Evaluation on the feasibility to implement rainwater harvesting systems

Field study to judge the viability of rainwater harvesting for drinking and irrigation purposes in the community of Jitpur Phedi and Taluwa

~Scientific Report~

Version 3.0

Solveig Höfer

Supervisor: Michiel Michels, Bhupendra Ghimire

25.01.2014, Nepal

Evaluation on the feasibility to implement rainwater harvesting systems

Field study to judge the viability of rainwater harvesting for drinking and irrigation purposes in the community of Jitpur Phedi and Taluwa

Höfer, Solveig

Supvervisor: Michels, Michiel

Ghimire, Bhupendra

25.01.2014

Abstract

The purpose of this research was to evaluate if the construction of rainwater harvesting (RWH) systems is a feasible solution to fight the present drinking and irrigation water scarcities in two rural and marginalized communities in Nepal. This project was assigned by the NGO Volunteers Initiative Nepal (VIN).

Water is the base of every human beings life, not only as a drinking source, but also as an irrigation source crucial for food provision. It is important to realize that a huge amount of people live under a constant water threat in a country which is indicated as the second richest country in water sources worldwide.

This research tried to find a sustainable solution for this paradox. In the community of Jitpur Phedi the focus laid on irrigation water scarcity, while the community of Taluwa was surveyed for both, drinking and irrigation water threats. The main concern of this research was to provide marginalized communities with a reliable source of irrigation water to ensure the ability for constant food supply, as well as a constant excess to clean drinking water, to make certain that the basic human needs are adequately supplied.

In order to get a step closer to a sustainable development of Nepal's countryside a field survey was conducted in both target communities. Therefore a questionnaire was created, specifically asking for threats in drinking and irrigation water supplies, as well as cultivation habits and owned cultivation land. All necessary data was collected by randomly surveying households in both communities with the help of a local translator and guide.

The researched confirmed that a huge amount of local people are facing drinking and irrigation water shortages, actively influencing their living standards. Low crop productivity or empty field over a period of several month are the results for the irrigation water shortages, while the outcomes of the drinking water survey showed, that a lot of families have to do a daily walk up to 1.5h to collect drinking water over a period of multiple month per year. Based on these findings and founded on meteorological data and overall circumstances it became clear, that RWH collection is a feasible solution to fight drinking water scarcities. Irrigation water needs on the other hand are difficult to meet with RWH-systems and should have therefore a further research in either limiting the field size that is allowed to irrigate with the alternative source, or find additional sources which can efficiently work in a combination to create a sustainable provision of irrigation water.

List of Figures

Figure 1: Location on Jitpur Phedi Community (Google Maps, 2013) 2
Figure 2: Location Taluwa (Google Maps, 2013) 2
Figure 3: Location overview Jitpur Phedi 3
Figure 4: Area overview Taluwa VDC 3
Figure 5: Roof dependent RWH-system (Madhya Pradesh Pollution Control Board , 2013) 4
Figure 6: Land surface catchment (isp, 2013) 5
Figure 7: Example of a Rain Saucer design (RainSaucers, 2009) 5
Figure 8: Approach of evaluating and designing RWH-systems (Worm & Hattum, 2006) 6
Figure 9: Climate diagram Jitpur Phedi 13
Figure 10: Irrigation water shortage over one year 14
Figure 11: Amount of cultivated crop by all farmers in Jitpur Phedi (%) 15
Figure 12: Cultivation period of different crop in Jitpur Phedi 16
Figure 13: Required water demand (m^3) for wheat cultivation (scarcity period) 17
Figure 14: Wheat, maximum water demand for all field sizes (shortage period) 18
Figure 15: Climate diagram Taluwa (Okhaldhunga) 20
Figure 16: Irrigation water shortage in Taluwa VDC 21
Figure 17: Amount of cultivated crop by all farmers in Taluwa (%) 22
Figure 18: Cultivation period of different crop in Taluwa 23
Figure 19: Required water demand (m^3) for wheat cultivation on biggest field sizes per Ward 24
Figure 20: Required water demand (m^3) for wheat cultivation on smallest field sizes per Ward 24
Figure 21: Required water demand (m^3) for corn cultivation on biggest fields per Ward 26
Figure 22: Required water demand (m^3) for corn cultivation on smallest fields per Ward 26
Figure 23: Drinking water shortages Ward 1 (one year period) 27
Figure 24: Drinking water shortage Ward 6 (one year period) 28
Figure 25: Meeting needed water demand (all Wards, Taluwa) 29
Figure 26: Map displaying all Wards of Jitpur Phedi VDC 38
Figure 27: Sketched map of all Ward of Taluwa VDC 39
Figure 28: Area overview east and south Jitpur Phedi 41
Figure 29: Small vegetable fields next to the house, Jitpur Phedi 41
Figure 30: Irrigation channel, Jitpur Phedi 42
Figure 31: Gravity fed tap, Jitpur Phedi 42
Figure 32: Example of fields in Jitpur Phedi 42
Figure 33: Corn min. and max. water demand for all field sizes, Jitpur Phedi (cannot grow) 45
Figure 34: Rice min. and max. water demand for all field sizes, Jitpur Phedi (cannot grow) 45
Figure 35: Wheat/Millet min. and max. water demand for all field sizes, Jitpur Phedi (cannot grow) 46
Figure 36: Mustard min. and max. water demand for all field sizes, Jitpur Phedi (cannot grow) 46
Figure 37: Vegetables min. and max. water demand for all field sizes, Jitpur Phedi (cannot grow) 47
Figure 38: Corn min. and max. water demand for all field sizes, Jitpur Phedi (can grow) 47
Figure 39: Rice min. and max. water demand for all field sizes, Jitpur Phedi (can grow) 48
Figure 40: Wheat/Millet min. and max. water demand for all field sizes, Jitpur Phedi (can grow) 48
Figure 41: Mustard min. and max. water demand for all field sizes, Jitpur Phedi (can grow) 48
Figure 42: Vegetables min. and max. water demand for all field sizes, Jitpur Phedi (can grow) 49
Figure 43: Existing irrigation water storage tank, Taluwa 50
Figure 44: Example of field location (Ward 4), Taluwa 50

