Complete aversion of the vagina.

UP risk factors also include age, early marriage, childbearing, parity, poor nutrition and predisposing factors such as obstetric conditions resulting from excessive stretching and ripping, multiple and frequent deliveries, vaginal delivery, high body mass index [16][56].
Considerable physical work during pregnancy and immediately after delivery, unskilled birth assistance, as well as lifting of heavy weights, especially on long and hilly paths, are some key risk factors favouring the UP onset, in Nepal [42][66].
UP can strongly reduce women's ability to work, which is important in societies that associate women's value with their aptitude to work.

The United Nations Population Fund (UNFPA) reports that 10% of women in Nepal are afflicted by the pelvic organ prolapse, with the lifting of heavy objects being one of the major factors [66].
The social consequences of prolapse are substantial, and include physical and emotional isolation, abandonment, divorce, ridicule, low self-esteem, abuse, lack of economic support, and domestic violence [35][66].

In addition to physical issues there are also some psycho-social consequences of water carrying on other daily tasks.
Girls occupied with water carrying cannot attend school, sometimes they cannot even engage themselves in full-time paid professions.
This fact is highlighting how water carrying can worsen the existing gender gap.
Women responsible for this task are easily victims of mental stress and emotional distress, they feel in charge of guaranteeing the availability of sufficient water in the household [58].

1.1.2 A patriarchal society and the gender gap issue

Women in Nepal and all over the world face daily tasks such as collecting water and transporting heavy loads to satisfy the family and household needs. These duties are predefined by the hierarchical structure of society (e.g. castes subdivision, observations of cultural and religious traditions) [5][20].
Despite impressive advancements in abating the overall poverty rate, which declined from 42% in 1996 to 25% in 2011, gender-based, social traditions and geographic disparities still remain. For instance, female-headed households are more easily victims of poverty than other households [20].
In Nepal, gender discrimination is evident [20].
Culturally speaking, marriage is seen as the most socially appropriate choice for women to increase their wealth status and therefore have more land or properties. The marriages generated by pacts between families are numerous and are the result of a strategy to disengage from the burden of having to look after the girls to whom a flourishing future cannot often be assured. Sometimes girls get married even before the age of majority of 20 years.

In case women interrupt their marriage, both by divorce or widowhood, they become more vulnerable to poverty.
Women are under male authority which is transmitted from father to husband, the power disparity between the two sexes is thereby marking society.

Nepal is in 105th position out of a 149 countries classified on the Global Gender Gap Index (2018) made by the World Economic Forum, hence revealing a crucial necessity to tackle this gap [6].

Episode of gender-based violence, especially domestic, still occur nowadays, mostly lead by the social attitude towards women and backed by a male-dominated ideology [5].

The Government laws concerning marriage, divorce, property rights and inheritance, still sustain a patriarchal structure of society and set strict limits on women rights over economic resource decisions [5].

The existing gender gap is emphasized by the fact that Nepal is one of the least-developed countries in the world. The survival of the population is mostly based on agriculture production led by women, whilst men have more possibilities to find a job as employers, in companies or government offices [43].

Male	**Year**	**Agriculture, Fisheries, Forestry**	**Industry related**	**Service related**
	1990	74,9%	3,4%	19,8%
	2001	60,3%	12,5%	24,9%
Female	**Year**	**Agriculture, Fisheries, Forestry**	**Industry related**	**Service related**
	1990	90,5%	1,2%	7,6%
	2001	72,8%	9,7%	14,9%

Table 3: Proportion of male and female workers, years 1990 and 2001 [43].

Table 3 shows the evident difference in employment between the two sexes in years 1990 and 2001 [43].
Nepal has a high rate of female labor: 85,4%. This is a result of a migration of men towards the cities in search of employment in offices, companies or industries; 76% of all households in Nepal are agricultural households [6].

The gender disparity in education level leaves women behind; often young girls are forced to marry early, thus restricting their access to school and leading to early pregnancies, generated also by very poor information on contraception. Consequently, they have the necessity to start working early in their lives [5].
Usually, once married a woman cannot return to her parents. Sometimes only for financial reasons as she must meet her family needs.
Nowadays 82,9% of adult women have completed their primary education. The primary school enrollment gap between women and men has been almost closed; enrollment figures for girls went from 64,6% in 2000 to 96,2% in 2016. However, only 30,7% of women have completed a secondary education.
Female students are more likely to give up earlier than male students, due both to the education system and to the social standards of their communities.

Year	Male/Female difference	Female	Male
1991	29,5%	25%	54,5%
2001	22,6%	42,5%	65,1%
2018	22,9%	48,8%	71,7%

Table 4: Adult literacy rate, years 1990, 2001 and 2018 [6][43].

In 2018 the literacy gap between genders was still remarkable: only 48,8% of women were literate while the rate for males was 71,7% (Table 4)

Women's access to political and administrative roles has been minimal until the end of the '90s (less than 10 and 5 percent, respectively) [5].

Years	Member of Parliament	Ministries	Managers	Technicians	Civil Service
1990	6%	-	17%	22%	-
2005	5,9%	7,4%	18%	24 %	5,1%
2018	32,7%	3,7%	NA	NA	NA

Table 5: Percentage of women in decision making positions in years 1990, 2005 and 2018 [6][43][50].

The percentage of women in national decision making positions has moderately increased from 1990 to 2005, except the percentage in ministries which has actually decreased (Table 5) [43][50].
Currently, the presence of women in local government representation has achieved some significant increase, nevertheless further efforts are needed to promote their participation in higher government level procedures; men continue to hold the majority of positions.
In 2018, there were 32,7% of women in parliament, but only 3,7% in ministries [6][43][50].

1.1.3 Sustainable Development Goals SGDs

The World Bank announced its new Global Strategy for Gender Equality in December 2015 [6]. The South Asia region cast off its own Regional Gender Action Plan to sustain the Global Strategy for Gender Equality (RGAP).
These attempts are particularly suitable for the Nepal Country Partnership Framework (CPF) which includes three priority points: Public Institutions, Private Sector Led Jobs and Growth, and Inclusion and Resilience. Gender is a key theme across these points and it is analyzed in the Gender Equality and Social Inclusion Strategy (GESI) [32].
Nepal, as member of the United Nations (UN), is committed to the global initiative for the Sustainable Development Goals (SDGs). The SDGs are acting as a universal call to stop poverty, protect the planet and improve the lives and prospects of every human being. The 17 Goals were adopted by all UN Member States in 2015 [41].
The Proposed SDGs for Nepal also include engagements to achieve gender equality and empower all women and girls (SDG 5) and ensure availability and sustainable management of water and sanitation for all (SDG 6) [18].
The SDG 6 includes the following points : "(i) achieving universal and equitable access to safe and affordable drinking water for all, (ii) achieving access to adequate and equitable sanitation and hygiene for all and end open defecation, (iii) improving water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, (iv) substantially increasing water-use efficiency across all sectors, (v) implementing integrated water resources management at all levels, and (vi) protecting and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes." [18].

To respond to the psycho-social and physical consequences of the tough daily life in rural Nepal, positive behaviours, as well as new supporting methods, must be considered in order to improve the quality of life for women and change the overall strenuous environment they are surrounded by. There are three levels of prevention suggested by the Journal of Positive Behavior Interventions to help women in strenuous situations [12] :

1. **Primary**: It is the highest level of prevention and it concerns the protection of women from physical impacts. For instance, with a conveying system which brings water closer to the household, or with safer individual water transport strategies. Community social support is also recommended (e.g. other household and community members can help the woman to carry water, especially during and after pregnancy).

2. **Secondary**: Medium level of prevention : it consists in increasing the awareness of physical and psycho-social impacts and detecting the eventual diseases earlier, through an immediate analysis of the symptoms. It then tries to prevent them from getting worse, for example with appropriate exercise (e.g. exercises for pelvic floor muscles).

3. **Tertiary**: The lower level is achieved through trying to limit to the minimum the symptoms of physical strain. It does not necessarily exclude psycho-social consequences such as social isolation. It intends to enhance positive social beliefs and improve health care services for the victims.

1.2 Purpose of the study

In this living condition framework in Nepal, this Master Project aims to contribute to understand the impact of water carrying on women's health and gain insight, through some statistical analysis, into possible impacts; it also considers and analyses other external factors that might contribute to worsen or mitigate the consequences of this task. Finally, it tries to identify the prevalent health issues that will be explored in relationship with social indicators.
Models able of predicting health outcomes were generated by including relevant health risk factors.
In accordance with the up-written three levels prevention in section 1.1.3 at page 11, this study tries to provide key points on which future research, Non Governative Organizations (NGO) teams, as well as sanitation services, might refer to, in order to act for an improvement of the current living conditions of women in Nepal.
A Water Supply Scheme (WSS) will be planned to deal with the water carrying burden, thus shortening distances women have to walk every day to the source. Moreover this Master Thesis could serve as reference, in addition to further literature, for information campaigns where women would be taught about the effects of water fetching and risky habits for health in general.
With a clearer idea of what the strongest health risk factors are, investments could be also better addressed in order to improve the quality of life.
Moreover, the third and very basic level of prevention (page 11) described in the suggestion guide states that knowledge of the health issues' causes -and relative symptoms- is necessary both to prevent and reduce its effects [12].

Therefore, this work will discuss the potential implications of implementing a primary prevention measure by bringing water closer to the households such as the extension of the water supply schemes to individual households or closest public fountains (technical and economic).

1.3 Research questions

1. Are there prevalent health issues afflicting women fetching water in the selected population?
2. What are the main water-carrying related factors that are associated with these health issues?
3. When considering water-carrying and non-water-carrying factors at the same time, what are the relevant risk factors that are associated with these health outcomes?
4. What is a technical solution for a water supply system?
5. What would be the cost of implementing a water supply scheme?

2 Materials and Method

2.1 Data source and Interview variables

This project used data from a cross-sectional study conducted in 2019 during the dry season in the Kavrepalanchowk and Sindhupalanchowk districts of Nepal (see Figure 1) which are typical low-income regions with sub-optimal water supply conditions, giving home to a mixture of households with in-house and external sources of water.
Quantitative data were collected during face-to-face interviews with women to assess some potential risk factors that might be related to the social context, the environment, the task and conditions of water carrying and the private living situation [9][22].
Physical examinations were carried out by qualified health workers to identify and quantify physical health disorders that could be linked to carrying water. Observations were conducted on how women carry their water containers.
Data and observations were collected through questionnaires and interviews with pre-coded questions with multiple choice answer categories, partly coded into likert scales.
The survey collected demographic information and included inquiries concerning exposure variables such as the distance and the time to walk to different water sources, the amount of water carried per trip and daily, their usual methods for carrying water, water carrying experience as girls as well as the degree of involvement of other household members in this task.
For some of the variables, information were requested either for rainy or dry season, some of them were also asked referring to the past.
The survey collected physical health outcome variables and included self-reported pain and pain location for head, neck, back, arms, shoulders, elbows, joints of hands, finger, legs, hips, knees, ankles and feet. For locations at the head, neck and back, questions about the severity of the pain (mild, moderate and severe), as well as the general frequency (occasionally, frequently and constantly) were asked.
Information was gathered about the frequency and duration experienced in the previous seven days [8], general health, disability and gynaecological problems (e.g. uterus prolapse).
Participants were asked to rate whether they had difficulty in doing the activities of seeing, hearing, breathing, walking or climbing steps, concentrating, remembering, self-caring and communicating [22].
The information related to potential confounding factors such as age, socio-economic status, nutrition, number of children living in the household, number of parities (e.g. births) and other physical work tasks have been reported.
The clinical examination complemented self-reported information, gained through the interview and it assessed gynaecological problems such as uterine prolapse and musculo-skeletal disorders.

Whenever possible the interviewer team walked with the woman to the source and back home and structured on site-observations were done notably on the method by which women transported the water or the number of filled water vessels, body postures adopted during lifting and lowering as well as while walking with containers. The respondents were requested to estimate the sensation of effort required for carrying water immediately after the completion of a water carrying trip and to point to the verbal descriptor, or number, most closely matching their sensation of efforts.
A GPS unit (Garmin CSX 60) was also used to measure the coordinates of the households (direct measures of the coordinates of the source were missing), the distance to the water source and the altitude difference (between source and household).

Figure 1: Districts of the study

2.2 Study Design and Participants

The sample size was planned to be at least of 1000 participants, using the approach outlined by Hsieh et al, based upon simple linear and logistic regression considering the power of 90%[29].
All resident women in the reproductive age, living in the project area were suitable participants. Whenever available, their mother-in law was also interviewed; mothers in law play an important role in the decisions around accessing health care facilities, medical visits and providers [57].
Five different villages (Salambhu, Bolde, Baluwa, Bahunipati and Dhungkharka) were purposefully selected to include a wide range of water service situations which expose women to different carrying methods and might have different effects and hence health outcomes.

The permission for conducting the work in each community was requested from the leadership of each village before starting the research.
Ethical approval for the study was obtained from the ethical committee of the Nepal Health Research Council at Nepal and from the ethical commission at the University of Bern.
Women observed carrying the water were initially approached and were briefly informed about the study objective and procedure in their preferred language.
The 1240 respondents willing to participate were provided with more detailed explanation of the study both verbally and with participant information sheets and informed consent written in Nepali language.

2.3 Selection of outcome variables for regression models

The following outcome variables were selected for GEE analysis: pain location at the ankles (dichotomous); head, neck and back intensity of pain (continuous); UP (dichotomous) (Appendix Table 27).

Pain location at the ankles was chosen as outcome variable for multivariate GEE model for the following reason: bivariate GEE using different pain locations as outcomes and the involvement of women in water carrying as predictor, revealed that the Odds Ratio (OR) for pain at the ankles was higher for women involved in water carrying now or in the past, compared to women who have never done it. Water carrying was not associated with other pain locations such as hands, feet, fingers and therefore not further analyzed in multivariate GEE.
The OR is a measure of association between an exposure and an outcome; it represents the odds that an outcome will take place given a certain exposure, compared to the odds of the outcome occurring in the absence of that exposure [59].
During the data analysis a 95% Confidence Interval CIs is used to estimate the precision of the OR.
A confidence interval for the mean is a range of scores constructed such that the population mean will fall within this range in 95% of samples [19].
A large CI indicates a low level of precision of the OR, whereas a small CI indicates a higher precision of the OR [59].

Variables for head, neck and back intensity of the pain were generated from the product between severity and frequency of the pain, they were used in the analysis for one main reason: evidence is available from literature about an association between water carrying (especially on the head) and musculo-sketal disorders such as physical stress at the neck, back and head through vertical compression which can lead to cervical degenerative disc disease [22]. Cervical pain is demonstrated to have impact on the everyday quality of life [61].

UP was chosen as outcome variable because previous literature had already investigated its influence on the quality of life [16][35][56], this work wanted to provide further insight into this topic.
The presence of UP has been reported as a simple dichotomous variable (1=UP present, 0= UP not present).

The independent variables (Table 28, 29, 30 and 31 in the Appendix) used in the multivariate GEE included history of water collection (currently involved, involved in the past and never involved), water-carrying-related factors (e.g. distance, trips per day, water load, type of path, position of the load, potential risk of handling loads, etc.), general and family factors (e.g. living alone or not, number of births, employment in agriculture, education level, wealth index, etc.), other habit factors mostly linked to the lifting of heavy loads (beside the water load) and finally pregnancy related factors (e.g. if they go fetching water and the type of food eaten during pregnancy, etc.).
The allocation of the independent variables into four different subgroups and tables (water carrying related, generals and family, other habits and pregnancy) was primarily done in order to organize data and make it easier at interpretation. However the main distinction on which the regression models rely on is: water-carrying-related and non-water-carrying-related factors.

The reason why all these independent variables were included in the data elaboration has been discussed in section 1.
All the water-carrying-related factors (Table 28) were chosen on the basis of previously gained ev-

idence on the association between health outcomes and water carrying (see section 1, page 8). All the non-water carrying related factors that have been previously used in health outcomes studies were involved in the model to control for potential confounding.

2.4 Statistical methods

All the analyses of this study were performed using SPSS software program version 26. The estimation of health disparities used for the analyses was the measure of association between the disease and the risk factor (Odds Ratio and 95% Confidence Intervals). The level of significance was $\alpha = 0.05$.

2.4.1 Frequency Analysis

The first step of the data elaboration has been a summary of descriptive statistic in order to make a clear framework of the investigated population.
They have been considered important to give a general overview of the sample population and its characteristics; these results are in term of demographic peculiarity, water-carrying-related and physical and mental health outcome features.
For dichotomous and categorical variables, the frequency of cases, the percentage over the total number, the valid percentage (excluding the missing values) and the cumulative percentage are provided; for the continuous variables the number of respondents, the minimum, the maximum, the mean and the standard deviation of the values are listed.

2.4.2 Three sets of analysis - three regression models generated

The statistical analysis was afterwards split into three sets according to three different objectives:

1. Find the pain location whereby women currently or previously involved in water carrying had a higher OR, compared to those who were never involved. When a pain location was discovered, it was studied in association with water-carrying factors.

2. Identify water-carrying-related factors that influence the health of women involved in fetching water at the time of the survey.

3. Outline water-carrying-related and non-water-carrying-related factors that affect the health of all women of the sample.