Figure 45: Example of dried out rice field, Taluwa 51
Figure 46: Example of field location, Taluwa 51
Figure 47: Irrigation channel, Taluwa 52
Figure 48: Leaking house water pipes connected to tap, Taluwa 52
Figure 49: Water demand of wheat (scarcity period), big field (left) small field (right) 54
Figure 50: Water demand of corn (scarcity period), big field (left) small field (right) 55
Figure 51: Water demand of millet (scarcity period), big field (left) small field (right) 56
Figure 52: Water demand of rice (scarcity period), big field (left) small field (right) 57
Figure 53: Water demand of mustard (scarcity period), big field (left) small field (right) 58
Figure 54: Water demand of vegetables (scarcity period), big field (left) small field (right) 59
Figure 55: Water demand of corn (shortage period), big field (left) small field (right) 60
Figure 56: Water demand of rice (shortage period), big field (left) small field (right) 61
Figure 57: Results for drinking water shortage Ward 2 62
Figure 58: Results for drinking water shortage Ward 3 62
Figure 59: Results for drinking water shortage Ward 4 63
Figure 60: Results for drinking water shortage Ward 5 63
Figure 61: Results for drinking water shortage Ward 7 64
Figure 62: Results for drinking water shortage Ward 8 64
Figure 63: Results for drinking water shortage Ward 9 65
Figure 64: Different gutter designs (Worm & Hattum, 2006) 67
Figure 65: Principle of a splash guard (smet, 2003) 68
Figure 66: Iron gutter holders (Luong, 2013) 69
Figure 67: Crossed-fixed wooden gutter holder (Luong, 2013) 69
Figure 68: Squared wooden gutter holder (Luong, 2013) 69
Figure 69: Tree-twig gutter holder (Luong, 2013) 69
Figure 70: Single saucer collection method........ 69
Figure 71: Multiple saucers collection method 70
Figure 72: Manual first flush method, movable downpipe (Worm & Hattum, 2006) 73
Figure 73: Manual first flush method, weight diverter practice (Worm & Hattum, 2006) 73
Figure 74: Half automatic first flush method, diverter pipe (Arkitrek, 2013) 74

List of Tables

Table 1: Inquiry results of irrigation water shortage Jitpur Phedi 14
Table 2: Average field sizes in Jitpur Phedi 16
Table 3: Water requirement for wheat (scarcity period) 16
Table 4: Water requirement for wheat (shortage period) 17
Table 5: Survey results of irrigation water shortage Taluwa 21
Table 6: Wheat water demand details (scarcity period) 23
Table 7: Wheat water demand details (shortage period) 25
Table 8: Results drinking water shortage Ward 1 27
Table 9: Meeting water demand Ward 1 27
Table 10: Results drinking water shortage Ward 6 28

Table 11: Meeting water demand Ward 6 28
Table 12: Ward ranking based on drinking water scarcity 28
Table 13: Average Rainfall (mm) – Jitpur Phedi (2001-2009) (Karki, 2013) 43
Table 14: Minimum Rainfall (mm) – Jitpur Phedi (2001-2009) (Karki, 2013)...................................... 43
Table 15: Average Temperature (°C) – Kathmandu Airport (Karki, 2013) 43
Table 16: Average Rainfall (mm) - Okhaldhunga (1981-2010) (Karki, 2013)....................................... 43
Table 17: Minimum Rainfall (mm) – Okhaldhunga (1981-2010) (Karki, 2013) 43
Table 18: Average Temperature (°C) – Okhaldhunga (1981-2010) (Karki, 2013) 43
Table 19: Details of crop growing period and water demand (Arab Forum for Environment and Development, 2013), (Agriinfo, 2011)... 44
Table 20: Wheat, irrigation water need details for all wards (scarcity period) 54
Table 21: Corn, irrigation water need details for all wards (scarcity period)....................................... 55
Table 22: Millet, irrigation water need details for all wards (scarcity period)..................................... 56
Table 23: Rice, irrigation water need details for all wards (scarcity period).. 57
Table 24: Mustard, irrigation water need details for all wards (scarcity period)................................. 58
Table 25: Vegetables, irrigation water need details for all wards (scarcity period) 59
Table 26: Corn, irrigation water need details for all wards (shortage period)..................................... 60
Table 27: Rice, irrigation water need details for all wards (shortage period)...................................... 61
Table 28: Run-off coefficients for traditional roofing materials (Worm & Hattum, 2006) 66
Table 29: Appropriate Widht of Gutter and Diameter of Outlet Drain and Various Roof Areas (Luong, 2013).. 68
Table 30: Advantages of surface and sub-surface tanks (Worm & Hattum, 2006).............................. 71
Table 31: Disadvantages of surface and sub-surface storage tanks (Worm & Hattum, 2006) 71
Table 32: Materials needed for cement rainwater jars (Luong, 2013) 72