Three final models were generated from each set including the identified relevant health risk factors.
Except for the first set of analysis which was developed in three stages, the other sets followed a two-step procedure: a bivariate analysis (GEE) and a multivariate analysis (GEE). GEE is the acronym for Generalized Estimating Equation, whose description will be discussed in the next section about statistical tools.
To set up the multivariate model, bivariate analysis GEE was performed first to assess associations between each independent variable and each outcome variable, resulting in odds ratios (OR) and their 95% confidence intervals (CIs). The predictor variables included in the multivariate GEE were picked based on the criterion of a p-value < 0,2 during bivariate analysis [55]. The second stage was the multivariate GEE model, adjusted for age.
To select statistically significant factors from the results of the multivariate regression, it was necessary to look at the p-value (short for "probability value"). It is the probability of finding a given deviation from the null hypothesis in a sample. The null hypothesis is the hypothesis that there is no

significant difference between specified populations, any observed difference being due to sampling or experimental error. A small p-value basically means that data are unlikely under some null hypothesis. A somewhat arbitrary convention is to reject the null hypothesis if $p < 0,05$ [19].
The municipality level (n=5) was included in the analysis as a random sampling effect due to geographic clusters.
Individuals from the same cluster likely tend to be more similar to each other therefore the assumption of independence, necessary in the creation of a model, does not hold [19]; total variance can be partitioned into between- and within-cluster variance.

First Set of Analysis
Bivariate GEE analyses were run between history of water carrying, predictor variable, and each pain location (see last line of Table 28 in the Appendix, page 64 and Table 32 at page 65). Participants with missing data were excluded from the analyses. All these outcome variables were dichotomous with 1 expressing the presence of pain and 0 its absence. Therefore a binomial GEE with a log link was chosen for all these models.
This first bivariate analysis GEE was indicating the OR of having pain, for each location, for women currently or previously involved in water carrying, with respect to women never involved (this category was chosen as the control category).
When making a comparison of a specific variable between different categories (e.g. history of water collection), an OR bigger than 1 indicates the predictor is positively associated with the outcome more than it does in the reference category predictor; if the OR is smaller than 1 it is the opposite way.
Once a statistically significant OR for any of the pain location was found, it was studied in details with the objective of looking for water-carrying-related factors that might have an influence over it (first model generation). If the relevant OR was found for women involved in the past, the further GEE analyses were run selecting only water-carrying-related factors of the past; if the resulting relevant OR was found for women currently involved in water carrying, the water-carrying-related factors to choose were those referred to the present; if the relevant OR was found for the two categories at the same time, both past and present water-carrying-related factors were picked.
The ankles resulted the pain location were women involved in water collection in the past had a statistically relevant higher OR with respect to women who were never involved.
Therefore Generalized Estimating Equation (GEE) were performed to assess associations between the independent water-carrying variables and the ankles pain. First, a bivariate GEE between the ankles pain and each water-carrying-related factor was run. Therefore a multivariate GEE was carried out, including all the variables that appeared relevant from the previous bivariate analysis GEE. The independent variables showing a p-value $< 0,05$ from the last multivariate GEE were considered predictors of the health outcome and included in the prevision model.

Second Set of Analysis
Women currently involved in water carrying (history = 1) were selected in this set of analysis. Those who were involved in the past were left out since water fetching methods and the overall context might have changed in the years.
In the first stage, every outcome was analyzed in association with potential risk factors by running a bivariate GEE with a binomial probability distribution and a logit link funktion (in case of binomial outcome such as UP) or GEE with a normal probability distribution and identity link function (in case of continuous outcome such as head, neck and back intensity of pain). In the second part, a multivariate GEE was carried out including all the factors that resulted signficantly associated (p-value $< 0,2$) with the outcome from the previous GEE.
Finally, the variables reporting a p-value $< 0,05$ were highlighted and considered potential health risk factors.

Third Set of Analysis

The third set of analysis followed the same two-steps procedure as the previous one. There were three main differences: all women (currently, previously and never involved in water collection) were selected, history of water collection was used in the bivariate and multivariate GEE as a water-carrying-related predictor and all the other non-water-carrying-related factors were also included in the analysis.

Resuming, three models were finally built on the basis of the outlined risk factors:

1. Water-carrying-related factors prediction model for the pain location of the body (ankles) where women currently involved in water collection or involved in water carrying in the past, have a statistically more significant OR with respect to women never involved;

2. Water-carrying-related factors prediction model for head, neck and back intensity of pain and UP selecting only women currently involved in water carrying;

3. Water-carrying-related and non-water-carrying-related factors prediction model for head, neck and back intensity of pain and UP for all the women of the sample.

2.4.3 GEE Regressions and Factor Analysis tools

Since Logistic and Linear Generalized Estimating Equation models (both bivariate and multivariate) were used in the project, a synthetic clarification of what they are is presented here.

GEE belong to a class of regression techniques that deal with correlated observations within subjects [28].

For this reason all the regression analyses were done following the Generalized Estimating Equation procedure. It extends the Generalized Linear Model (GLM) to allow the analysis of repeated measurements or other correlated observations, such as clustered data [30].

The GEE model is often based on fewer assumptions than a GLM [46]. For instance predictors can be correlated (there is no assumption of multicollinearity) and heteroscedasticity is admitted (i.e. inequalities of the variance among the residuals; residuals are the difference between the observed value of the dependent variable and the predicted value) and data distributions can differ from a normal distribution [46].

Cases are assumed to be dependent within subjects (clustering variable) and independent between different subjects, the correlation matrix that represents the within-subject dependencies is estimated as part of the model [23]. Thereby assumptions are checked while running the model, if they are not met the final model significance will not be statistically relevant (p-value will be > 0,05).

There must be independence among observations over time, this is not an assumption to check in this work, since it has not looked at the evolution in time of the outcome.

The models from a GEE can be several, in this project the choice was done between two only: logistic (it specifies Binomial as the distribution and Logit as the link function) and linear (it specifies Normal as the distribution and Identity as the link function).

The focus of the GEE is on estimating the average response over the population ("population-averaged" effects) rather than the regression parameters that would enable prediction of the effect of changing one or more covariates on a given individual.

Given a mean model μ_{ij} for subject i and time j that depends upon regression parameters β_k and variance structure V_i, the estimating equation is formed via:

$$U(\beta) = \sum_{i=1}^{N} \frac{\partial \mu_{ij}}{\partial \beta_k} V_i^{-1} \{Y_i - \mu_i(\beta)\} \quad (1)$$

The parameters β_k are estimated by solving $U(\beta) = 0$ and are typically obtained via the Newton–Raphson algorithm [38].

Bivariate GEEs were run when dealing with an outcome and a single predictor; multivariate GEEs instead, when taking into account several predictors at the same time for an outcome.

Another important statistical tool was used in SPSS to build up a Wealth Index: the Principal Component Analysis PCA [36].
This tool is very helpful when there is a will to use a single index quantifying complex conditions, moreover it is meaningful in understanding area-level factors, rather than employing various variables in the form of numbers or proportions separately. An approach of this kind does not only allow comparisons across groups, but also makes it easier to design theories and conceptual frameworks of a complex phenomenon, like health issues [36].
The general reason why socioeconomic indicators have been included as predictors in the analysis has been discussed in section 1.
Nevertheless, there are many previous researches [3][7][14][33] and theoretical reasons to believe that a socioeconomic status variable, such as wealth or education, may have an influence over health outcomes in different ways, based on how it is being perceived or measured. A variable, such as car ownership, can reflect a different picture about wealth from that of home ownership, but both contribute to an understanding of an individual's or area's wealth status [36].
In order to create the Wealth Index, the World Food Program [7] directives as well as the method used by Vijaya Krishnan [36] were followed.

First of all the variables that were thought to bee relevant in the index generation were selected from the data set and included in the Factor Analysis on SPSS and choosing the Varimax rotation method (see Table 33 in the Appendix).

Afterward, according to the Kaiseron's criterion seven factors were created.
Kaiseron's criterion states that it is recommended retaining all factors with eigenvalues greater than 1. This criterion is based on the idea that the eigenvalues represent the amount of variation explained by a factor and that an eigenvalue of 1 represents a substantial amount of variation[19].
Factors are statistical entities that can be visualized as classification axes along which measurement variables can be plotted [19].
After using the Point of Inflection criterion it was decided to retain only the first three factors; this technique, well explained in Andy Field's Manual [19] intends to plot a graph of each eigenvalue (Y-axis) against the factor to which it is associated (X-axis).
The graph is known as a scree plot. Through graphing the eigenvalues, the relative importance of each factor becomes apparent. This graph has a very characteristic shape: there is a sharp descent in the curve followed by a tailing off.
The point of inflexion is where the slope of the line changes dramatically; then the point of inflexion is the data point at which these two lines meet. In this case (Figure 2) the point of inflexion occurs at the forth data point (factor); therefore, three factors were extracted.

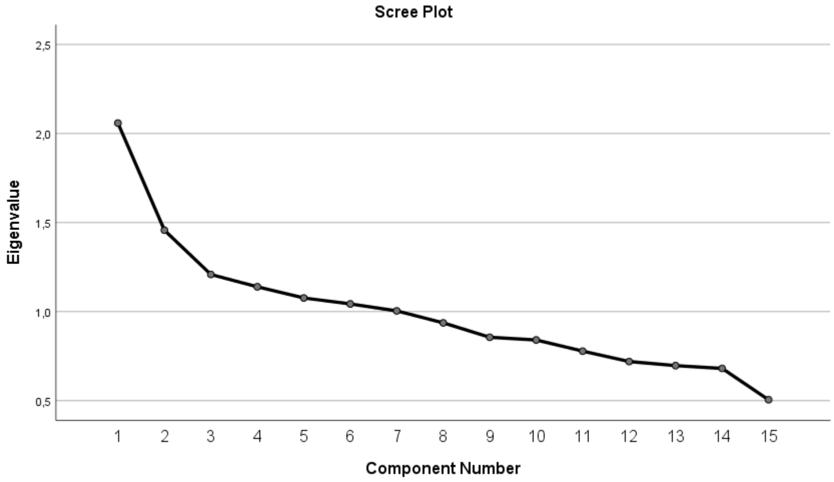

Figure 2: Scree Plot

The total variance explained by the three factors is 31,493% of the total variance; respectively:

Factor	Variance explained (% of the total)
Factor 1	13,723
Factor 2	9,715
Factor 3	8,056

Table 6: Percentage of the total variance explained by each factor.

Following the directives of Vijaya Krishnan [36] a Non Standardized Coefficient was calculated, according to the formula (2):

$$NSI = (\frac{Var1}{TotVar})Factor1score + (\frac{Var2}{TotVar})Factor2score + (\frac{Var3}{TotVar})Factor3score \tag{2}$$

where:

- NSI is the Non Standardized Index
- $Var1$, $Var2$ and $Var3$ are the percentage of explained variance respectively of factor 1, 2 and 3
- $TotVar$ is the sum of all the percentages variance of the three factors
- $Factor1scores$, $Factor2scores$ and $Factor3scores$ are the factor scores of each factor; generally speaking, factor scores are composite variables which give information about an individual's placement on the factor(s) [15];

The value of the Non Standardized Index can be positive or negative, making it difficult to interpret. Therefore, a Standardized Index (SI) was developed [36]:

$$SI = \frac{(NSI - minNSI)}{(maxNSI - minNSI)} 100 \tag{3}$$

where:

- SI is the Standardized Index, thereby the WI
- $minNSI$ is the minimum value of the NSI
- $maxNSI$ is the maximum value of the NSI

Once having obtained the final WI a classification in quintiles was done, as recommended by Bottone Rossella [7] and by the World Food Program Vulnerability Analysis Guidelines; the wealth index quintiles divide the whole population into five equally large groups, based on their wealth rank.
Levene's test for homogeneity of variances was also used to test whether the variance in scores was the same for each of the five groups (quintiles) [19].

2.5 Calculation of a water carrying related risk score

A water carrying related risk score was calculated for women currently involved in water carrying based on data generated during the observation of women's water carrying practice.
The calculation of the score followed the method suggested by 'SuvaPro' – Secteur de la Protection de la santé en Suisse [47].
The risk score was integrated as a predictor into the three models generation.
The score is a variable that considers different aspects of handling and moving of a heavy load (such as the body position during lifting and lowering; the amount of load being carried, etc.) and it tries to determine a potential health risk, especially on the dorso-lumbar region, by creating a score which corresponds to the final variable; the document proposed by the Health Protection Service of Switzerland [47] reports also a related danger scale able to give information about the type and the degree of danger people could have when having a certain score, the total score is a good indicator of the measures to take in order to prevent and/or take care of the health issues.
Four criteria were employed in the score evaluation: weights of the charge, posture, execution conditions and solicitation duration.

Therefore the four steps of the score evaluation are:

1. Time evaluation (Table 7): there are three different methods for this calculation based on the three different possible situations. i) It considers the number of trips per day (frequency) when it comes to short lifting/lowering process; ii) it considers the total time spent per day in minutes (product of trips per day and time for each trips) when the process of interest is the carrying and the supporting of a load in a still position; finally iii) it considers the total distance walked per day (product of distance of each trip times the number of trips per day) when it comes to load transport.

Manual lifting or transporting processes (<5 s) Number of processes per day	**Carrying and sustaining (>5 s) Total duration per day**	**Transporting (>5 m) Total journey per day**	**Time evaluation**
<10	<5 min	<300 m	1
10 to <40	5 to 15 min	300 m to <1 km	2
40 to <200	15 min to <1 h	1 to <4 km	4
200 to <500	1 to <2 h	4 to <8 km	6
500 to <1000	2 to <4 h	8 to <16 km	8
>1000	>4 h	>16 km	10

Table 7: Time evaluation

2. Charge evaluation (Table 8): it is differently assessed for women and men; the effective load weight in kilograms is used.

Effective charge for men	Effective charge for women	Charge evaluation
<10 kg	<5 kg	1
10 to <20 kg	5 to <10 kg	2
20 to <30 kg	10 to <15 kg	4
30 to <40 kg	15 to <25 kg	7
>40 kg	>25 kg	25

Table 8: Charge evaluation

3. Posture evaluation (Table 9): the posture is evaluated by considering the posture characteristics during the activity of manipulation of the load; the characteristics are: straight back; back torsion; distance between the charge and the body; back inclination.

Posture, load position	Posture evaluation
- Straight back - Load close to the body	1
- Low inclination or twist of the back - Load close to the body	2
- Deep flexion or strong inclination - Low inclination and twist of the back at the same time - Load far from the body	4
- Strong inclination and twist of the back at the same time - Load far from the body - Reduced stability	8

Table 9: Posture evaluation

4. Execution evaluation (Table 10): it considers the overall external conditions where the activity is carried out, such as ergonomic conditions, space availability and type of soil.

Execution conditions	Execution evaluation
Good ergonomic conditions (e.g. sufficient space, no obstacles in the work area, flat non-slippery floor, sufficient lighting, good grip conditions)	0
Restricted movement freedom and unfavorable ergonomic conditions (e.g. limited travel due to lack of height or work-space less than 1,5 m^{2}; lack of stability due to soft or uneven soil)	1
Severely restricted freedom of movement and / or instability of the center of gravity of the load	2

Table 10: Execution evaluation

The final score is obtained by summing the score of charge, posture and execution and multiplying the result by the time evaluation score:

$$FinalRisk = (ChargeScore + PostureScore + ExecutionScore)TimeScore \tag{4}$$

Risk level	Final risk score	Description
1	<10	Low solicitation, danger due to physical overwork is unlikely.
2	>10	Increased solicitation, physical overexertion is possible for people with reduced resistance. Ergonomic measures are recommended.
3	>25	High solicitation, overwork is also possible for people with normal resistance. Ergonomic measures and/or training measures are essential for this group of people.
4	>50	Extreme solicitation, physical overwork is also possible for people who have received the necessary instruction and fully trained professionals. Ergonomic adjustments as well as organizational and/or training measures are essential

Table 11: Final evaluation

Table 11 describes the potential risk and recommended measures, associated to a certain score. A risk range is created: from 1 to 4, with a corresponding increasing probability of having consequences over the health.

The following decisions were taken during the calculation of the risk score. During each calculation step the variables that yielded a higher score were selected. Some variables or evaluation methods were preferred with respect to others because they provided a higher score. For instance, in the time evaluation procedure, all three of the methods presented above were calculated, the method of the total time spent per day (ii) gave the highest score, therefore it was later included in the final risk score; when assessing the posture evaluation both lifting and lowering variables were initially calculated, the lifting variables were used since reporting a higher risk score.
In the load evaluation the mean water load was used.
Since the provided data set did not include a variable directly representing the stability of the posture, the variable about the position of the feet was used; this variable reported if the feet were far apart from each other during the observation. As recommended in the Eawag Research Manual [31] the position of the feet at a certain distance helps in maintaining a certain body stability.
When assessing the execution conditions evaluation the score was fixed at 1 (see Table 10) as suggested by the interviewer team who went on site for the data collection.

2.6 Water Supply System design

2.6.1 Site and piping path definition

When starting the WSS project, it was necessary to find a cluster of households and their corresponding water source from which women collect water from. The choice of the cluster was primarily done looking for one representative of the entire sample, and therefore having a good reproducibility.

Altitudes of the water sources and households were available; whilst coordinates were available only for the households.
In order to find the coordinates of the source -fundamental for the creation of the piping system- a method was implemented on qGIS software. First coordinates of the houses were entered, then buffers around them were created. Their rays were equal to distances women of these households

reported to walk every day to the source. The buffering procedure on qGIS created two areas (see Figure 3): one area that is within a specified ray (the distance) to selected real world features (the houses coordinates) and the other area that is beyond. The area that is within the specified distance is called the buffer zone and in this project was circle-shaped [65].
In this example the source was identified as the intersection point in the low-left area of the buffers zone (blue circle on figure 3). For this achievement a minimum of three buffers, hence three households were necessary.
This procedure was adopted despite some uncertainties: interviewers walking with the woman registered, on the GPS, a tracked distance, whereas the distance used in this procedure was a ray between two points; the intersection points could result unclear, maybe due to the presence of several sources.
The choice of the source location was carried out by applying the up-written method and a careful observation of the satellite image of the area on Google Earth (see Figure 4), in order to have a clearer idea of the site morphology. Furthermore the altitude of the source was available from the data-set, hence it was adopted as verification tool on Google-Earth to compare its value with the one of the intersection point (source) on qGIS.

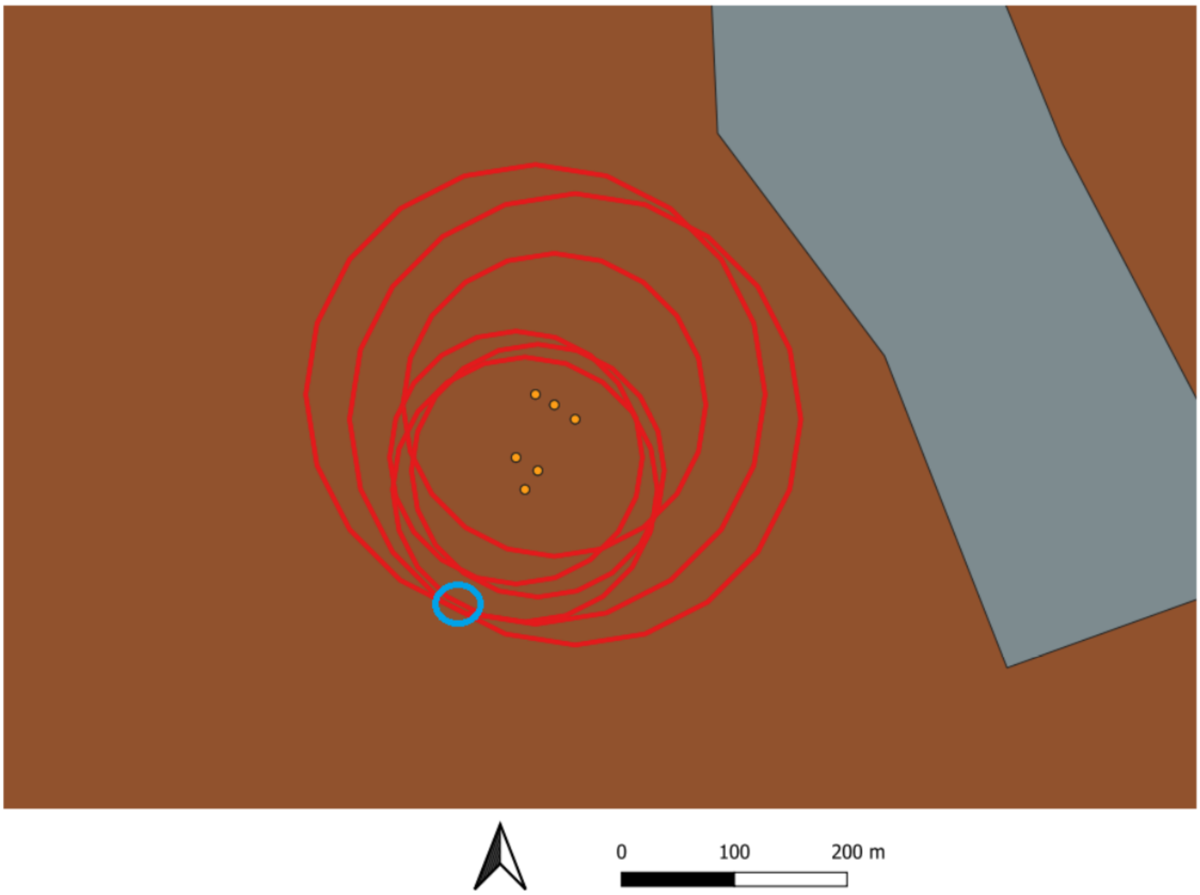

Figure 3: Intersection of buffers on qGIS

In the satellite image, the yellow dots represent the households whose coordinates were available, blue lines are the main and secondary water pipelines, the light-blue square represents the water-tank close to the source (on the left extremity).

Figure 4: Satellite image. Note three sub-groups of households (one for each sub-branch of the main pipe).

2.6.2 Project and dimensioning of the supply system

Once the households cluster was identified, the water flow has been calculated.
Considering a mean water flow per day of 100 l/inh [39][49] and on average five persons per household, a total of 500 l per day per household were calculated.
It is fundamental to clarify that during the whole project water from the source was assumed drinkable -no data were available about the quality-, therefore any treatment system has not been included here.

2.6.3 Water demand variation

A water distribution system is typically designed to cater for the maximum hourly demand [27][49]. Nepalese WSS guideline [49] set the annual population growth rate in rural village area at 2,3%; the WSS was assumed to have a useful service life of 30 years. With these data it was possible to calculate the population growth factor with the following formula:

$$P_{gf} = (1 + \frac{P_{gr}}{100})^{y} \tag{5}$$

Where:

- P_{gf} is the population growth factor
- P_{gr} is the fixed population growth rate (%)

- y is the number of service years

The ultimate water demand was therefore calculated multiplying the actual population amount by the population growth factor.

2.6.4 Capture system

The major components in the design of a spring-source water supply system include the actual spring water collection area – where water from the aquifer is actually being channelled to a single discharge point – the supply pipe, the collection chamber, and the outlet to a storage tank [27] (see Figure 5).
From satellite images and reported information, the collection mechanism at the water spring appeared already installed and functioning.
Details regarding the type of spring (depression or tubular) or its daily yield were not available, insights into the capture system building were likewise not provided. For this reason the supply system design actually started from the supply pipelines.

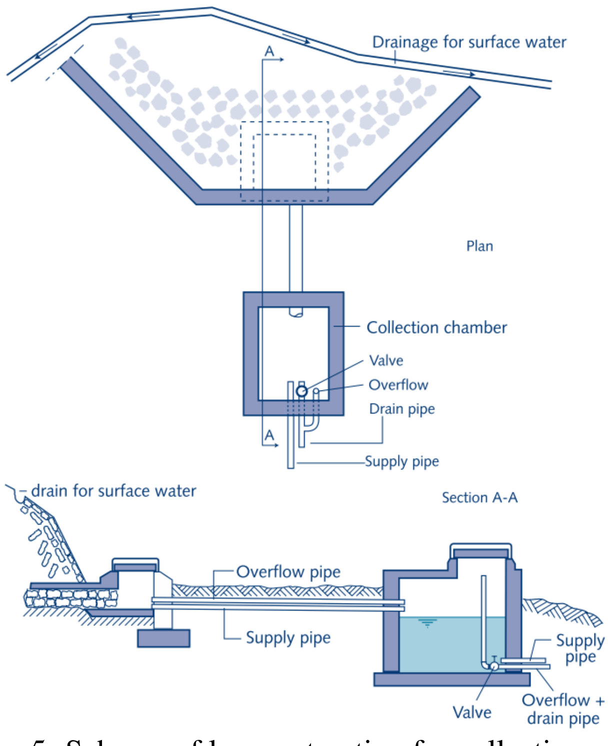

Figure 5: Scheme of low cost option for collection area

Something that deserves particular attention is the protection of the source and the direct spring surroundings [27], for two main reasons: (i) to improve the recharge of the aquifer, and (ii) to prevent contamination of the groundwater. It involves planning, implementation and commitment to refrain from or substantially reduce human activities that could cause adverse effects on the quality and quantity of the water from the spring. Production of fodder grass and crops not requiring application of chemicals are permitted, but the feeding of animals on this fodder grass should be outside the source area. Protection rules and other decisions are rather made by local communities after analysing the situation and the most suitable actions that can be taken.
Although trees stabilise the soil and reduce erosion, they should be carefully selected to those that compete for water (such as eucalyptus). Useful trees are, for example, pines [27].
The immediate area around the spring (about 50 m radius) should be fenced with barbed wire or an alternative barrier decided by the local users. Moreover, definitely, no human activities such as farm-

ing, grazing and hunting should be allowed in the source surroundings [27][39][49].

2.6.5 Transmission system to water-tank

In this part of the project the transmission design, dimensioning methods for pipes and water tank will be explained.
The water pipelines can be made of different materials.
The transmission pipelines was designed from the spring source to the water-tank storage [27]. The altitude (m) at which the storage tank should be settled is evaluated from the following formula (6):

$$H_{wt} = z_{hh} + a_{hh} + c \tag{6}$$

Where:

- H_{wt} is the altitude of the water-tank (m)
- z_{hh} is the altitude of the closer household to the source (m)
- a_{hh} is the average height of households, in this case it was fixed at 3 m
- c represents a constant that usually varies between 5 and 10 m, useful to include head losses in the system

In order to find out the correct diameter for the transmission lines, the difference in altitude between the source (H_s) and the water-tank was evaluated, Equation 7:

$$\Delta H = H_s - H_{wt} \tag{7}$$

Once this data was available the calculation of the diameter was carried out using the Equation 8 [27][39][49]. It takes into account the distributed and concentrated head losses. The firsts occur because of the friction inside pipes; the second ones are mostly linked to the inlet of water into the pipe from the spring, and the outlet of water into the water-tank from the pipe.

$$\Delta H = \beta \frac{Q^2}{D^{5,33}} L + k_{in} \frac{v^2}{2g} + k_{out} \frac{v^2}{2g} \tag{8}$$

Where:

- β is a coefficient that considers the effective roughness of materials, it is equal to $\frac{10,33}{k_s}$, where k_s is the Strickler-Manning coefficient $\frac{m^{1/3}}{s}$; for polyethylene PE pipelines is 80 $\frac{m^{1/3}}{s}$
- Q is the total water-flow for the whole village ($\frac{m^3}{s}$)
- D is the unknown diameter (m)
- L is the total length of the pipeline (m)
- k_{in} is the coefficient that determines the head loss at the inlet, its value is 0,5
- k_{out} is the coefficient that determines the head loss at the outlet, its value is 1
- v is the velocity of the water inside the pipe ($\frac{m}{s}$), it is evaluated as $\frac{Q}{\Omega}$, where ω is the section of the pipe (m^2): $\pi\frac{D}{4}^2$

- g is the constant of gravitational acceleration (9,8 $\frac{m}{s^2}$)

Once the previous equation was applied, the theoretical diameter was found. Hence an effective diameter, larger than the theoretical one was found and chosen from PE pipelines catalogue [53].

The design proceeded with the water-storage assessment (m^3) [1]; the total volume of a water-tank in a supply system is evaluated as the sum of three volumes (Equation 9):

$$V_t = V_r + V_f + V_c \tag{9}$$

Where:

- V_t is the volume of the tank (m^3)
- V_r is the reserve volume (m^3), namely the capacity of the reservoir associated with interruptions of the water supply; it is calculated as the daily volume requested on the day of maximum peak on the day of maximum peak (24 hours)
- V_f is the firefighting volume (m^3); its value was here considered equivalent to the reserve capacity value
- V_c is the compensation capacity (m^3), meaning the amount of water necessary to compensate variations/fluctuations in the daily water demand; it was estimated as the product between the daily volume requested on the day of maximum peak on the day of maximum peak and a coefficient of 0,25

When adopting an effective diameter of the pipelines larger then the theoretical one the water flow increases. A valve is therefore necessary for the flow control; it could also result useful for eventual stops of the system.
The valve must be regulated in accordance to the value of head it must support; this is calculated by using the Equation 8 and adding a new unknown term: ΔH_v (head loss at the valve in m). In this case the diameter D (effective) is known and applied.

2.6.6 Distribution system from storage tank to houses groups

For the design of the distribution system a 'simplified method' (in Italian it is called 'Acquedotto consortile') was applied, which is often adopted for WSS in mountainous or hilly regions [1][49].
This method is based on the research of the main pipe diameters (m). It assumes that the main pipe is split into as many sections as the principal groups of houses of the village. The first section of the main pipe must be designed to provide the whole village water demand; once the first group of households has been reached the water-flow decreases and the diameter too in order to serve the remaining households. The design for the following sections must be planned the same way. The last households represent the end of the scheme.
The secondary pipes -directed to the group of households- are usually smaller and shorter; in this procedure they are always ignored because they are considered less influential on the overall cost.
Two equations were applied: energy equation (10) and minimum cost equation (11).

$$Y = \sum_{j=1}^{b} \beta \frac{Q_j^2}{D_j^5,33} L_j \tag{10}$$

Where:

- Y is the difference in altitude between the water-tank and the lowest group of houses (m)
- j is an index varying accordingly to the pipe section whose diameter is the unknown variable
- b is the total number of sections
- β is the coefficient considering the Strickler-Manning coefficient $\frac{m^{1/3}}{s}$, related to the roughness of the material
- Q is the water-flow ($\frac{m^3}{s}$) that must be satisfied by the j section
- D is the unknown diameter (m) of the j section of the pipe
- L is the length (m) of the j section of the pipe

The minimum cost equation is:

$$C = [\frac{\beta}{Y}\sum_{j=1}^{b}(Q_j^{\frac{2\alpha}{5,33+\alpha}}L_j)]^{\frac{5,33+\alpha}{5,33}} \tag{11}$$

Where:

- α is an exponent coefficient obtained from an interpolation -with a power law- of the linear prices (e/m), taken as a function of the diameter

From the previous equations the values of the diameters of each section were calculated as follows:

$$D_j = C^{\frac{1}{5,33+\alpha}}Q_j^{\frac{2}{5,33+\alpha}} \tag{12}$$

As for the transmission system design, the effective available diameters that were chosen were larger than the theoretical ones obtained from the calculations.

2.6.7 Water storage and connections pipe-households

A single water tank located above all houses might represent a limitation: in case of problems or operational stops, all households would have no water available.
For this reason, installing small plastic containers at each households group (three different groups were identified in the cluster) was proposed as a solution to cover the autonomy for a short interval of time.
There are different options for the choice of water storage containers; different materials, shapes, sizes and applications. It is up to the users to choose the most suitable; in the next chapter one option will be provided in order to have an example of the type and, particularly its price.
Each household must be connected to the water pipeline. The connection of the pipework to the taps uses pipe-to tap fittings; these are available with either a compression and a solder joints onto the pipework - both use a screw fitting onto the tail of the tap and a fibre washer to make the seal. The tail is the threaded part going through the unit, is secured by a nut underneath and to which the water supply is connected. Shut-off valves are often a requirement for all new installations to isolate the taps if required in future - they are especially useful where a tap is fed directly from a storage tank (as in this case, the connection would be made with the small water tank installed at each sub-group of households); alternatively, a gate valve could be added to the outlet of the tank so all taps fed from it could be isolated from the one gate valve.

2.6.8 Excavation -pipes in narrow trenches-

Trenches of excavation can be both large or narrow (see Figure 6); in this case narrow trenches were chosen [27].
The condition that must be respect when dealing with narrow trench is: B≤2D and H≥ 1,5B.
Where B is the trench width, H the depth of pipe laying and D is the pipe diameter.

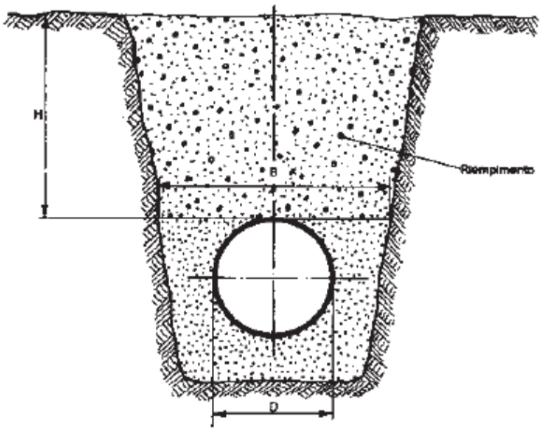

Figure 6: Narrow trench

When laying water pipelines underground some checks must be carried out to assess the resistance of the pipe to external and internal stress.
In this project three external loads (kN/m) were calculated and used in the pipe verification. The first load that was considered is related to the bury in narrow trench:

$$Q_b = c\gamma_g BD \tag{13}$$

Where:

- Q_b is the total bury load ($\frac{N}{m}$)
- c is the Marston coefficient:
$$c = \frac{1 - exp(-2k_a\mu\frac{H}{B})}{2k_a f} \tag{14}$$
  With:
  - k_a is the coefficient of active thrust equal to
  $$\tan^2(45 - \frac{\varphi}{2}) \tag{15}$$
  Where φ is the internal friction angle of the ground [°]
  - f indicates the coefficient of friction between undisturbed ground and ground, it is equal to
  $$\mu = \tan\varphi \tag{16}$$
- γ_g is the specific weight of the soil ($\frac{N}{m^3}$)
- B and D the details of excavation geometry up-described (m)

The second load that was included in the pipe check is linked to the pipe weight:

$$G_p = \gamma_p \pi D s \tag{17}$$

Where:

- γ_p is the specific weight of the pipe ($\frac{N}{m^3}$)
- s is the thickness of the pipe (m)

The third load considered the water weight:

$$G_w = \gamma_w \frac{\pi^2}{4} \tag{18}$$

Where:

- γ_w is the specific weight of water (9,78 $\frac{N}{m^3}$)

Four aspects were verified:

1. Flexibility test: a pipe is flexible if the condition $n \geq 1$ is respected. It is a necessary condition to carry on the next tests as well. n indicates the elastic coefficient, it is equal to:

$$\frac{E_g}{E_p}(\frac{r}{s})^3 \tag{19}$$

   Where:

   - E_g is the elastic modulus of the ground ($\frac{N}{m^2}$)
   - E_p is the elastic modulus of the pipe ($\frac{N}{m^2}$)
   - r is the annular rigidity ($\frac{N}{m^2}$)
   - s is the thickness of the pipe (m)

2. Static test of the maximum stress: in order to verify that stresses in the most vulnerable sections are lower than the maximum allowable for the material, it was necessary to calculate the specific stresses that occur in the three most significant points: at the top, on the side and at the bottom of the pipe. It was therefore needed to calculate the values of the parameters M (moment, N) and N (normal force, $\frac{N}{m}$) at the three significant points. They are functions of the angle of support (2α, in this case 180°), Q_b, G_p, G_w, H_0 ($\frac{N}{m}$, it indicates the uniformly reaction and it is equal to $\gamma HDNk_a$) and H_t ($\frac{N}{m}$, it is the horizontal thrust linearly distributed and it is equal to $\frac{\gamma_g D^2 k_a}{2}$). Once these parameters were found, the values of σ (stresses, $\frac{N}{m^2}$) were calculated:

$$\frac{N}{s} \pm 6\frac{M}{s^2} \tag{20}$$

   Positive and negative results of σ indicate traction and compression respectively.
   Since the traction stress is considered the worst [1][49], the most negative result of σ is used to find the pressure P_0 ($\frac{N}{m^2}$) that creates that same traction stresses due to external loads; the Mariotte formula was employed:

$$P_0 = \frac{2|\sigma|s}{D} \tag{21}$$

   Summing the pressure obtained from equation 21 to the maximum operational pressure (P_e) it was possible to compare the outcome to the Nominal Pressure of the material.