Table of Content

1.1 Foreword 1

1.2 Background 1

1.2.1 Overview 1

1.2.2 Area description of Jitpur Phedi 2

1.2.3 Area description of Taluwa 3

1.2.4 Rainwater harvesting designs 4

2. Materials and method 6

2.1 Preparation – Inquiry 7

2.1.1 General pre-research 7

2.1.2 Inquiry- performance and evaluation 7

2.1.3 Observations 8

2.2 Calculations to identify water demand and design possibilities 9

2.2.1 Supply 9

2.2.2 Catchment area 9

2.2.3 Demand and storage capacity 10

3. Results 12

3.1 Jitpur Phedi 12

3.1.1 Observation 12

3.1.2 Meteorological conditions 12

3.1.3 Irrigation water shortage 13

3.1.4 Cultivated crop and cultivation period 15

3.1.5 Irrigation water demand examples 16

3.2 Taluwa 18

3.2.1 Observation 18

3.2.2 Meteorological conditions 19

3.2.3 Irrigation water shortage 20

3.2.4 Cultivated crop and cultivation period 21

3.2.5 Examples for irrigation water need 23

3.2.6 Drinking water shortage 26

3.2.7 Feasibility evaluation 28

4. Conclusion 30

4.1 Irrigation water Jitpur Phedi 30

4.2. Irrigation water Taluwa 30

4.3 Drinking water Taluwa 30

5. Solutions ... 31
5.1 Irrigation water collection for Jitpur Phedi and Taluwa ... 31
5.2 Taluwa drinking water collection ... 31
6. Discussion ... 33
7. Advices ... 34
Bibliography ... 35
Appendix I - Questionnaire ... 37
I.I Farmer - Irrigation ... 37
I.II Citizens-Drinking water ... 37
Appendix II – VDC maps ... 38
II.I Jitpur Phedi VDC map ... 38
II.II Taluwa VDC map ... 39
Appendix III – Observation tools ... 40
Appendix IV – Observations Jitpur Phedi ... 41
Appendix V- Meteorological data ... 43
V.I Jitpur Phedi ... 43
V.II Taluwa ... 43
Appendix VI- Crop water demand ... 44
Appendix VII- Irrigation water needs Jitpur Phedi ... 45
VII.I Irrigation water needs scarcity period ... 45
VII.II Irrigation water need shortage period ... 47
Appendix VIII– Observations Taluwa ... 50
Appendix IX- Irrigation water needs Taluwa ... 54
IX.I Water demand (WD) for different crops during water scarcity period ... 54
IX.II Water demand (WD) for different crops during water scarcity period ... 60
Appendix X- Drinking water shortage results ... 62
Appendix XI– Details of RWH-system parts ... 66
XI.I Catchment area ... 66
XI.II Gutters ... 66
XI.III Storage Tank ... 70
XI.IV Taps and pumps ... 72
XI.V First Flush ... 73
XI.VI Water quality ... 74

1. Introduction

1.1 Foreword

Prayer flags and snowcapped mountains. The image of modern Nepal is not always reflecting the actual situation in one of the world's poorest countries. Characterized by the omnipresence of the Himalaya range, with the highest point on earth, the Mount Everest, Nepal is a small country located in Asia surrounded by India and China and a newly formed federal republic since 2008 (Wikipedia, 2013). This amazing land locked country is facing the problems of a huge variety of ethnical groups, low level of education, insufficient infrastructure and severe water scarcity.

As a part of the four year bachelor study program International Water Management, the third year student of the HZ University of Applied Sciences is assigned to complete a five month internship in a field related to the study program. The chosen company is a NGO called Volunteer Initiative Nepal which works in various projects to support local communities in order to improve their living standards. VIN included a new project in their community work in Jitpur Phedi and Taluwa and it aims to support local people which suffer from severe drinking and irrigation water scarcities. A feasibility survey shall be conducted investigating if it is feasible to implement rainwater harvesting systems in these communities to enhance people living quality. The aim of this study is to survey if the needed water demand can be met by collecting rainwater.

1.2 Background

1.2.1 Overview

Water in Nepal is not scarce in absolute terms, and most areas receive about 1500 mm of precipitation each year, while certain areas may receive up to 5000mm (TECA, 2013) together with glacial water supply it is the second riches country in water sources. Still Nepal is facing in many part of the country, especially during the dry season, huge water scarcity in terms of irrigation water as well as drinking water.