3. Maximum ovality test: the condition of acceptable ovality is $\frac{\Delta x}{D} \leq 4 - 8\%$ (see Figure 7). Δx was evaluated from the Splanger equation (22):

$$\frac{Q_b r^3}{E_p I} \frac{KF}{1 + 0,0061 \frac{E_g r^3}{E_p I}} \tag{22}$$

Where most of the terms were described in previous equations and:

- I is the moment of inertia equal to $\frac{s^3}{12}$ (m^3)
- K is a coefficient that can assume different value according to the support angle 2α
- F is a security factor whose range is $1,25 \div 1,50$

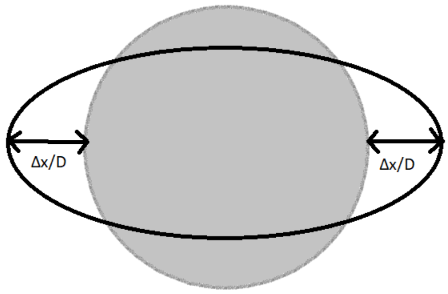

Figure 7: Maximum ovality for water pipe

4. Test of instability at elastic equilibrium: the condition that must be respected is $\Delta P + \frac{Q_b}{D} \leq \frac{P_c}{2,5}$ ΔP is the difference between external and internal pressure and P_c is the critical pressure $(\frac{N}{m^2})$, equivalent to:

$$P_c = \frac{2E_p}{1-\upsilon^2}(\frac{s}{D})^3 \tag{23}$$

Where υ is the Poisson modulus of the water pipe $(\frac{N}{m^2})$ and 2,5 is a security factor.

2.6.9 Service conditions

When installing a WSS there are some operational conditions for which standardized regulations should be respected.

1. Maximum consumption with minimum storage level in the water tank: $h \geq a + 5$ (m) where h is the water level with respect to the ground plan and a is the average height of households ($\approx$ 3 m)

2. Minimum consumption with maximum storage level in the water tank: $h \leq 50$ (m)

3. Water velocity $(\frac{m}{s})$ in the pipes should fall into the range: $0,5 \leq v \leq 2$

4. Reynolds' hypotheses on turbulence must be respected when applying all the up-reported formulas relative to the pipe design: $Re \gg 2000$

2.6.10 Costs

The final step of this WSS design was to evaluate its total cost and the monthly liability [27][49]. The total cost assessment included:

1. Capture structure: since the capture system was assumed already installed and functioning, its cost was considered not influencing the overall cost. An amount of money was anyway included in the contingent fund because some modifications or additions to this part of the WSS might be necessary.
2. Transmission pipeline: material and excavation costs were found, thus including the trench filling and the sand layer as well.
3. Water storage tank: excavation and concrete structure costs were evaluated.
4. Valve chamber: excavation, concrete material and valve costs were included.
5. Distribution pipeline: material and excavation costs were found both for main and secondary pipes.
6. Fittings such as small tanks at groups of households and water pipe connections to the households were calculated.
7. Contingency were added: modifications of the capture system, transport of material, elbows and extra valves of the supply system.
8. The Value Added Tax (VAT) of Nepal.

Once the total expenditure was calculated the monthly liability per household was found and compared to one suggested minimum water tariff in Nepal [25].
A rate of depreciation and annual maintenance was adopted in order to estimate the annual liability per household.

3 Results

3.1 Descriptive Statistics

The Descriptive Statistics tables are: table 34 for demographic frequencies, table 35 for the water load aspect frequencies, table 36, table 37 and table 38 for the health outcomes frequencies -referred to the three different categories of history of water collection-.
All these tables are presented in the Appendix section. The sample population was constituted only by women with an average age of 39 years.
78,5% of the sample population carried water at the time of the survey, the majority of women received help in water carrying (88,1% Table 35) and the methods through which they transported the container filled with water are: shoulders (51,5%), waist (47,3%) and head (1,2%).
The mean distance between the house and the water source is 74 m; the mean frequency of trips per day in rainy season is 2,63. It increases in the dry season (2,82), which is characterized by a more pronounced lack of water [45]; in this season 44,1% of women collect water from a source located farther than the village.
The mean of the maximum water loads in the dry season is 30,5 l, against the 24,56 l of the rainy season.
The mean value of the water carrying related risk score is almost three times higher in dry season with

respect to the rainy season (for example the number of trips per day, the water load in dry season are higher and make the water carrying related risk score higher).
Tables 36, 37 and 38 evidenced that there are more women currently or previously involved in water fetching, suffering from general pain (75,6% and 89,5%), than women who have never engaged themselves into this task (61,1%). Considerable percentages of women felt unhappy (30%, 29,4% and 18,6% respectively for the three categories of history of water collection) and complained about suffering from work (28,7%, 31,4% and 19,5%).

A summary descriptive table of the selected health outcomes percentages (for dichotomous variable) and mean value (for continuous variable) is here presented for the three different groups of women (currently, previously and never involved in water carrying) in order to highlight likely differences. Table 13 shows the percentage distribution (for categorical variables) and the min, max and mean value (for continuous variables) of some of the water-carrying and social factors considered key indicators of the water-carrying and social context. The values are again reported for the three different categories in which women have been split: currently, previously and never involved in water collection.

Health Outcomes		**Women currently involved in water collection**	**Women previously involved in water collection**	**Women never involved in water collection**
Intensity of pain at the head	mean	4,214 (N=145)	6,889 (N=9)	3,267 (N=15)
	min	1	1	1
	max	15	15	15
Intensity of pain at the neck	mean	4,323 (N=31)	5,750 (N=8)	1 (N=1)
	min	1	1	1
	max	15	12	1
Intensity of pain at the back	mean	4,350 (N=371)	5,828 (N=58)	3,970 (N=33)
	min	1	1	1
	max	15	15	12
UP	NO	87,6%	78,8%	94,7%
	YES	12,4%	21,2%	5,3%

Table 12: Frequency distribution and mean value of the health outcomes among different categories of women

The mean values of head, neck and back intensity of pain are the highest among women involved in water collection in the past, second among women currently involved and last among those who have never done it (see table 12). The same trend was found for the UP onset (table 12).

Main Water Carrying and Social Indicators		**Women currently involved in water collection**	**Women previously involved in water collection**	**Women never involved in water collection**
Distance [m]	mean	74,68 (N=945)	79,32 (N=114)	-
	min	0	0	-
	max	922	835	-
Water Carrying related risk score dry season	mean	59,462 (N=352)	-	-
	min	6	-	-
	max	168	-	-

Age of marriage	mean	18,24 (N=942)	15,58 (N=152)	19,24 (N=99)
	min	7	4	9
	max	45	30	30
Number of births	mean	2,93 (N=970)	5,62 (N=151)	2,17 (N=113)
	min	0	1	0
	max	12	15	26*
Wealth Index	poorest	21,2%	-	10,3%
	2	20,1%	-	19,6%
	3	19,9%	-	21,5%
	4	19,7%	-	22,4%
	wealthiest	19,1%	-	26,2%

Table 13: Frequency distribution and mean value of some water carrying and other indicators among different categories of women. *Notes: *It must be an outlier*.

Mean value of distance walked by women in the past seems to be higher than nowadays. Mean value of age of marriage was lower in the past, moreover women never involved in water collection have the highest mean value. The number of births given was also higher in the past. The distribution of the women into the WI quintiles are not available for those involved in the past in water carrying, but it is possible to notice a different behaviour between women currently involved and those never involved. For the first group, as the WI index increases the percentage of women decreases, for the second group of women it is the contrary; thus, out pointing an overall higher wealth status among women who do not practice water collection.

3.2 First Set of Analysis

The results from the first set of analysis (see page 18 in section 2) are represented in the following tables.

As Table 14 shows, pain location at the ankles is the only location where women that carried water in the past have a statistically significant higher OR with respect to women who have never practiced water carrying: OR=2,353; p-value= 0,025 and 95%CIs= 1,111; 4,985.
Where Beta is the gradient coefficient, 'NV' means that it was not possible running the GEE for that variable.
No other of the health outcomes were associated with a history of water carrying.
Since the relevant OR was found for women involved in water carrying in the past, the further GEE analysis were run by selecting water-carrying-related factors of the past.

Pain location	Predictor variable	N	p-value	OR	L95% CI	U95% CI
Head	intercept		0.116	2.198	0.822	5.875
	women currently involved	736	0.963	1.012	0.610	1.679
	women previously involved	136	0.088	2.336	0.881	6.191
	women never involved	69		1		
	age	941	0.031	1.017	1.001	1.032
Neck	intercept		0.000	127.501	22.220	731.620
	women currently involved	736	0.194	0.385	0.091	1.627
	women previously involved	136	0.312	0.448	0.095	2.121

	women never involved	69		1		
	age	941	0.111	0.980	0.956	1.005
Back	intercept		0.375	1.192	0.809	1.755
	women currently involved	736	0.825	0.920	0.441	1.921
	women previously involved	136	0.516	1.353	0.544	3.362
	women never involved	69		1		
	age	941	0.540	0.997	0.988	1.006
Muscles of the arms	intercept		0.000	11.763	5.101	27.125
	women currently involved	736	0.351	0.659	0.274	1.583
	women previously involved	136	0.634	0.776	0.272	2.210
	women never involved	69		1		
	age	941	0.003	0.982	0.970	0.994
Shoulders	intercept		0.000	13.974	8.167	23.912
	women currently involved	736	0.258	1.192	0.880	1.614
	women previously involved	136	0.777	1.115	0.524	2.371
	women never involved	69		1		
	age	941	0.031	0.985	0.972	0.999
Elbows	intercept		0.000	26.294	6.965	99.268
	women currently involved	736	0.966	0.984	0.463	2.089
	women previously involved	136	0.725	0.816	0.263	2.530
	women never involved	69		1		
	age	941	0.191	0.985	0.962	1.008
Joints of hands	intercept		0.000	26.829	11.961	60.177
	women currently involved	736	0.051	0.559	0.311	1.003
	women previously involved	136	0.293	0.612	0.245	1.529
	women never involved	69		1		
	age	941	0.001	0.977	0.963	0.991
Fingers	intercept		0.000	161.231	30.508	852.075
	women currently involved	736	0.259	2.617	0.493	13.901
	women previously involved	136	0.699	0.653	0.075	5.686
	women never involved	69		1		
	age	941	0.155	0.973	0.937	1.010
Muscles of legs	intercept		0.000	14.946	8.536	26.168
	women currently involved	736	0.157	0.715	0.449	1.138
	women previously involved	136	0.855	1.061	0.559	2.014
	women never involved	69		1		
	age	941	0.021	0.983	0.969	0.997
Hips	intercept		0.000	7.468	2.725	20.464
	women currently involved	736	0.986	0.993	0.432	2.282
	women previously involved	136	0.708	0.755	0.173	3.296
	women never involved	69		1		
	age	941	.431	1.011	0.983	1.040
Knees	intercept		0.000	3.216	1.690	6.121
	women currently involved	736	0.254	0.796	0.538	1.178
	women previously involved	136	0.070	0.602	0.348	1.042
	women never involved	69		1		
	age	941	0.000	0.977	0.971	0.982
Ankles	intercept		0.000	6.488	3.724	11.305

	women currently involved	736	0.148	1.776	0.816	3.868
	women previously involved	136	0.025	2.353	1.111	4.985
	women never involved	69		1		
	age	941	0.001	0.984	0.975	0.993
Feet	intercept		0.000	22.556	8.512	59.769
	women currently involved	736	0.295	1.677	0.637	4.411
	women previously involved	136	0.968	0.983	0.434	2.226
	women never involved	69		1		
	age	941	0.002	0.989	0.983	0.996

Table 14: Logistic GEE model for pain location according to history of water carrying, adjusted for the age and accounting for clusters.

Notes: N=number of cases, p-value=probability value, OR=Odd Ratio, L95%95CI=Lower Confidence Interval, U%95CI=Upper, NV=Not valid; Confidence Interval; Probability Distribution=Binomial; Link Function=Logit. All p values are two-tailed.

Water-carrying-related factors referring to the past were included in the GEE elaboration: the variable declaring if they transported water in the past, the maximum water load transported in the past, the mean water load transported in the past, the time in minutes spent to reach the water source, the type of path walked in the past to reach the water source (up-hill = 0, down-hill = 1).
The bivariate analysis GEE and the multivariate analysis GEE results are reported in table 15.

Predictors	**Bivariate GEE**					**Multivariate GEE: Final**				
	Beta	SE	p	OR	CI 95% (LO-UP)	Beta	SE	p	OR	CI 95% (LO-UP)
intercept						0,727	0,316	0,021	2,070	1,114 ; 3,845
water transport in the past 0 = no 1 = yes	NV									
maximum water load	0,039	0,013	0,003	1,04	1,014 ; 1,067					
mean water load	0,035	0,010	**0,001**	**1,035**	1,015 ; 1,056	0,038	0,012	**0,002**	**1,039**	1,014 ; 1,064
minutes to the source	0,006	0,0046	**0,200**	**1,006**	0,997 ; 1,015	0,002	0,004	0,506	1,002	0,995 ; 1,009
up/down -hill to the source	NV									

Table 15: Water carrying factors associated with pain in the ankles among women carrying water in the past.

Notes: Beta=gradient coefficient , SE=Standard Deviation, p=probability value, OR=Odd Ratio, CI=Confidence Interval, LO-UP=lower-upper; Probability Distribution=Binomial; Link Function=Logit. All p values are two-tailed.

3.3 Second Set of Analysis

Biivariate GEE and multivariate GEE results are in tables 16 for the intensity of pain at the head, 17 for the neck, 18 for the back and 19 for the UP.
The significant values are in bold font.

Predictors	**Bivariate GEE**					**Multivariate GEE: Model 2**				
	Beta	SE	p	OR	CI 95% (LO-UP)	Beta	SE	p	OR	CI 95% (LO-UP)
intercept						0,658	0,786	0,403	1,932	0,414 ; 9,022
distance	-0,002	0,001	**0,000**	**0,998**	0,997 ; 0,999	-0,010	0,003	**0,000**	**0,990**	0,984 ; 0,996
trips per day rainy season	0,169	0,1477	0,252	1,184	0,887 ; 1,582					
trips per day dry season	0,225	0,110	**0,042**	**1,253**	1,008 ; 1,556	0,239	0,548	0,664	1,270	0,433 ; 3,722
absolute value of difference in altitude	-0,008	0,006	0,180	0,992	0,980 ; 1,004					
up/down -hill to the source rainy season	-1,424	0,275	**0**	**0,241**	0,140 ; 0,413	-1,486	0,715	**0,038**	**0,226**	0,056 ; 0,919
up/down -hill to the source dry season	1,807	2,317	0,435	6,092	0,065 ; 571,264					
loading on the head	NV									
loading on the waist	0,559	0,213	**0,009**	**1,749**	1,152 ; 2,654	-0,500	1,069	0,640	0,606	0,075 ; 4,928
loading on shoulders	-0,559	0,213	0,009	0,572	0,377 ; 0,868					
water carry risk score dry season	-0,008	0,006	**0,162**	**0,992**	0,981 ; 1,003	0,030	0,007	**0,000**	**1,031**	1,017 ; 1,044
water carry risk score rainy season	-0,004	0,014	0,761	0,996	0,969 ; 1,024					
type of source rainy season	0,003	0,285	0,991	1,003	0,575 ; 1,752					
type of source dry season	0,338	0,270	0,210	1,403	0,827 ; 2,380					

help in water carrying	1,365	0,349	**0**	**3,915**	1,974 ; 7,765	4,288	1,334	**0,001**	**72,814**	5,326 ; 995,471
maximum water load rainy season	-0,015	0,006	0,018	0,985	0,974 ; 0,997					
mean water load rainy season	-0,022	0,005	**0,000**	**0,978**	0,968 ; 0,987	0,123	0,081	0,131	1,131	0,964 ; 1,325
maximum water load dry season	-0,011	0,011	0,297	0,989	0,968 ; 1,010					

Table 16: Water carrying factors associated with intensity of pain in the head among women currently carrying water.

Notes: Beta=gradient coefficient , SE=Standard Deviation, p=probability value, OR=Odd Ratio, CI=Confidence Interval, LO-UP=lower-upper; Probability Distribution=Normal; Link Function=Identity. All p values are two-tailed.

Predictors	**Bivariate GEE**					**Multivariate GEE: Model 2**				
	Beta	SE	p	OR	CI 95% LO-UP	Beta	SE	p	OR	CI 95% LO-UP
intercept						0,843	2,462	0,732	2,322	0,019 ; 289,163
distance	0,000	0,003	0,954	1	0,994 ; 1,005					
trips per day rainy season	-0,042	0,128	0,742	0,959	0,746 ; 1,232					
trips per day dry season	-0,694	0,269	**0,01**	**0,499**	0,295 ; 0,846	-0,506	0,390	0,194	0,603	0,281 ; 1,294
difference in altitude	-0,014	0,008	**0,084**	**0,986**	0,97 ; 1,002	0,004	0,012	0,729	1,004	0,980 ; 1,029
absolute value of difference in altitude	-0,001	0,008	0,873	0,999	0,983 ; 1,014					
up/down -hill to the source rainy season	4,500	3,522	0,201	90,017	0,090 ; 89546,954					
up/down -hill to the source dry season	3,833	3,749	0,307	46,216	0,030 ; 71723,696					

loading on the head	8,000	0,7371	**0**	**2980,958**	702,92 ; 12641,713	NV				
loading on the waist	1,211	1,317	0,358	3,357	0,254 ; 44,39					
loading on shoulders	-2,326	1,905	0,222	0,098	0,002 ; 4,086					
water carry risk score dry season	0,001	0,023	0,949	1,001	0,958 ; 1,047					
water carry risk score rainy season	0,018	0,038	0,625	1,019	0,946 ; 1,097					
type of source rainy season	0,296	0,829	0,722	1,344	0,265 ; 6,826					
type of source dry season	0,508	0,378	**0,18**	**1,661**	0,791 ; 3,487	1,506	1,155	0,192	4,507	0,469 ; 43,345
help in water carring	-2,528	1,236	**0,041**	**0,08**	0,007 ; 0,899	-0,779	2,513	0,757	0,459	0,003 ; 63,157
maximum water load rainy season	0,016	0,0173	0,363	1,016	0,982 ; 1,051					
mean water load rainy season	0,007	0,015	0,63	1,007	0,979 ; 1,036					
maximum water load dry season	-0,006	0,010	0,555	0,994	0,974 ; 1,014					
mean water load dry season	-0,006	0,009	0,462	0,994	0,977 ; 1,010					

Table 17: water carrying factors associated with intensity of pain in the neck among women currently carrying water.

Notes: Beta=gradient coefficient , SE=Standard Deviation, p=probability value, OR=Odd Ratio, CI=Confidence Interval, LO-UP=lower-upper; Probability Distribution=Normal; Link Function=Identity. All p values are two-tailed.

Predictors	**Bivariate GEE**					**Multivariate GEE: Model 2**				
	Beta	SE	p	OR	CI 95% (LO-UP)	Beta	SE	p	OR	CI 95% (LO-UP)
intercept						4,061	2,023	0,045	58,006	1,100 ; 3060,055

distance	0,001	0,001	0,271	1,001	0,999 ; 1,003					
trips per day rainy season	0,177	0,055	**0,001**	**1,193**	1,071 ; 1,330	0,429	0,295	0,146	1,535	0,861 ; 2,737
trips per day dry season	0,377	0,265	0,154	1,457	0,868 ; 2,447					
difference in altitude	0,027	0,013	**0,039**	**1,027**	1,001 ; 1,054	0,032	0,024	0,174	1,033	0,986 ; 1,081
absolute value of difference in altitude	0,022	0,016	0,159	1,022	0,991 ; 1,054					
up/down -hill to the source rainy season	2,101	0,941	**0,026**	**8,178**	1,293 ; 51,738	1,186	1,444	0,411	3,275	0,193 ; 55,481
up/down -hill to the source dry season	1,721	0,899	0,056	5,590	0,958 ; 32,618					
loading on the head	3,281	0,399	**0,000**	**26,595**	12,170 ; 58,119	NV				
loading on the waist	0,365	0,096	0,000	1,440	1,194 ; 1,737					
loading on shoulders	-0,538	0,210	0,010	0,584	0,387 ; 0,880					
water carry risk score dry season	0,008	0,004	**0,04**	**1,008**	1,000 ; 1,015	-0,006	0,015	0,705	0,994	0,966 ; 1,023
water carry risk score rainy season	0,000	0,006	0,940	1,000	0,987 ; 1,012					
type of source rainy season	-0,527	0,265	**0,046**	**0,590**	0,351 ; 0,992	-0,098	0,200	0,623	0,906	0,612 ; 1,342
type of source dry season	-0,353	0,333	0,297	0,703	0,362 ; 1,363					
help in water carrying	0,612	0,410	**0,135**	**1,844**	0,826 ; 4,118	-1,030	0,218	**0,000**	**0,357**	0,233; 0,547
maximum water load rainy season	-0,015	0,006	0,018	0,985	0,974 ; 0,997					
mean water load rainy season	-0,022	0,005	0	0,978	0,968 ; 0,987					

maximum water load dry season	0,034	0,010	**0**	**1,035**	1,015 ; 1,054	-0,018	0,038	0,627	0,982	0,912 ; 1,057
mean water load dry season	0,038	0,027	0,154	1,039	0,986 ; 1,094					

Table 18: Water carrying factors associated with intensity of pain in the back among women currently carrying water.

Notes: Beta=gradient coefficient , SE=Standard Deviation, p=probability value, OR=Odd Ratio, CI=Confidence Interval, LO-UP=lower-upper; Probability Distribution=Normal; Link Function=Identity. All p values are two-tailed.

Predictors	**Bivariate GEE**					**Multivariate GEE: Model 2**				
	Beta	SE	p	OR	CI 95% LO-UP	Beta	SE	p	OR	CI 95% LO-UP
intercept						2,012	0,334	0,000	7,475	3,887 ; 14,373
distance	-0,002	0,001	**0,005**	**0,998**	0,997 ; 0,999	-0,002	0,002	0,114	0,998	0,994 ; 1,001
trips per day rainy season	-0,094	0,029	**0,001**	**0,91**	0,86 ; 0,963	-0,138	0,099	0,168	0,871	0,716 ; 1,060
trips per day dry season	-0,082	0,051	0,111	0,921	0,833 ; 1,019					
difference in altitude	-0,011	0,002	**0**	**0,99**	0,987 ; 0,992	-0,010	0,007	0,125	0,990	0,977 ; 1,003
absolute value of difference in altitude	-0,011	0,004	0,002	0,989	0,982 ; 0,996					
up/down -hill to the source rainy season	0,184	0,247	0,456	1,202	0,741; 1,948					
up/down -hill to the source dry season	1,087	0,517	**0,036**	**2,964**	1,073 ; 8,19	0,815	0,482	0,091	2,259	0,878 ; 5,811
loading on the head	-1,324	0,215	0	0,266	0,174 ; 0,406					
loading on the waist	1,059	0,261	**0**	**2,884**	1,729 ; 4,811	1,022	0,338	**0,003**	**2,780**	1,432 ; 5,396
loading on shoulders	-0,934	0,233	0	0,393	0,249 ; 0,62					
water carry risk score dry season	-0,012	0,005	0,017	0,988	0,978 ; 0,998					
water carry risk score rainy season	-0,009	0,003	**0,003**	**0,991**	0,985 ; 0,997	0,005	0,008	0,544	1,005	0,989 ; 1,021

type of source rainy season	-0,233	0,153	**0,128**	**0,792**	0,587 ; 1,07	-0,042	0,165	0,797	0,958	0,693 ; 1,325
type of source dry season	0,168	0,256	0,51	1,183	0,717 ; 1,953					
help in water carrying	-0,216	0,294	0,463	0,806	0,453 ; 1,433					
maximum water load rainy season	-0,012	0,0044	**0,004**	**0,988**	0,979 ; 0,996	0,002	0,0150	0,909	1,002	0,973 ; 1,032
mean water load rainy season	-0,011	0,006	0,054	0,989	0,977 ; 1,000					
maximum water load dry season	-0,009	0,006	0,127	0,991	0,980 ; 1,003					
mean water load dry season	-0,014	0,011	0,187	0,986	0,965 ; 1,007					

Table 19: Water carrying factors associated with UP among women currently carrying water.

Notes: Beta=gradient coefficient , SE=Standard Deviation, p=probability value, OR=Odd Ratio, CI=Confidence Interval, LO-UP=lower-upper; Probability Distribution=Binomial; Link Function=Logit. All p values are two-tailed.

3.4 Third Set of Analysis

In this case the number of variables drastically increased because it considered all the different domains: water-carrying-related as well as non-water-carrying-related (general and family Table 29, other habits 30 and pregnancy 31, in section 6).
For this reason only the final multivariate GEE model results have been reported, without each bivariate GEE.

It was also decided to indicate the result of the 1-tailed significance beside the significance value (2-tailed) because a hypothesis on the direction of causality was sometimes done.
Indeed, a one-tailed significance is when the direction of the hypothesis is assumed, a two-tailed significance does not consider the direction of the assumption [19].

Again as in the second model, four tables were obtained referred to the four health outcomes (see Tables 20, 21, 22 and 23).
The significant values are in bold font again.

Predictors	**Multivariate GEE: Model 3**					
	Beta	SE	p	1-tailed p	OR	CI 95% LO-UP

intercept	5,506	2,142	0,010	0,005	246,139	3,695 ; 16397,092
history 1,2 respect to 3*	0,193	0,714	0,786	0,393	1,213	0,300 ; 4,915
help in water carrying	0,409	0,297	0,168	0,084	1,505	0,842 ; 2,692
currently pregnant	NV					
delivered in the previous three months	-1,843	0,375	**0,000**	**0,000**	**0,158**	0,076 ; 0,330
up/down -hill in rainy season	NV					
heavy lifting per day in rainy season	0,383	0,285	0,180	0,090	1,466	0,838 ; 2,564
age of marriage	-0,192	0,078	**0,014**	**0,007**	**0,825**	0,708 ; 0,962
mean water load rainy season	-0,014	0,008	0,081	**0,040**	**0,986**	0,970 ; 1,002
distance	-0,002	0,000	**0,000**	**0**	**0,998**	0,997 ; 0,998
loading on the waist	0,484	0,453	0,285	0,143	1,623	0,668 ; 3,944
number of living children	0,446	0,312	0,153	0,076	1,561	0,848 ; 2,875
number of births given	1,244	0,605	**0,040**	**0,020**	**3,469**	1,060 ; 11,359
age	0,025	0,038	0,511	0,256	1,025	0,951 ; 1,105
trips per day in dry season	NV					
difference in altitude	-0,003	0,006	0,597	0,299	0,997	0,985 ; 1,009

Table 20: Factors associated with intensity of pain in the head among all women.

*Notes: *Women currently involved in water carrying (history=1) and women involved in the past (history=2) are compared to women never involved (history=3); Beta=gradient coefficient , SE=Standard Deviation, p=probability value, OR=Odd Ratio, CI=Confidence Interval, LO-UP=lower-upper; Probability Distribution=Normal; Link Function=Identity.*

Predictors	**Multivariate GEE: Model 3**					
	Beta	SE	p	1-tailed p	OR	CI 95% LO-UP
intercept	19,634	5,5211	**0,000**	**0,000**	**0,000**	6716,224 ; 16,840*10^12
loading on the head	2,274	2,214	0,304	0,152	9,722	0,127 ; 744,647
employment in agriculture	3,949	1,693	**0,020**	**0,010**	**51,898**	1,878 ; 1434,131
water carrying during pregnancy	-0,495	0,5494	0,367	0,184	0,609	0,208 ; 1,789
age since which they have lifted loads	-0,477	0,146	**0,001**	**0,001**	**0,620**	0,466; 0,826

trips per day in dry season	NV					
lifting other heavy loads beside water load	NV					
heavy lifting per day rainy season	-2,904	1,480	**0,050**	**0,025**	**0,055**	0,003 ; 0,996
help in water carrying	4,427	2,222	**0,046**	**0,023**	**83,690**	1,074 ; 6519,211
difference in altitude	-0,045	0,020	**0,023**	**0,012**	**0,956**	0,920 ; 0,994
education	0,609	0,286	**0,033**	**0,017**	**1,839**	1,050 ; 3,221

Table 21: Factors associated with intensity of pain in the neck among all women.

Notes: Beta=gradient coefficient , SE=Standard Deviation, p=probability value, OR=Odd Ratio, CI=Confidence Interval, LO-UP=lower-upper; Probability Distribution=Normal;Link Function=Identity.

Predictors	**Multivariate GEE: Model 3**					
	Beta	SE	p	1-tailed p	OR	CI 95% LO-UP
intercept	4,570	1,9225	**0,017**	**0,009**	**96,537**	2,230; 4179,769
loading on the head	7,278	1,020	**0,000**	**0,000**	**1447,480**	195,826; 10699,305
help in lifting heavy loads during pregnancy	0,848	0,479	0,077	**0,038**	**2,335**	0,913; 5,974
currently pregnant	0,978	0,464	**0,035**	**0,018**	**2,658**	1,070; 6,604
trips per day in rainy season	0,231	0,067	**0,001**	**0,000**	**1,259**	1,104; 1,436
age	0,028	0,036	0,433	0,216	1,029	0,958; 1,104
how often would they carry if not delivered in the previous 3 months	-0,033	0,112	0,765	0,383	0,967	0,777; 1,204
number of pregnancies	0,714	0,252	**0,005**	**0,002**	**2,042**	1,246; 3,347
number of births given	-0,204	0,187	0,277	0,138	0,816	0,565; 1,177
number of living children	-0,441	0,443	0,319	0,160	0,643	0,270; 1,533
difference in altitude	0,025	0,013	0,058	**0,029**	**1,025**	0,999; 1,051
up/down -hill to the source in rainy season	NV					
water carrying during pregnancy	-0,430	0,205	**0,036**	**0,018**	**0,651**	0,435; 0,972
education	-0,018	0,158	0,911	0,455	0,982	0,721; 1,339
age of marriage	NV					

Table 22: Factors associated with intensity of pain in the back among all women.

Notes: Beta=gradient coefficient , SE=Standard Deviation, p=probability value, OR=Odd Ratio, CI=Confidence Interval, LO-UP=lower-upper; Probability Distribution=Normal;Link Function=Identity.

Predictors	**Multivariate GEE: Model 3**					
	Beta	SE	p	1-tailed p	OR	CI 95% LO-UP
intercept	0,888	3,3955	0,794	0,397	2,430	0,003; 1887,200
loading on the waist	1,523	1,0968	0,165	0,082	4,586	0,534; 39,361
nutritious food was eaten during the last pregnancy	-0,781	0,6079	0,199	0,099	0,458	0,139; 1,508
history 1,2 respect to 3*	2,044	0,5154	**0,000**	**0,000**	**7,722**	2,812; 21,204
help in lifting heavy loads during pregnancy	-1,931	0,9795	**0,049**	**0,024**	**0,145**	0,021; 0,989
education	-0,479	0,2009	**0,017**	**0,009**	**0,619**	0,418; 0,918
number of living children	0,152	0,3107	0,626	0,313	1,164	0,633; 2,139
number of pregnancies	-0,952	0,7633	0,212	0,106	0,386	0,086; 1,723
number of births given	0,548	0,8128	0,500	0,250	1,730	0,352; 8,509
age of marriage	0,012	0,0258	0,652	0,326	1,012	0,962; 1,064
age	-0,021	0,0170	0,227	0,113	0,980	0,947; 1,013
Wealth Index	-0,012	0,0489	0,805	0,403	0,988	0,898; 1,087
maximum water load in rainy season	-0,003	0,0044	0,481	0,240	0,997	0,988; 1,005
difference in altitude	-0,009	0,0113	0,448	0,224	0,991	0,970; 1,014
water carrying during pregnancy	1,293	0,7694	0,093	**0,046**	**3,643**	0,806; 16,458
trips per day in rainy season	-0,108	0,0524	**0,040**	**0,020**	**0,898**	0,810; 0,995
heavy lifting per day in rainy season	-0,045	0,3824	0,906	0,453	0,956	0,452; 2,023
how often would they carry if pregnant	0,485	0,3312	0,143	0,072	1,624	0,849; 3,108
age since which they have lifted loads	0,118	0,0655	0,072	**0,036**	**1,125**	0,989; 1,279
currently pregnant	NV					
distance	-0,005	0,0022	**0,030**	**0,015**	**0,995**	0,991; 1,000
up/down -hill to the source in dry season	0,304	0,8117	0,708	0,354	1,356	0,276; 6,655

type of source in rainy season	0,329	0,1806	0,069	**0,034**	**1,389**	0,975; 1,979

Table 23: Factors associated with UP among all women.

*Notes: *Women currently involved in water carrying (history=1) and women involved in the past (history=2) are compared to women never involved (history=3); Beta=gradient coefficient , SE=Standard Deviation, p=probability value, OR=Odd Ratio, CI=Confidence Interval, LO-UP=lower-upper; Probability Distribution=Binomial;Link Function=Logit.*

3.5 WSS results

3.5.1 Technical aspects

The cluster that was picked for the design of the WSS is in Bolde district of Nepal.
The coordinates achieved by intersection of buffers on qGIS are: latitude 27,559217 and longitude 85,732904; the final coordinates obtained through a careful analysis of satellite image (Figure 4) are instead: 27,559722 and 85,732778.

The total amount of households -currently present- included in the design of the WSS is fifteen, six of which were interviewed women's houses, the remaining households were also considered in order not to exclude anybody from having an easier access to drinking water. Therefore the total water flow was evaluated as 7500 l/day for the entire village.

The population growth factor calculated using equation 5 was 1,98 (the P_{gr} was 2,3%), resulting in 149 people that needed water supply; the ultimate water demand of the cluster was 14900 l/d.

The altitude of the water tank was determined with equation 6: 660 m. The difference in altitude (ΔH, equation 7) between the water spring (666 m) and the water tank was estimated: 6 m.
This value was included in equation 8 to find out the diameter of the pipeline, upstream of the reservoir. The total length of the transmission line was 20 m. The theoretical diameter was 16,95 mm. The pipeline that was chosen is made by polyethylene PE. From catalogue the effective diameter that was selected was 17 mm (internal diameter, 20 mm external diameter) [53].