Resulting from geographical and geomorphologic attributes Nepali weather can be divided into four seasons with spring between March and May, summer from June till August, autumn from September until November and finally winter from December to February. Summer from June till September is the monsoon season where almost all the yearly rain fall takes place. The rest of the year from October till June is generally referred to as dry season (Visit Nepal, 2013). As agriculture dry seasons farmers usually describe the month from mid December until mid April.

The two chosen communities where the research is conducted are lying in different parts of Nepal. Jitpur Phedi is located in the Kathmandu Valley around 15km outside of Kathmandu Centre (Figure 1) whereas Taluwa is located in the district of Okhaldhunga, around 200km away from Kathmandu (Figure 2) and is part of the Sagarmatha Zone (Wikipedia, 2013). In these two communities inquiries will be implemented to evaluate the current situation of the local people and to decide if rainwater harvesting is the right answer to their water scarcity problem.

Figure 1: Location on Jitpur Phedi Community (Google Maps, 2013)

Figure 2: Location Taluwa (Google Maps, 2013)

1.2.2 Area description of Jitpur Phedi

The investigated Village Development Committee (VDC) Jitpur Phedi consists of nine wards, which is the smallest administration unit in Nepal, distributed over an area of 13.26km². These nine wards accommodate approximately 31 villages widely scattered over the complete area. It is a hilly region at the edge of the Kathmandu Valley which results in the fact that there are villages present along the foothills from the mountains far away from any highway until all the way up to the top of the mountains. Some areas are dominated by thick untenanted forest (Figure 3) while deforestation took place along other places where a mixture of forest and villages are present. The VDC is connected to one major highway passing by only a small number of villages, while the most villages are only reachable by gravel roads in the best case. All of the fields are small and terrace like arranged.

Figure 3: Location overview Jitpur Phedi

1.2.3 Area description of Taluwa

Taluwa district with its nine wards is covering a total area of 19km² in the mountainous area of the Sagarmata Zone. The wards are all located alongside the south side of steep hills and covering an area from the River all the way to the top of the mountain peak (Figure 4). All wards found on the upper part of the mountain are more dry and colder than the wards lying at the lower altitude of the area. Most houses are found in a small number of villages and only distributed over a little area of the whole ward, only in ward number three and nine the houses are more scattered. Some parts of the area are dominated by stepp hills sides, while other wards have a more gentle slope with some plateus. Areas covered by the jungle are also present. At the moment there are four roads in the VDC, making it possible to reach a view villages in all wards exept of Ward 3. The roads are very basic and only accesible by 4WD and motorbikes.

Figure 4: Area overview Taluwa VDC

1.2.4 Rainwater harvesting designs

Two main approaches can be defined for rainwater harvesting (RWH). It is either the collection of land based runoff in any kind of storage tank, reservoir or direct infiltration into the ground to recharge the groundwater table or the collection of rainwater runoff straight away from rooftops. The idea of both systems is basically the same. During a period of precipitation the rainwater is falling down on the surface, either land or rooftops, and from there it is directly guided into storage tanks. This collected water can then be used for every purpose like irrigating fields, to bathing or washing laundry and, if several precautions are made, even as drinking water. If the collected water should serve as a drinking water source it is advisable to only use water collected from rooftops since the land based collected water would need some treatment to make it potable (Khoury-Nolde, 2013).

A proper design for a RWH-system depends on three basic components: the catchment area or roof surface as collection device, the delivery system comprising gutters and drainpipes and last but not least the storage reservoir or tank including and extraction device (Worm & Hattum, 2006). These three components are found in any kind of RWH system regardless which final design and method is chosen.

A division between three major designs can be made. The most common and know system is to use the roof from the house or a shed as catchment area and store the collected water in a nearby tank (Figure 5)

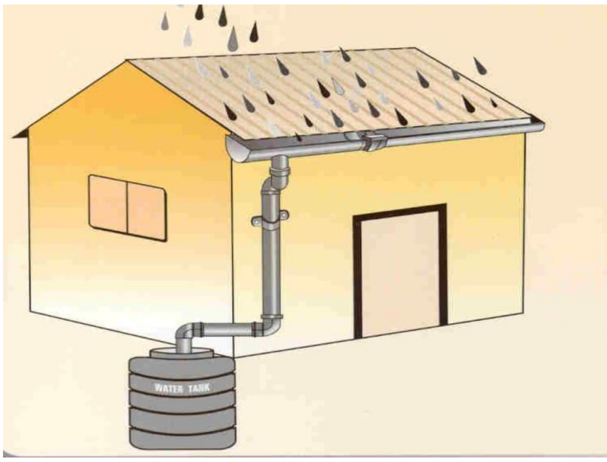


Figure 5: Roof dependent RWH-system (Madhya Pradesh Pollution Control Board , 2013)

A second technique is “Land surface catchments” (GDRC, 2013). It involves collecting rainwater as surface and sub-surfacing runoff by improving the runoff and guiding it into a storage tank. This can be done by either introducing drain pipe in the chosen area or manipulate the present vegetation to increase the runoff capacity. Additionally the flow of small creeks and streams can also be used to fill the storage tanks (Figure 6).

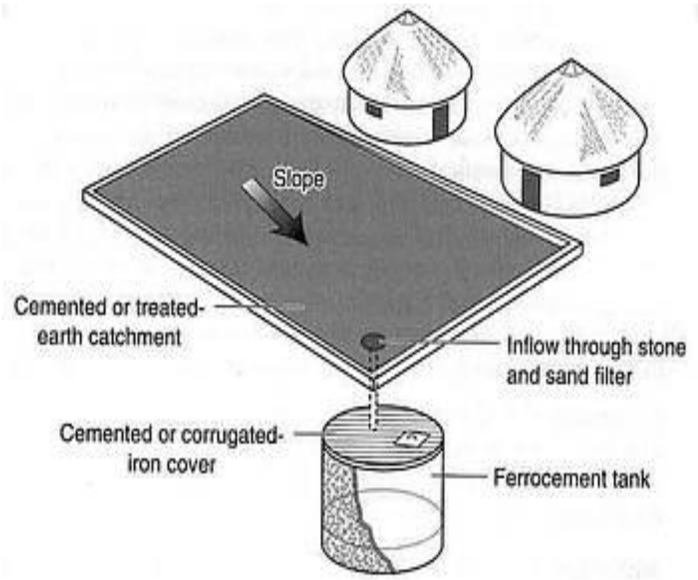


Figure 6: Land surface catchment (isp, 2013)

As a third method the “Rain Saucers” (RainSaucers, 2009) design can be mentioned. In this technique the idea of the roof catchment is comprised to use an alternative catchment area, a “Saucer” (RainSaucers, 2009) which catches the rain. This approach aims for a house independent solution, enabling a higher flexibility of the actual location where the water is needed and preferably collected (Figure 7).

Figure 7: Example of a Rain Saucer design (RainSaucers, 2009)

2. Materials and method

In order to perform a reliable evaluation of the feasibility of rainwater harvesting (RWH) techniques in rural areas of Taluwa and Jitpur Phedi a variety of different factors have to be considered. The major points are evaluation of eventually existing RWH-systems, research on environmental conditions, evaluation of possible location, and determination of total water demand per household or community, most suitable design and guarantee of sufficient water quality. A basic illustration of all crucial aspect is shown in Figure 8.