The total volume of a the water-tank (40,3 m^3) was estimated by summing the following terms (equation 9): V_r (17,88 m^3), V_f (17,88 m^3) and V_c (4,47 m^3); the height of the tank was fixed at 3 m, the surface area was therefore measured: its value is 13,41 m^2.
Capacity of water storage tank have been standardised in Nepal [62], a water tank of 40 m^3 was chosen.

Since the utilization of a valve was considered necessary, its relative head loss (ΔH_v) was calculated and found as 3,41 m.

The resulting diameter (mm) of the distribution system were obtained with equations 10 and 11.
Since 149 people gave a result of 29,8 households (5 people each), it was decided to split the main pipe into three parts according to three sub-groups of households (see Figure 4, page 25), with 10 households in every sub-group.
The difference in altitude between the water-tank and the lowest group of houses Y was 33 m, the

total number of sections of the main pipe b was 3 (same number of the three sub-groups created from the cluster), β is the same as the upstream pipeline section (0,0016 $\frac{s}{m^{1/3}}$) with K_s equal to 80 $\frac{m^{1/3}}{s}$, the length L_j of each of the three section was: 21 (m), 50,7 (m) and 58,2 (m). The water-flow Q_j (the water-flow on the peak day was used and calculated as: $1,2Q\ \frac{l}{d}$ where 1,2 is the peak coefficient [27]) at each section was accounted to satisfy the water demand of the group of households it was meant to supply: 18000 $\frac{l}{d}$ to satisfy the entire village, 12000 $\frac{l}{d}$ the value of the flow after having served the first group of houses and 6000 $\frac{l}{d}$ for the last group, finally α was estimated as 1,88 $\frac{e}{m}$.
The final theoretical diameters downstream of the reservoir were obtained (equation 12): 15,17 (mm), 13,55 (mm) and 11,18 (mm). Since the smallest PE diameter available found was 17 mm (as for the upstream transmission pipeline), it was selected for all the three sections.

To cover the water autonomy for a short period of time, some options of plastic water tank were searched for each sub-group of houses, one was found on "The tank depot web-site" (https://www.tank-depot.com/) and proposed. For the three groups of households plastic tanks of 40 gallon (151,42 l) were found available on the web with prices ranging from 80 to 100 $.

In deciding which fittings include in the pipe-to-house connection examples of previous WSS design were employed [24]. A water meter, a sadder plate, a gate valve and other fittings such as elbows were considered.

After the choice of pipe diameters and material (again PE as for the upstream pipeline) the pre-excavation verification was carried out; thus, in order to check if the pipe can manage operational stresses.
A table is here provided to present the main parameters values (presented in section 2) for the verification of the excavation conditions (24). For the choice of specific parameters of the ground (e.g. specific weight γ_g) information were directly addressed to a Nepalese researcher who contributed to interviews and data collection in Bolde. It has been reported that, in this district the ground is «red mud with some stones and dry as well»; for this reason the type of soil was labeled as "mixed and compact soil".

D external (mm)	20
D internal (mm)	17
s (mm)	1,5
H (m)	1
B (m)	0,04
γ_g (KN/m^3)	20
γ_p (KN/m^3)	9,22
φ (°)	33
c (KN/m^3)	2,652
Q_b (KN/m)	0,042
G_p (KN/m)	0,001
G_w (KN/m)	0,002
E_g (kN/m^2)	500
E_p (kN/m^2)	1200000
r (kN/m^2)	337,5

Table 24: Main ground and PE pipe parameters for the excavation check.

The flexibility test was the first to be conducted, the resulting n is equal to 9,09E+11. This value is respecting the test condition, therefore the pipe were justifiably considered flexible.
The following table is instead reporting the results of the static test of the maximum stress (25).

	$\sigma+$ (MPa)	$\sigma-$ (MPa)
top	-0,246	0,246
side	0,299	-0,193
bottom	**-0,247**	0,246

Table 25: Values of sigma at top, side and bottom of the pipe.

With the most negative value of σ (highlighted in bold font), the P_0 was obtained: 0,044 MPa. The maximum operational pressure P_e was calculated adopting the maximum head loss (33 m), its result is 0,305 MPa. The sum of the two terms (0,349 MPa) is smaller than the Nominal Pressure (PN) of PE pipe of 2,5 MPa. The second condition was verified.

The maximum ovality test was then carried out, the value of $\frac{\Delta x}{D}$ was evaluated from equation 7. Its result is 0,007%, which is respecting the condition of the maximum ovality. The moment of inertia I that was employed turned out to be 2,81E-10.

For the control of the last condition (instability at elastic equilibrium) the Poisson coefficient that was used for PE pipelines is equal to 0,4. The P_c was therefore calculated: 1205,357 MPa. The value of ΔP was considered to be 0 because the external pressure to the pipe was neglected since the depth of laying was quite low. The remaining term is $\frac{Q_b}{D}$, with a value of 2,12 $\frac{kN}{m^2}$ it respected the condition ($\leq$482,143 MPa).

Service conditions, presented at page 32, were afterwards inspected for the distribution water pipes:

1. The altitude of the water tank H_{wt} (660 m) was designed using equation 6. This equation includes itself the minimum water level condition, this implies that the first condition is always met.
2. For morphology reasons the maximum water level is 33 m (660 m altitude of the water tank and 627 altitude of the lowest households), thus complying with the second service condition.
3. In water pipes of diameter equal to 17 mm, the resulting velocities in each of the three sub-section were evaluated: 0,92 m/s, 0,61 m/s and 0,31 m/s. Thus complying with the third condition.
4. The just reported velocities are also satisfying the Reynolds' assumption on turbulence.

3.5.2 Costs

Estimated costs for the WSS will be provided in Nepalese rupees (Rs) (see Table 26).
The total final estimated amount is highlighted in bold font.

	Rs/m	**Lenght (m)**	**Width (m)**	**Height (m)**	**Volume (m^3)**	**Rs/m^3**	**Cost (Rs)**
Transmission pipelines							

Material	25,92	20					518,4
Excavation		20	0,04	1,4	1,12	260,59	291,86
10% sand bed filling					0,112	1343,99	150,53
Pipe trench filling					1,00	162,87	164,17
Main water tank							
Excavation				3	22	260,59	5732,98
Material							230382,55
Valve chamber							
Valve							35402,79
Chamber		1,2	1,2	1,7	2,448	39751,81	97312,43
Distribution -main pipe							
Material	25,92	129,9	3367				
Excavation		129,9	0,04	1,4	7,27	260,59	1895,53
10% sand bed filling					0,73	1343,99	977,08
Pipe trench filling					6,55	162,87	1066,80
Distribution -secondary pipes							
Material	25,92	56	1451,52				
Excavation		56	0,04	1,4	3,14	260,59	817,21
10% sand bed filling					0,31	1343,99	421,48
Pipe trench filling					2,82	162,87	459,68
Fittings							
Small tanks							
10 househols					0,151416		10270,66
10 households					0,151416		10270,66
10 households					0,151416		10270,66
Household connection							231870
Sub-total							643094,2
7% contingencies							45016,59
13% VAT							83602,25
Total estimated amount							**771713,04**

Table 26: Total expenditure for the WSS project.

Assuming to recover the initial sum in 20 years, the depreciation and maintenance rate are 5% each (10% total). The annual liability is equal to the initial total estimated amount multiplied by this 10% rate: 77171,3 Rs. The value, if considering the population growth, would be 215,8 Rs per household per month. The value is 321,5 Rs if considering 100 inhabitants.

4 Discussion and Conclusions

4.1 Descriptive Statistics

The investigated population, despite mainly coming from rural areas, has shown a certain heterogeneity in social and demographic characteristics [20]; for instance, the WI frequency distribution among the quintiles (from the poorer to the wealthiest) is very uniform among the whole sample (Table 34). Moreover the education level did not show a large gap: even if the highest percentage is the one composed by illiterate woman (29,1%), there is a considerable portion of the population that has reached some level of literacy (i.e. 11,8% has passed the primary level and 11,3% the secondary level).

The higher percentage of women is occupied in agriculture fields (81,7%) as expected since the investigated area is rural [20].

Concerning the marital and family status, most women live with their husband (78,6%) and have a mean age of marriage of 18,5 years (see Table 34 in Results section). This shows the delicate situation of premature marriages for girls in Nepal [5].

The average number of children living in the household is close to three, which is a considerable number of children to take care of in addition to all the the physical work they undergo each day.

The average age at which they start lifting heavy loads is 11,36; a quite alarming value since it has been already demonstrated how this task can negatively affect health [34].

The least used water carrying method is the head loading (1,2%). Since it was discovered to be the most dangerous, it can be assumed that women of the survey have been already told about its risks, or they have seen themselves its negative consequences and have consequently adapted their transporting method [22].
Percentages of women suffering from excessive work load and general pain are higher among those involved in water carrying (currently or in the past) compared to those who were never involved (see Tables 36, 37 and 38 in the Appendix). The same trend was highlighted for the intensity of pain at the head, neck, back and for the UP onset (see the summary Table 12 in the Results).
These results are in line with what was presented in the Introduction (page 7): women from hilly and mountainous areas are even more disadvantaged than women living in the urban areas. These are all important findings, supporting the original hypothesis of this work: water carrying is associated to a negative impact on women's health (presented in the Introduction, page 12).

Despite this, 47,7% of them rate their quality of life to be rather good, and 42,7% of them to be good. This underlines a general acceptance or even a well-rooted passivity towards their living condition and their pain.

4.2 First Model: Ankles pain - women involved in water carrying in the past

The ankles have been found out as the pain location where women involved in the past in water carrying have a higher OR with respect to women who have never been submitted to this charge. This result answers to the first research question: 'Are there prevalent health issues afflicting women fetching water in the selected population?'(section 1, page 13).

This is a new finding compared to previous literature, where pain at the hands and back were discovered to be more relevant in women involved in water carrying with respect to women never involved [22].
Thus perhaps evidencing how different settings and areas can diversely affect health.
Moreover it has been verified that aging and lack of physical activity are two causes of pain at the ankles [51]. The age was included as confounder and the GEE procedure was adjusted for it, indeed, selecting women involved in water carrying in the past may lead to selecting older women (the average age of women who carried water in the past is 62 years old).
Women in rural areas of Nepal are often busy with household and children care, thus preventing them from practicing regular physical activity.

From Table 15, page 37, it is possible to notice that the mean value of water load and the mean value of minutes to reach the source in the past, are the only statistically significant predictors from the Bivariate analysis (GEE); however once the Multivariate analysis (GEE) was also run, only the mean value of the water load remained statistically relevant: OR=1,039; P-value=0,002 and CI95%=1,014; 1,064.
Even if very slightly larger than one, the OR proved that a linear proportional relationship exists between the mean water load women used to carry in the past and their current pain at the ankles.
It is an interesting new result: no earlier literature has been found investigating relationship between ankles pain and water load. It might be a new useful evidence to consider when dealing with a medical assistance planning. For instance, women could receive proper shoes able to sustain the ankles.

4.3 Second Model: Health outcomes - women currently involved in water carrying

Since this model, as well as the third, deals with the four health outcomes it was decided to split this subsection in four paragraphs to better organize the discussion of each result.
It is worth recalling that in the creation of this model only women currently involved in water carrying were included.

4.3.1 Intensity of pain at the head

As shown in Table 36, the mean value of head intensity of pain is 4,214 in a range of values that varies from 1 to 15.
The second model from the multivariate GEE pointed out four significant predictors for this outcome:

1. Distance: a very significant p-value (0,000) with an OR slightly smaller than 1 (0,990) suggested that as the distance increases the pain slowly decreases; this result was not expected, but it is in line with previous studies looking into the relationship between pain and walking distance. The article "Domestic water carrying and its implications for health" [21] revealed that for interviewed participants who carried water, the distance walked by those who reported pain was significantly less than those who did not. Even if the OR is very close to 1, this finding might outline how pain can lead to disability in achieving a specific task.

2. Up hill or down hill type of path: OR equals to 0,226 (up=0 and down=1) and a p-value of 0,038; it indicates women walking down-hill with the load have more head pain than those walking up-hill to go back home.

The reason why this happens is not clear, further research is needed, it might be that those women carry more load, since carrying heavy load uphill is more difficult [37]; however it has already been scientifically reported that during downhill walking large joint exertions can occur and it may explain some health issues [37].

3. Water carrying related risk score: a high value of the score of the variable describes a strong, unhealthy solicitation of the body [47].
   Even if the OR is only barely larger than 1 (1,031 and p-value=0,000), this means that pain is increasing as the potential risk score rises, in line with the definition of the potential risk variable itself.

4. Help in water carrying : in this case the OR was very interesting: 72,814 and a p-value of 0,001. The pain increases together with its predictor.
   This finding implies that women who do not receive help are more inclined to have a stronger head intensity of pain.
   It is an important finding: a step forward for improving women living conditions and decreasing pain suffer could be achieved through simply equally distributing the burden of household water carrying among family members.

4.3.2 Intensity of pain at the neck

The mean of the neck intensity of pain is 4,323 in range from 1 to 15 (Table 36).
Although earlier research discovered neck pain is somehow linked to water-carrying-related factors (i.e. water load and especially head loading mode) [21][22], in this project, the second model suggested no significant predictors.
This is not surprising as pain in the neck is likely to be related to carrying loads on the head. But the practice of carrying loads on the head is very uncommon in Nepal.

4.3.3 Intensity of pain at the back

The back intensity of pain has a mean value of 4,350 in a range from 1 to 15 (Table 36), higher than the head and neck intensities of pain.
The second predictor model revealed only one predictor for the back pain intensity: help in water collecting (0,357 and p-value = 0,000). This finding contrasts with what was previously found for the head intensity of pain (head pain decreased when help was given); here, it seemed that women receiving help in water carrying slightly tend to have a higher back pain intensity.
It could be assumed that as the intensity of pain increases excessively they ask for more help.
Back pain is considered one of the most common pain among women that carry water [22].

4.3.4 UP

12,4% of women in this study suffer from UP (Table 36 page 70).
The waist loading mode has been detected as a predictor of the UP issue (OR=2,780 and P-value=0,003).
Among all, one of the risk factors of UP is the increased abdominal and lower abdominal areas pressure [16]; namely, given their proximity to the waist, it could be hypothesized this loading method leads to pressure gradually causing the occurrence of UP.

Moreover it was found out that waist position of the load is quite stressful when dealing with cardiovascular, muscular and bio-mechanical efforts; it has been also suggested that the waist loading method should be avoided if the load exceeds 10 kg [54].

4.3.5 Conclusions of the second model

The realisation of a predicting model for the four health outcomes which selected women currently involved with water carrying brought some interesting findings. These answered to the second research question: 'What are the main water-carrying-related factors that are associated with these health issues?'(section 1 at page 13).
Nevertheless, sometimes it was not possible to highlight any predictor (i.e. neck pain intensity was not associated with water carrying related factors) or the finding was not coherent with different outcomes (i.e. assistance in water-carrying influences head and back pain intensity). In all the other cases some associations -even if quite weak sometimes- were extrapolated.
Water carrying conditions are somehow having an effect on the health of women submitted to this charge, such as the loading modality (e.g. loading on the waist influences UP occurrence), or the type of path taken, but primarily, receiving help or not makes the most difference on physical well-being (e.g. back pain). Hence, the dominant influencing factors that have been identified are: water carrying related risk score for the pain at the head and help in water carrying for what concerns both back and head pain; the waist loading mode was detected as the prominent risk factor for UP.
Women should be assisted and guided by institutions and government to express their distress about work, ask for help and receive positive feedback.

4.4 Third Model: Health outcomes - water-carrying and non-water-carrying related risk factors

This model was generated with the aim of finding predictors (water-carrying-related or not) of the selected health outcomes.
In this case all of the sample population was analyzed.

4.4.1 Intensity of pain at the head

The significant predictors in table 20, page 44, are shown in bold and they result from the multivariate analysis (GEE) for the head intensity of pain; findings will be discussed here.

1. Delivered in the previous three months (delivered): the head intensity of pain and the fact that they have delivered during the previous three months (1 = yes and 0 = no) are negatively associated (OR = 0,158 and p-value = 0,000). It means that those who have delivered in the three previous months suffer from a weaker intensity of pain at the head; it can be caused by their incapacity to perform this task during that time.

2. Age of marriage: as the age of marriage decreases (girls get married sooner in their life) an increase in head pain intensity was expected [5]; this assumption was validated, the OR is smaller than one (0,825) and the significance is 0,007.

3. Mean value of water load in the rainy season: a very light inverse association between head intensity and water load (kg) in rainy season (OR=0,986 and 1-tailed p=0,04) was found. Ac-

tually the direction of causality was thought so that the higher the load the higher the intensity (for this reason it was decided to show the 1-tailed significance), but the result is in contrast with the assumption.
Perhaps the head intensity affects the ability to transport loads, as it was earlier evidenced when dealing with distance and head intensity with the second model [21].

4. Distance: as for the water load, the distance seems to be decreasing when the intensity increases (OR=0,998 and p-value=0,000); in line with the finding of the second predictor model [21]: women suffering from stronger headaches walk shorter distances [21].

5. Parity (e.g. number of births): with an interesting OR > 1 (3,469) and a 1-tailed significance equal to 0,02 (it was assumed that women that had given more births suffered more from general pain, including headaches [5]) the findings outlined that the more parities they had the stronger the headache was; the assumption was met.
More births means more times in pregnancy, when women are weaker, more vulnerable and they need care; an uninsured medical assistance during this moment of their life can have strong implication on their health and those of their newborns [63].