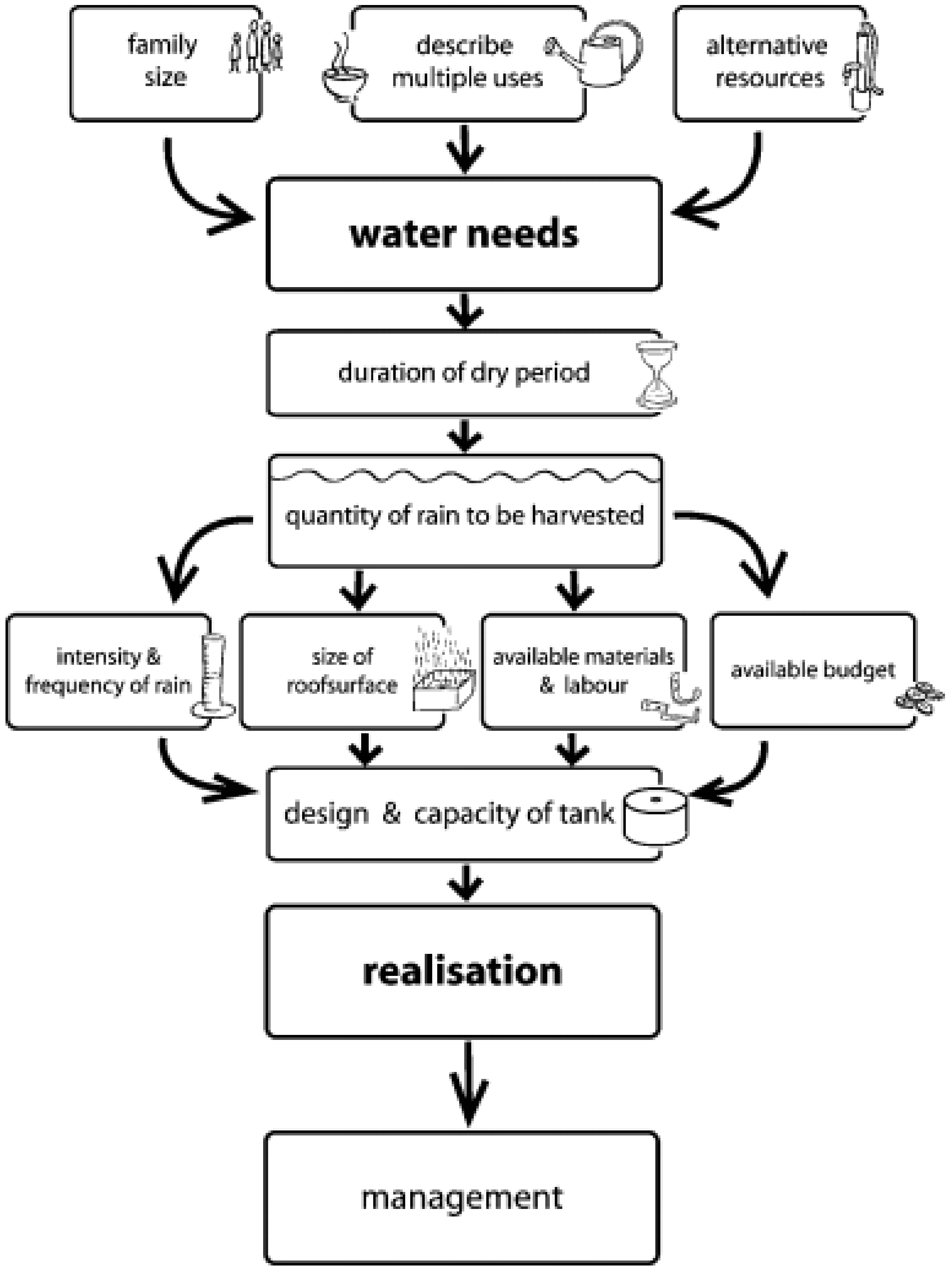


Figure 8: Approach of evaluating and designing RWH-systems (Worm & Hattum, 2006)

2.1 Preparation – Inquiry

2.1.1 General pre-research

A major aspect of guaranteeing a successful and reliable evaluation for future implementation of RWH-systems is to investigate if any kinds of RWH-systems are already implemented in the given area. If so, what kinds of systems are used? How big is the harvested amount of water? And what is the current quality of this harvested water? Based on these information advantages and disadvantages of the used RWH-systems can be evaluated and included in any future designs.

If no RWH-systems exist, all steps mentioned in Chapter 2.2, have to be followed for a proper evaluation of a needed and most suitable design.

As a first step to determine whether or not any rainwater harvesting system is feasible in the research area is to ensure that either a monthly rainfall of over 50mm or minimum 300mm rainfall per year is given. With this data including eventual losses by evaporation, leakages overflow and transportation as well as the reliability of used rainfall data a good estimation of a harvest volume can be made (Worm & Hattum, 2006). The needed data is obtained from the Department of Hydrology and Meteorology of Nepal. In case of usage for irrigation purposes the water demand of the cultivated crop must be defined. These data are provided by Dr. Kedai Budathoki, a well-known Nepali horticulturist.

Furthermore the water demand per household or community has to be defined as well as the purpose of water usage. Regarding to the achieved results the needed volume of rainwater can be verified and finally checked whether the local circumstances, like size of the catchment area, allow meeting the needed demand.

2.1.2 Inquiry- performance and evaluation

To obtain the required information a special questionnaire (Appendix I) has been developed to perform an inquiry among the local people. On account of VIN the research purpose diversifies slightly between Jitpur Phedi and Taluwa and therefore the questionnaires vary from each other. In Jitpur only the need for additional irrigation water is researched, while Taluwa is also investigated for drinking water scarcity. Therefore the inquiry will have some additional questions.

The inquiry is carried out in the two communities by the researcher and a Nepali translator. The method in Jitpur Phedi is rather pragmatic. Due to a lack of a proper map and limited time a minimum amount of five surveyed farmers is set, preferably more, and if possible over a broad area. Depending on the ward size and geographical conditions up to ten farmers are randomly surveyed. It is an on-site inquiry, visiting the farmers at their houses, which are reached by foot. All questions mentioned in the questionnaires are asked in English and translated into Nepali by the translator and vice versa. If any important information is giving despite the necessary ones they are marked down in a special column.

In Taluwa the inquiry performance will look differently. Due to a longer provisioning of a translator a greater amount of households is surveyed and also non farmers are people of interest in this community, to research the additional need of drinking water as well. With the help of a local translator with area knowledge, preferably, data from every village is taken to collect brought and reflective data. The basic implementation of the interviewing is the same as in Jitpur Phedi mentioned above. Hence it is an on-site, random survey as well.

A basic map of both VDC's is presented in Appendix II.

All collected data are digitalized and for Jitpur Phedi, scanned for irrigation water shortages and the duration. Moreover it is also detected whether a water shortage occurs during cultivation season occurs or even a lack of water resulting in a cultivation break. After those aspects are identified the actual water demand is determined with several calculations explained more in detail in Chapter 2.2. The water demand is then compared to the actual water that could be harvested based on the meteorological data from this region and if the demand can be met in theory the project is rated as feasible in terms of water availability. Besides that the storage capacity and ergo the storage tank size have a feasibility limit which, in this case, lies at a total amount of 200m³.

In Taluwa the need for irrigation water is assessed in the same way as in Jitpur Phedi, after the random inquiry the data will show if irrigation water shortages is an actual threat to the people in this area. The achieved results are then compared to the actual amount of water that could be harvested and the required storage capacity and founded on these results a judgment on the feasibility is made. For the survey of drinking water scarcity the results per household and per village/ward are compared in order to investigate if some villages have a greater need of water than others. An ascertainment of rainwater needs per household depends on the family size the multiple use of water per family member per year. Multiple uses include needed quantity for drinking, cooking, personal hygiene and gardening use plus eventual other individual purposes usually 15l-25l per person per day is sufficient to meet the needed demand (Worm & Hattum, 2006). In this way already a selection for possible project sites is made. In the end the example calculation based on obtained meteorological data is executed to prove if the actual required water demand can be achieved with the given environmental circumstances. Justified on these outcomes a final statement is made to clear whether an implementation of rainwater harvesting systems is feasible to fight drinking water shortages.

2.1.3 Observations

Besides the on-site inquiry performance it is important to furthermore investigate the area itself too. This is conducted by using several observation tools (Appendix III). It is necessary to asses if the collected data from the inquiry represents the actual situation, as well as to check where additional solutions might already have a positive result on the water availability. This approach enables further judgment of possible solutions and designs for RWH systems.

2.2 Calculations to identify water demand and design possibilities

2.2.1 Supply

A basic formula to calculate the rainwater supply is following:

$$S = R * A * C_r$$

With:

S = Mean annual rainwater supply (m³)

R = Mean annual rainfall (m)

A = Catchment area (m)

C_r = Run-off coefficient

(Worm & Hattum, 2006)

2.2.2 Catchment area

Calculation the area size of a flat roof is quite easy since it is only the two dimensional shape of the house.

$$Area = lenght * width$$

For a pitched roof the calculation includes also the height of the roof.

$$Area = l * (f + \frac{g}{2})$$

With:

l= Length of the roof

f= Width of the roof till the pitch

g= Height of the roof

(ACO Building Drainage, 2011)

With the given catchment area the total supply can be calculated.

$$S = R * A * C_r$$

With:

S = Mean annual rainwater supply (m³)

R = Mean annual rainfall (m)

A = Catchment area (m²)

C_r = Runoff coefficient (Worm & Hattum, 2006)

Land catchment

$$A = l * w$$

With:

A= Catchment area (m²)

l= Length (m)

w= Width (m)

RainSaucers

Catchment area can be calculated as followed

$$A = \pi * r^2$$

With:

A= Area

r = Radius of the base area

2.2.3 Demand and storage capacity

Storage tanks or reservoirs have by far most the biggest variety of possible designs and material. For every type of usage, available material, size, catchment system and preference a different tank can be constructed. Leaving all those final shape and material problems at the side a few steps are the same independent from the final design.

The most important aspect of the tank is that its capacity matches the demand during the complete dry season. Therefore two simple calculations have to be made.

For drinking water

Required demand:

$$Demand = \frac{Water\ Use * Household\ Members * 365 days}{12\ months}$$

With:

Demand (l/month)

Water Use (l) (Worm & Hattum, 2006)

For irrigation water

Required storage capacity:

$$Required\ storage\ capacity = (water\ demand - precipitation) * field\ size$$

With:

Storage capacity (m^3)

Water demand (m^3/m^2) for total growing period

Precipitation (m^3/m^2) of total shortage period

Field size (m^2)

Required demand:

$$Water\ demand = total\ water\ demand\ /1000$$

With:

Water demand (m^3/m^2)

Total water demand per growing period (mm/m^2)

3. Results

3.1 Jitpur Phedi

3.1.1 Observation

At the current moment no form of rainwater harvesting is used in the community of Jitpur Phedi. Therefore no experiences or comparison to any known technique can be done.

While performing the local inquiry observations of the environment and area in Jitpur Phedi were made. Many interviewed farmers mentioned that only their vegetable fields are next or close to their house while rice paddies usually are located in the two valleys of Jitpur Phedi and corn fields all along the hill sites. This distribution of the fields was clearly visible during the research, confirming the gained information.

Moreover several irrigation channels were detected, proper constructed ones as well as unconstructed ones, whereby the proper constructed ones were definitely the exception, which was also mentioned by the surveyed farmers. It must be mentioned that the state of the constructed irrigation channels differed from maintained to highly unmaintained, with segments suffering from a high rate of vegetation growing in the channel and broken sections. Some farmers mentioned that even though there are irrigation channels close to their fields they cannot use them due to the fact that they located lower than the fields. Also this information is confirmed by observation. Many bigger and especially constructed channels run alongside the roads being lower than the fields.

In addition a few storage tanks were detected, one connected to a groundwater well another one connected to the river which then, via pipelines, fed a few community taps. Most of those connected taps where running all day long while others were leaking water. This water mostly ended up flowing into natural small irrigation rivulets leading to some nearby fields.

Another important finding, which has to be mentioned, is that most of the fields, particularly more uphill, are very small and steep. This proves the statements of some farmers where they mentioned that it is difficult to irrigate their land, because the water flows off too quick causing more erosion than actual irrigation. All pictures proving the observed situation are provided in Appendix IV.

3.1.2 Meteorological conditions

The VDC Jitpur Phedi has an average annual precipitation of 1800mm with its peak during the monsoon season from mid May till end of September. During this time a maximum rainfall of up to 517.6mm in July can be found. November and December are detected as far driest month during the year, with a rainfall of only 4.9mm during November (Appendix V).

Looking at the yearly temperature the differences are not very high, the warmest months are May till October with temperature above 20 °C and maximum temperatures of 24.3 °C during July and August. The coldest month is January with an average of 10.8 °C. The temperature and the rainfall pattern linked in the way, which during the monsoon the temperature becomes highest and vice versa (Figure 9).