4.4.2 Intensity of pain at the neck

In this section the predictors for the neck intensity of pain will be analysed and discussed (Table 21).

1. Employment in agriculture: with a meaningful OR (59,898 and a significance of 0,002), women employed in agriculture (81,7%) manifested a higher intensity of pain at the neck. Women make essential contributions to agriculture and rural economies across the developing world [60]. Prakash et al. published a remarkable paper with the aim of finding out the prevalence of work-related musculo-skeletal disorders in agricultural farmers [40]. That is a descriptive cross-sectional study design where 246 farmers from Bhaktapur district (Nepal) were included; the results are very interesting: all the farmers (n=246) accused pain in all the nine areas of the body mentioned in the survey. The neck pain was one of the six major areas of pain that were identified.

2. From which age have they started lifting heavy loads: it looks like as the years spent lifting heavy loads increases, the neck pain rises as well. The two variables are associated with an OR=0,620 and 1-tailed significance=0,000. Here the direction of causality was assumed and it is in line with the result.

3. Frequency of lifting heavy loads in the rainy season: the times per week women lift heavy loads is inversely proportional to the neck pain intensity (OR=0,055 and p-value=0,000); it might be - as previously reported- that the accumulation of pain prevent them from conducting the activity [21].

4. Help in water carrying: assistance during water carrying had once more an impressing influence over the intensity of pain (OR=83,690 and 1-tailed sign=0,023). In this case the direction of causality has been hypothesised on the basis of the earlier finding between the same predictor and head ache intensity (in the second prevision model, page 53): the less they receive help the stronger the pain.

The direction of influence has been validated by the result.

5. Difference in altitude: in this case the OR is very close to 1 (0,956) with a p-value of 0,023. The finding revealed a mild decrease of the pain when the source is located at a higher altitude; on the other hand, the pain increases when the source is located at a lower altitude with respect to the household, thus making woman walk up-hill holding the water containers. This result was expected and in line with previous literature [37].

6. Education: an unexpected result was obtained because the pain intensity raises together with education level (OR=1,839 and 1-tailed sign=0,017). The direction of influence was thought to be the contrary [12]. It might be assumed that women with a higher education level worry less in expressing physical discomfort than less-educated women

4.4.3 Intensity of pain at the back

Remarkable results (Table 22, page 45) concerning back pain intensity have been found.
The predictors from the multivariate GEE analysis are:

1. Loading on the head: in accordance with previous inquiry which suggested head loading modality having negative implications over health, especially the cervical zone [21][22], it was discovered that pain intensity at the back increases rapidly when women carry the water containers on their head (OR=1447,480 and p-value=0,000).

2. Help in lifting loads during pregnancy: the back pain intensity increases when women do not receive help in lifting loads during pregnancy (OR=2,355 and 1-tailed sign=0,038). It has already been discussed how this period of life is delicate, primarily in terms of physical vulnerability. Women need assistance and cannot be left alone in the maintenance of the house; the direction of causality was supposed and validated [63].

3. Current pregnancy: it seems that as they get pregnant the back pain intensity raises concurrently (OR=2,658 and p-value=0,035). Back pain is very common among pregnant women, especially in the lower back or low pelvic zone, preventing them from normal movement and causing pain [4]. A further conclusion could be drawn: they do not receive enough help in daily tasks [63].

4. Number of trips in rainy season: with an OR of 1,259 and a p-value equals to 0,001, the back pain intensity increases with the number of trips per day fetching water. It was not possible to find previous research gaining insight between back pain and frequency of water collection; but, a previous study carried out by Geere et al. [21] has found evidence that women suffering from spinal pain (comparable to generic back pain of the present study) spent a total time per day in water collection (trips per day*minutes spent walking per trip) shorter than those who did not have pain; in order to follow their direction of causality, it was then assumed that the frequency of trips and the minutes for each were negatively correlated, but the result of the correlation did not show any significance (Pearson Correlation coeff=-0,008 and 1-tailed sign=0,397).
consequently, this finding can not be compared to the one of Geere et al.; but it is possible to state that those women making more trips per day to get water have a stronger back pain.
Even if sometimes in the results it was founded the direction of causality as: stronger pain leads to less water collection, it must be underlined that in some cases women have no alternative and, in order to guarantee the water availability in the household, they need to search it, despite the increasing pain.

It can be hypothesized that those women reporting higher back pain and making more trips per day, receive less help from other members of the family, have husbands working away in cities, with respect to those having less pain and making less trips.

5. Number of pregnancies: the back pain intensity worsen as the number of pregnancies increases (OR=2,042 and 1-tailed sign=0,002), this finding provided further support to what was earlier mentioned about pregnancies and back pain issues.

6. Difference in altitude: from the analysis women walking down hill carrying water are afflicted by a stronger pain (OR=1,025 and p-value=0,029). It was therefore assumed that they carried heavier loads and the hypothesis was met with these significant results: B=0,179; SE=0,0718; 1-tailed sign=0,013; OR=1,196 and CI95%(LO-UP)=1,039; 1,377.

7. Carrying during pregnancy: pregnant women transporting the same amount of water as usual (category 1 of wat_preg variable) are afflicted by a more intense back pain with respect to those who carry less (category 2) or do not carry at all (category 3) (OR=0,651 and p-value=0,036); this provides further supports to the already examined subject of vulnerability of pregnant women.

4.4.4 UP

The last health outcome of interest is the UP, the related predictors from the third multivariate GEE analysis are (Table 23 page 47):

1. History of water collection: a relevant result was obtained because women belonging to categories 1 and 2 of history of water collection had an OR significantly higher with respect to those of category 3 (OR=7,722 and p-value=0,000). It means that overall, water carrying has negative implications over the pelvic organs, such as UP.
   In the Introduction (page 9) the UP risk factors have been presented, including loads lifting such as water [42][56][66].

2. Help in lifting heavy loads during pregnancy: women during pregnancy received assistance in lifting heavy loads UP issue (OR=0,145 and p-value=0,049).

3. Education: an interesting result between the education level and the UP onset came out; as the level of literacy increases the UP seems to occur less frequently, and vice-versa (OR=0,619 and p-value=0,017). It has been significantly discussed along the whole project, how information and education are the first steps towards an improvement of the health status of people in developing countries [18].

4. Water carrying during pregnancy: with an interesting OR=3,643 and p-value=0,046; if pregnant women practice water collection, the risk of UP increases. This is in accordance with previous studies on UP onset [35].

5. From which age have they started lifting heavy loads: with an OR=1,125 and p-value=0,036, this finding was against our assumption and the previous result between this predictor and other health outcome (i.e. neck pain).

6. Trips per day in rainy season: as for other health outcomes, the relationship between UP and trips per day is negative (OR=0,898 and p-value=0,040). The reason for this result could be the inability of suffering women to walk more times per day to collect water; moreover, it has been discovered that women with UP tend to have more help in water carrying, thus maybe avoiding them to do many trips.

7. Distance: it is negatively associated with the onset of UP as well (OR=0,995 and p-value=0,030). Actually this finding is in line with all the previous ones concerning distance and health outcome and with earlier literature [21].

8. Main source in dry season: as the water source is located further away in the village (see Table 28 at page 64 in the Appendix) the UP seems to occur more often.
   Off-plot sources implies longer trips, higher risk of assuming inadequate posture while handling the load, etc. All of this, obviously leading towards a more likely exposure to health problems (e.g. uterine prolapse) [16][56].

4.4.5 Conclusions of the third model

It can be concluded that considering water carrying together with other daily life factors provides a deepest insight into the identification of potential health risk factors. For this reason, the results from the third model appeared more abundant than the other models. Consequently, this could help in the design of an action plan that does not include water supply system only, but a project of social improvement as well.
This model generation was useful to answer the third research question: 'When considering water-carrying and non-water-carrying factors at the same time, what are the relevant risk factors that are associated with these health outcomes?'(see section 1, page 13).
Although the direction of influence has not always been clarified and sometimes it was not in accordance within different health outcomes, statistically significant relationships were highlighted and discussed.
When including non-water-carrying-related factors, some interesting results were outlined, some of which were indicators of the social and medical status; the dominant ones are: the age of marriage, the number of births given, the employment in agriculture and the distance walked to reach the source, for what concerns the head ache; employment in agriculture and help in water carrying when considering the neck pain; loading mode on the head, help in lifting heavy loads during pregnancy, trips to the water source per day, number of pregnancies, when concerning the back pain; history of water collection (thereby if women were involved in water carrying at the time of the survey, in the past or never), education level and type of water source when looking at the UP.
It can be concluded that the victims of the studied physical pains are those women who are more involved in water carrying (and practice it in more dangerous conditions) and are socially or medically disadvantaged at the same time.
Once these main risk factors have been outlined and the more vulnerable victims identified, active interventions should be defined and, afterwards implemented.
For example, women in Nepal need an easier access to education, which would prevent them from

having premature marriages, pregnancies and their implications; moreover, at school, they would receive the proper "instruments" to face daily problems and find quick solutions.
Nonetheless they should be given proper medical care, especially during pregnancy. As it was evidenced in this study and in previous research, pregnant women are more easily victims of health issues.
Intervention strategies to shorten the distance to the water source, especially during the dry season, would be an important target to help women, pregnant or not, in charge of water collection.
Not only women, but all members of the family should be taught about the effects of water carrying and other habits (such as heavy lifting) on health. An increased general awareness and a subsequent subdivision of the work load is the first goal to reach, not only to relieve women from the water transport burden, but to contribute to limit the existing gender gap as well.

4.5 Comments on the WSS design

A solution was designed to answer to the research questions 4 and 5 (page 13): ‘What is a technical solution for a water supply system?’ and ‘What would be the cost of implementing a water supply scheme?’.
Nepal has set specific targets in Sustainable Development Goal (SDG) for the year 2030 among which basic water supply coverage to 99 percent households [10]. For this reason a WSS was designed for a hamlet of a district included in the cross-sectional study.
In this project thirty houses were taken in consideration to be provided with water. To maximize the use and the water access, households that were not included in the questionnaire were instead accounted in the WSS project.
When planning a WSS there is no single solution, it is up to the collaboration of team members (technicians, engineers and users) to find out the most suitable one for specific site conditions, the water demand and the economic availability.
The value of water demand that was adopted (100 l/d per person) was chosen by reference to the World Health Organization (WHO) recommendations on this subject.
In Europe an average of 144 l/d per inhabitant is supplied [2]: almost 1,5 times higher than the water demand that was employed in Bolde. Thus underlying the water consumption gap over the globe.
The scheme of a water supply obtained for this context was smaller and simpler than other WSS schemes used as references, for this reason some assumptions were often necessary.
The final water demand for the whole cluster (14900 l/d) provided a resulting diameter of 20 mm in the transmission line. If it is compared to diameters of other traditional WSS, it resulted quite small, indeed it was the lowest available value of PE pipes diameters.
The PE is light to transport, cheapest than other material, easy at handling; it represents a good option in developing countries where the site conditions are even harsher than normal. PE pipe provides a competitive environmental and economic advantage for its use in a variety of water and sewer infrastructure projects, PE pipe addresses affordability concerns and enables communities to work towards meeting their sustainable infrastructure goals because of its durability, low break rate, corrosion resistance and long-lasting performance [53]. On the other hand, due to their non-decomposing properties, plastic pipes are not installed at high temperature and they are easily cracked if earth movements occur.
PE pipes with 25 bar Nominal Pressure (PN) were selected for this project.
Packaging in rolls was chosen since cheaper than packaging in bars [53].
In Nepal there are six volumes of water tank that have been standardised (from 2,5 m^3 to 40 m^3); 40 m^3 is the standardised volume that was selected for this project because it was the most similar to the theoretical value that was obtained (40,23 m^3) [62].
Several options for different small water tanks at each sub-group were available. In this case a plastic

tank of 151,42 l was proposed; its total capacity (m^3) was considered enough to cover the water demand for short periods of time in case of stop of the system (on average the small tank would provide 15 l of water per household).
The pre-excavation verifications were carried out and validated. According to the parameters that were adopted, all the conditions were satisfied. Decisions on the type of soil and other parameters that characterized the equations were taken on the basis of technical support and advise (e.g. people who went on site for the data collection were submitted to relative questions).
Service conditions were met as well. Therefore -despite unmissable uncertainties- an overall favourable result for the WSS design was gained.
A further on-site analysis would be the next step to validate or reject the assumptions and the results that were here obtained.
In the cost evaluation all the design aspects were included. A 7% of contingencies was added, this accounting for the transport of material, adjustments of the capture system, elbows and additional valves; 13% of VAT was also included. From the final total amount, the liability per month (per household) was calculated considering the amortisation and maintenance rate (10%), it provided a final cost of 215,8 Rs. This value is referred to the final population after having applied the growth factor. If a population of 100 people is considered, the value becomes 321,55 Rs.
The minimum water tariff which is suggested in rural areas of Nepal is 110 Rs [44]. This value is smaller than the result of this project. For this reason some strategies were proposed to cover the basic level of service and guarantee access to water throughout a proper WSS [25]:

1. High investment priority will be given to serve the un-served population in order to achieve the universal coverage
2. Basic level of service provision will be targeted to low income remotely located communities
3. Communities receiving basic level of services will be required to pay minimum of contribution to the cost of the scheme
4. Communities served with basic level of services will be provided necessary technical support to enable them to operate and maintain the facilities and maintain the sustainability of the services
5. Simpler technical options with low operation and maintenance cost will be preferred

As the third strategy suggests, the government of Nepal stated that economical support should be addressed to communities with basic level of services. In the same document the Government affirmed that it will continue to provide 80 to 90 percent of the water supply and sanitation project construction costs with the provision of basic level of services. The remaining 10 to 20 percent of the construction cost shall be contributed by the users, preferably in cash term, depending on the affordability of the community. Moreover the government will create enabling environment for banks and other financial institutions to provide investment loans to local bodies, Corporations, and companies for the development of water supply.
All these strategies conducted by the authorities were thought to make the project sustainable.
Beyond the main purpose of giving good quality water to as many people as possible, another aim would be to educate users to an independent maintenance of the system, maybe creating a favourable environment for the creation of work employment as well.
Although a direct inspection on site was missing, this project wanted to provide the first step to a likely organization of a WSS in Bolde, or in other rural districts. Indeed, this project proposed a strategy of WSS for a single households cluster, but a similar design and calculations -with site specific modifications- could be applied to other cases in order to extend the water access to more Nepalese people.

Economic and social benefits can result from improved WSS services. From time saving, due to the proximity of improved system, to reductions in illnesses and deaths associated with adverse health impacts. Economic benefits would be ranging from savings capital from seeking health care, to reduced losses of productive time due to disease and to a reduction in premature mortality [26].
The main contributor to overall benefits of drinking-water systems and sanitation services is the value of time savings which accounts for almost 70% of total benefits in developing countries. In Asia, the health improvements contribute to at least 35% of overall benefits. Health care savings account for more than 10% of total benefits in all regions of developing countries [26].
Every US$ 1 spent on improving sanitation brings an average economic return of US$ 4.8 in the form of time savings, lower health costs and improved productivity [52].
In conclusion, the benefits of improving small-scale water supply systems cover a wide range: from building healthy and resilient communities, to improving the human rights situation and increasing gender gap equity, to finally achieve economic advantages.

5 Limitations and Future Recommendations

Some limitations were encountered during the elaboration of the project.
First of all the interpretation of data and open questions was difficult, when the interviewer probably had some pressure in the annotation of the answer of the participant.
Usually it is a good strategy if the interviewer is the person in charge of the data analysis as well, so that he/she can have clear in mind what he/she meant with certain answers; unfortunately, due to the Covid-19 situation it has not been possible to travel to Nepal, to directly visit the investigated areas nor to meet with the interviewer team and the women.
Therefore interpretation advice for open questions had to be sought from the study supervisor.

In addition, the survey was carried out in autumn after monsoon; it should have been dry season but it still rained quite often, subsequently some of the closer sources were operational due to sufficient water availability. Thus, water access was probably almost similar to the rainy season and the survey observations might have been affected.

As already reported, women in developing countries prefer not exhibit their suffering and this can result in a large amount of missing data or even underestimated answers to the questionnaire.

On the other hand it has been also pointed out that water fetching can be somehow positive to women; Geere et al. [21] suggested that it could result in a physical activity which might also lead to beneficial health effects in some individuals.
Moreover women fetching water could also benefit from a moment in the day when they can meet friends on their path to the water source.
Obviously when this task becomes too strenuous compared to other occupations there is no longer an advantage from practicing it.

When doing a regression operation such as using a GEE, and subsequently interpreting the results one could only state if there is an association between an outcome and a predictor and at which level it is statistically significant, but it is not possible to state what is the cause of what.
Hypothesis on the direction of the causality are made mostly by referring to earlier scientific findings, but the results are never 100% assured.
It is a continuous work of research, the bigger the amount of consistent findings the more reliable the assumed direction of causality is. This can seem logical but it can quickly change when considering the context and other relevant factors.

For all these presented reasons further research on the topic is suggested.
Particular attention should be given to data quality and subsequently on the creation of the questionnaire; the survey implementation on site that should be conducted by the same person that will make the data analysis in the future.
It would be of further interest to include mental outcomes beyond physical ones, in order to fully understand the effects living conditions and habits have over health.

When developing the WSS scheme, quantity and quality of available data had certainly strong consequences.
First of all the water source localization was missing, the method (described in the subsection 2.6.1 at page 23) was implemented being aware of its uncertainty, especially due to the difference in the type of distance that was recorded on site with the GPS (tracked distance) and the one implemented on qGIS (ray distance).
Other limitations are linked to lack of information on the type of capture system and the quality and quantity of water from the spring. Considering these two aspects would create a risk of influencing on the overall project and costs.
The localization of the water source was completed with some doubts, the distance as already mentioned, the satellite images were not always perfectly readable, objects were also often mixing; it was not possible to find free and good quality maps of Nepal on the web.
When assessing the total cost of the project, some hypothesis from previous WSS projects were necessary. Thus making this project more credible but dependent on these assumptions at the same time.
The final aim of the WSS design was to achieve a sustainable final cost; the parameters to define the sustainability of the water scheme were not always indisputable. References to other water system cost analysis have been done; moreover, understanding which was the minimum affordable water tariff in rural area of Nepal was not simple. This value changes quick among districts and over time, depending on political decisions, willingness and availability of people to pay.
The inability to visit the site was again a further and important limitation for the design of this scheme. For this reason, the first recommendation to proceed in the WSS design, is to wait for favourable conditions and travel to Nepal. A visit to local users and the site where they live would be very practical and beneficial for the achievement of this project.

6 Appendix

6.1 Variables used in the study

Dependent variable description	Variable name	Data type
Ankles pain (1=yes; 0=no)	painlocation12	categorical
Head intensity of pain	head_intensity	continuous
Neck intensity of pain	neck_intensity	continuous
Back intensity of pain	back_intensity	continuous
Uterine Prolapse presence (1=yes; 0=no)	uterus_prolapse	categorical

Table 27: Dependent/outcome variables

Variable description	Variable name	Data type
distance house-source	distance	continuous
trips per day in rainy season	trips_rainy	continuous
trips per day dry season	trips_dry	continuous

difference in altitude (between the source and the household)	delta_alt	continuous
absolute value of the difference in altitude	abs_delta_alt	continuous
up-hill or down-hill path in rainy season (up=0; down=1)	up_down_rainy	categorical
up-hill or down-hill path in dry season (up=0; down=1)	up_down_dry	categorical
load position on the head (1= yes; 0=no)	head_posit	categorical
load position on the waist (1=yes; 0=no)	waist_posit	categorical
load position on the shoulder (1=yes; 0=no)	shoulder_posit	categorical
potential risk of handling loads in dry season	risk_dry	continuous
potential risk of handling loads in rainy season	risk_rainy	continuous
type of water source in rainy season (1=Private tap, hand pump or tank delivery in the court or in the house; 2=Shared tap, hand pump, tank delivery or surface water in the close neighborhood; 3= Community tap, hand pump, tanker delivery or surface water in the village; 4= Water source further away than the village)	mainsource_rainy	categorical
type of water source in dry season (1= Private tap, hand pump or tank delivery in the court or in the house; 2= Shared tap, hand pump, tank delivery or surface water in the close neighborhood; 3= Community tap, hand pump, tanker delivery or surface water in the village; 4= Water source further away than the village)	mainsource_dry	categorical
assistance in water carrying (0=somebody helps; 1=nobody helps)	water_assurance_oth8	categorical
value of the maximum warerload in rainy season (liters)	waterload_max_rainy	continuous
value of the mean waterload in rainy season (liters)	waterload_mean_rainy	continuous
value of the maximum waterload in dry season (liters)	waterload_max_dry	continuous
value of the mean waterload in dry season (liters)	waterload_mean_dry	continuous
value of the maximum waterload in the past	waterload_max_past	continuous
value of the mean waterload in the past	waterload_mean_past	continuous
time to go to the source in the past (minutes)	minutes_past	continuous

history of water collection (1=women involved now; 2= women involved in the past but not now; 3= women never involved)	history	categorical

Table 28: Independent water-carrying-related factors

Indipendent variable description	Variable name	Data type
Living alone (1=alone; 0=not alone)	alone	categorical
Number of living children in the household	living_children	continuous
Number of births given	parity	continuous
Number of pregnancies had	nopregnancies	continuous
Employment in agriculture (1= yes; 0= no)	agricolture_empl	categorical
Age (years)	age	continuous
Age of marriage (years)	ageofmarriage	continuous
Education level (1= Illiterate; 2= Informal education; 3= Pre-primary; 4= Primary passed; 5= Lower secondary passed; 6= Secondary; 7= Higher secondary and above)	education	categorical
Wealth Index	wealthindex	continuous
Living with husband (1= yes; 0=no)	husbandlive	categorical
Living with mother in law (1=yes; 0=no)	motherinlawlive	categorical

Table 29: Generals and family factors

Indipendent variable description	Variable name	Data type
Lifting other heavy loads beside water load (1= yes; 0= no)	carryloads	categorical
Weight of other loads (Kg)	weight	continuous
Frequency per week of lifting heavy loads in rainy season	loads_rainy	continuous
Frequency per week of lifting heavy loads in dry season	loads_dry	continuous
Since what age they have lifted heavy loads (years)	since_age	continuous
Assistance in lifting heavy loads during pregancy (1= nobody helps; 0=somebody helps)	help	categorical

Table 30: Other habits factors

Indipendent variable description	Variable name	Data type
Currently pregnant (1= yes; 0=no)	curr_pregn	categorical
Water carrying during pregnancy (1= yes, the same amount as usual; 2= I carry less; 3= No, I don't carry)	wat_preg	categorical
How often would they carry if not pregnant	carrywaternotpregn	continuous
How often would they carry if pregnant	carrywatpregn	continuous

If they had delivered in the previous 3 months	delivered	categorical
How often would they carry if not delivered in the previous 3 months	carrywaternotdeliv	continuous
How often would they carry if delivered in the previous 3 months	carrywatdeliv	continuous
If nutritious food was eaten during the last pregnancy	eat_food	categorical

Table 31: Pregnancy factors

Pain location	**Part of the body**
1	Head
2	Neck
3	Back
4	Muscles of arms
5	Shoulders
6	Elbows
7	Joints of hands
8	Fingers
9	Muscles of legs
10	Hips
11	Knees
12	Ankles
13	Feet

Table 32: Pain locations

Independent variable description	**Name of the variable**	**Data type**
Own a radio (1= yes; 0=no)	ownitem1	Categorical
Own a TV (1=yes; 0=no)	ownitem2	Categorical
Own a solar pannel (1= yes; 0= no)	ownitem3	Categorical
Own a mobile phone (1= yes; 0= no)	ownitem4	Categorical
Own a bicycle (1= yes; 0= no)	ownitem5	Categorical
Own a motor bike (1= yes; 0= no)	ownitem6	Categorical
Own a car (1= yes; 0= no)	ownitem7	Categorical
Own a fridge (1= yes; 0= no)	ownitem8	Categorical
Own a watch (1= yes; 0= no)	ownitem9	Categorical
Own none of the previous items (1= yes; 0= no)	ownitem10	Categorical
Use wood as fuel (1= yes; 0= no)	fuel1	Catefgorical
Use charcoal as fuel (1= yes; 0= no)	fuel2	Categorical
Use kerosene as fuel (1= yes; 0= no)	fuel3	Categorical
Use gas as fuel (1= yes; 0= no)	fuel4	Categorical
Use electricity (1= yes; 0= no)	fuel5	Categorical
Owner of the house (1= yes; 2= no, renting)	owner_house	Categorical
Number of rooms in the house	rooms	Continuous
Amount of land owned	landownership	Continuous
Average expenditure of the family per month <2400 rupee	average_expenditure1	Categorical

Average expenditure of the family per month from 2500 to 4800 rupee	average_expenditure2	Categorical
Average expenditure of the family per month from 4900 to 9600 rupee	average_expenditure3	Categorical
Average expenditure of the family per month from 9700 to 24000 rupee	average_expenditure4	Categorical
Average expenditure of the family per month >25000 rupee	average_expenditure5	Categorical

Table 33: Variables included in the Wealth Index generation

6.2 Descriptive Statistics Results

Dichotomous variable	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**	
Currently pregnant					
0 = no	1119	90,2	96,5	96,5	
1 = yes	41	3,3	3,5	100	
Lifiting other heavy loads in the week					
0 = no	127	10,2	10,2	10,2	
1 = yes	1113	89,8	89,8	100,0	
Nobody helped during pregnancy in the lifting task					
0 = somebody helps	654	52,7	79,4	79,4	
1 = nobody helps	170	13,7	20,6	100,0	
Living alone					
0 = no	188	15,2	75,5	75,5	
1 = yes	61	4,9	24,5	100,0	
Living with mother in law					
0 = no	170	13,7	68,3	68,3	
1 = yes	79	6,4	31,7	100,0	
Categorical variable	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**	
Education level					
Illiterate	361	29,1	29,1	29,1	
Informal education	314	25,3	25,3	54,4	
Pre-primary	55	4,4	4,4	58,9	
Primary passed	146	11,8	11,8	70,6	
Lower secondary passed	101	8,1	8,1	78,8	
Secondary	123	9,9	9,9	88,7	
Higher secondary and above	140	11,3	11,3	100	
Wealth index quintiles					
Poorest	190	15,3	19,9	19,9	
2	191	15,4	20,0	40,0	
3	191	15,4	20,0	60,0	
4	191	15,4	20,0	80,1	
Wealthiest	190	15,3	19,9	100,0	

Employment					
Agriculture	679	54,8	81,7	81,7	
Small business	70	5,6	8,4	90,1	
Daily labourer	18	1,5	2,2	92,3	
Retired with pension	1	0,1	0,1	92,4	
employed	20	1,6	2,4	94,8	
Government service	22	1,8	2,6	97,5	
Other independent work	7	0,6	0,8	98,3	
None	14	1,1	1,7	100,0	
Marital status					
Living together with husband	751	78,6	78,6	78,6	
Husband is not living together	169	17,7	17,7	96,3	
Widow	34	3,6	3,6	99,9	
Others	1	0,1	0,1	100	
Continuous variable	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Number of children in the house	1234	0	10	2,69	1,716
Number of given births	1234	0	26	3,19	2,270
Number of pregnancies	1160	1	15	3,39	2,096
Current age	1239	16	84	38,62	13,821
Age of marriage	955	8	45	18,5	3,604
Since what age they lift other loads	1113	4	38	11,36	3,746
WI: Wealth Index	953	0,00	100,00	12,096	5,921

Table 34: Demographic descriptive statistics

Dichotomous variable	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**	
Help in water carry					
0 = somedy helps	1093	88,1	88,1	88,1	
1 = nobody helps	147	11,9	11,9	100,0	
Up or down rainy					
0 = up	159	12,8	67,4	67,4	
1 = down	77	6,2	32,6	100,0	
Up or down dry					
0 = up	225	18,1	83,3	83,3	
1 = down	45	3,6	16,7	100,0	
Categorical variable	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**	
Load position					
Waist	445	35,9	47,3	47,3	
Shoulders	484	39,0	51,5	98,8	
Head	11	0,9	1,2	100,0	
Main sourcein in dry season					
Private tap, hand pump or tank delivery in the court or in the house	14	1,1	3,6	3,6	

Shared tap, hand pump, tank delivery or surface water in the close neighborhood	66	5,3	16,9	20,5	
Community tap, hand pump, tanker delivery or surface water in the village	136	11,0	34,9	55,4	
Water source further away than the village	172	13,9	44,1	99,5	
Water is bought at the market	2	0,2	0,5	100,0	
History of water collection					
1 = involved now in water collection	974	78,5	78,5	78,5	
2 = involved in past and not now	153	12,3	12,3	90,9	
3 = not involved now or in the past	113	9,1	9,1	100,0	
Continuous variable	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Distance to the source	1163	0	922	74,47	140,502
Number of trips rainy season	1001	0	20	2,63	2,439
Number of trips dry season	390	0	30	2,82	2,617
Delta altitude: difference in altitude between source and household	1158	-233,00	206,00	-1,871	19,069
Absolute value of the delta altitude measure	1158	0,00	233,00	7,647	17,568
Water load max rainy season (kg)	987	4,00	175,00	24,563	15,860
Water load mean rainy season (kg)	984	5,00	237,50	21,203	13,718
Water load max dry season (kg)	384	1,50	155,00	30,504	16,681
Water load mean dry season (kg)	383	5,00	125,00	26,073	13,626
Water carrying related risk score rainy season	879	4,00	168,00	21,588	24,209
Water carrying related risk score dry season	352	6,00	168,00	59,642	42,418

Table 35: Water load descriptive statistics

Dichotomous variable	Frequency	Percent	Valid percent	Cumulative percent	
General pain: do you feel pain at the muscles, bones or joints of your body?					
0 = no	238	24,4	24,4	24,4	
1 = yes	736	75,6	75,6	100,0	
UP					
0 = no	850	87,3	87,6	87,6	
1 = yes	120	12,3	12,4	100,0	
Unhappy: do you feel unhappy?					
0 = no	681	69,9	69,9	69,9	
1 = yes	293	30,1	30,1	100,0	
Worksuffering: is your daily work suffering?					
0 = no	694	71,3	71,3	71,3	
1 = yes	280	28,7	28,7	100,0	
Endilife: have you ever thought of ending yout life?					
0 = no	791	81,2	81,2	81,2	
1 = yes	183	18,8	18,8	100,0	
Categorical variable	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**	
Life quality: how would you rate your life quality?					
Very poor	4	,4	,4	,4	
Poor	30	3,1	3,1	3,5	
Rather good	470	48,3	48,3	51,7	
Good	397	40,8	40,8	92,5	
Very good	73	7,5	7,5	100,0	
Health satisfaction: how satisfied you are with your health?					
not at all satisfied	53	5,4	5,4	5,4	
somewhat satisfied	91	9,3	9,3	14,8	
rather satisfied	404	41,5	41,5	56,3	
quite satisfied	279	28,6	28,6	84,9	
very satisfied	147	15,1	15,1	100,0	
Abortion: have you ever experienced abortion?					
0 = no	841	86,3	86,7	86,7	
1 = yes, spontaneous	93	9,5	9,6	96,3	
2 = yes, induced	36	3,7	3,7	100,0	
Continuous variable	**N**	**Min**	**Max**	**Mean**	**Std Dev**

Head pain intensity	145	1,00	15,00	4,214	3,134
Neck pain intensity	31	1,00	15,00	4,323	3,772
Back pain intensity	371	1,00	15,00	4,350	3,780

Table 36: Physical and mental outcomes statistics fro women currently involved in water carrying

Dichotomous variable	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**	
General pain: do you feel pain at the muscles, bones or joints of your body?					
0 = no	16	10,5	10,5	10,5	
1 = yes	137	89,5	89,5	100,0	
UP					
0 = no	119	77,8	78,8	78,8	
1 = yes	32	20,9	21,2	100,0	
Unhappy: do you feel unhappy?					
0 = no	108	70,6	70,6	70,6	
1 = yes	45	29,4	29,4	100,0	
Worksuffering: is your daily work suffering?					
0 = no	105	68,6	68,6	68,6	
1 = yes	48	31,4	31,4	100,0	
Endilife: have you ever thought of ending yout life?					
0 = no	121	79,1	79,1	79,1	
1 = yes	32	20,9	20,9	100,0	
Categorical variable	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**	
Life quality: how would you rate your life quality?					
Very poor	1	,7	,7	,7	
Poor	3	2,0	2,0	2,6	
Rather good	72	47,1	47,1	49,7	
Good	71	46,4	46,4	96,1	
Very good	6	3,9	3,9	100,0	
Health satisfaction: how satisfied you are with your health?					
not at all satisfied	29	19,0	19,0	19,0	
somewhat satisfied	23	15,0	15,0	34,0	
rather satisfied	60	39,2	39,2	73,2	
quite satisfied	23	15,0	15,0	88,2	
very satisfied	18	11,8	11,8	100,0	

Abortion: have you ever experienced abortion?					
0 = no	121	79,1	80,1	80,1	
1 = yes, spontaneous	28	18,3	18,5	98,7	
2 = yes, induced	2	1,3	1,3	100,0	
Continuous variable	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Head pain intensity	9	1,00	15,00	6,889	5,25463
Neck pain intensity	8	1,00	12,00	5,750	4,268
Back pain intensity	58	1,00	15,00	5,828	4,206

Table 37: Physical and mental outcomes statistics fro women involved in water carrying in past

Dichotomous variable	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**	
General pain: do you feel pain at the muscles, bones or joints of your body?					
0 = no	44	38,9	38,9	38,9	
1 = yes	69	61,1	61,1	100,0	
UP					
0 = no	107	94,7	94,7	94,7	
1 = yes	6	5,3	5,3	100,0	
Unhappy: do you feel unhappy?					
0 = no	92	81,4	81,4	81,4	
1 = yes	21	18,6	18,6	100,0	
Worksuffering: is your daily work suffering?					
0 = no	91	80,5	80,5	80,5	
1 = yes	22	19,5	19,5	100,0	
Endilife: have you ever thought of ending yout life?					
0 = no	98	86,7	86,7	86,7	
1 = yes	15	13,3	13,3	100,0	
Categorical variable	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**	
Life quality: how would you rate your life quality?					
Very poor	1	,9	,9	,9	
Poor	50	44,2	44,2	45,1	
Rather good	49	43,4	43,4	88,5	
Good	13	11,5	11,5	100,0	
Very good	6	3,9	3,9	100,0	

Health satisfaction: how satisfied you are with your health?					
not at all satisfied	6	5,3	5,3	5,3	
somewhat satisfied	11	9,7	9,7	15,0	
rather satisfied	35	31,0	31,0	46,0	
quite satisfied	42	37,2	37,2	83,2	
very satisfied	19	16,8	16,8	100,0	
Abortion: have you ever experienced abortion?					
0 = no	102	90,3	90,3	90,3	
1 = yes, spontaneous	9	8,0	8,0	98,2	
2 = yes, induced	2	1,8	1,8	100,0	
Continuous variable	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Head pain intensity	15	1,00	6,00	3,267	1,668
Neck pain intensity	1	1,00	1,00	1,000	.
Back pain intensity	33	1,00	12,00	3,970	3,264

Table 38: Physical and mental outcomes statistics fro women never involved

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