It is important to note that the pre-condition of a monthly rainfall of 50mm or total annual rainfall of at least 300 mm rainfall, for successfully implementing RWH – systems, is met in this area. The total amount of 1800mm per year exceeds the minimum requirement and also during seven month of the year the rainfall is higher than 50mm. Therefore it can be said that the environmental pre-condition addressing the rainfall, to make RWH systems feasible, are met. However during the other five month (November until March), the average precipitation lies under the 50mm border which could lead to the fact that throughout this time no or only a small amount of water can effectively be harvested. To avoid misleading results with higher harvesting rate then actual possible, the total amount of rainfall of these months will be subtracted from the overall precipitation and can be seen as a bonus in case some water can be harvested. Thus the effective annual precipitation in the Jitpur Phedi VDC is approximately 1700mm.

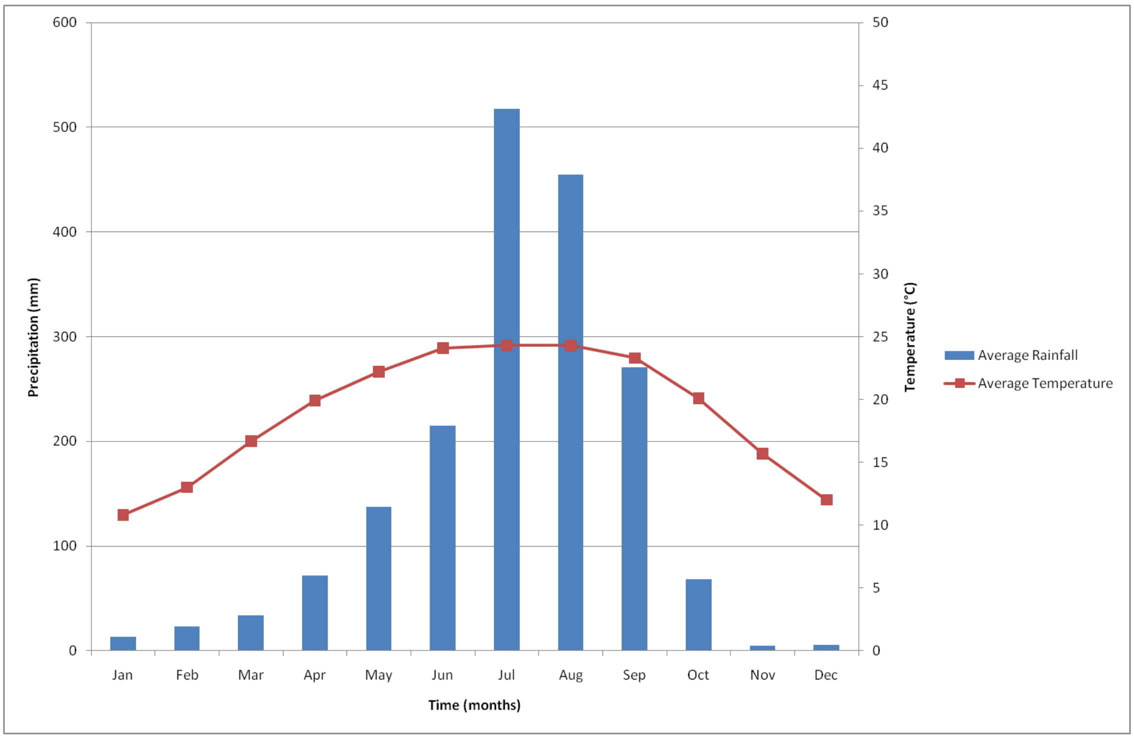


Figure 9: Climate diagram Jitpur Phedi

3.1.3 Irrigation water shortage

The inquiry shows that out of 59 surveyed households 39 households face water shortages for one or more months a year. Furthermore out of these 39 households 13 households cannot cultivate due to a lack of water. Moreover only 12 households do not have any water shortages at all and another 6 households only have low irrigation water availability outside of the cultivation season and are not negatively affected by it. One household suffers from water shortage but they do not cultivate during this time because they do not have anyone for the work and one farmer did not give any information about additional water shortages (Table 1).

Table 1: Inquiry results of irrigation water shortage Jitpur Phedi

Farmer	Total (households)	Percentage (%)
Water shortage (total)	**39**	**67**
• Lack of water	13	33
• Only shortage	26	67
No water shortage	12	21
Water shortage outside of season	6	10
Others	1	2

Those numbers result in an overall outcome of 67% households with irrigation water shortages and of which 33% even face irrigation water scarcity and on the other hand only 21% do not have any water shortages at all.

The periods of water shortages varies from 1 up to 9 month per year with an average time of 3.64 month neglecting the month where a water shortage appears outside of the cultivation period. The most severe months are from mid December till mid June, with the period from mid March to mid April is by far most the hardest month where the most farmers face water shortages and have a need for an alternative water source. The rest of the year only a few farmers face water shortages (Figure 10).

During the time from mid June until mid September all farmers can cultivate their crop without any water shortage. From mid September till mid December farmers cannot cultivate due to a lack of water and from mid December until mid June a variety of farmers who can cultivate, farmers who cannot cultivate because of a lack of water and farmers who do not cultivate because it is not the right season for the crop, are found. It is important to see that during the whole year the number of farmers who can cultivate exceeds the amount of farmer which cannot cultivate (Figure 10).

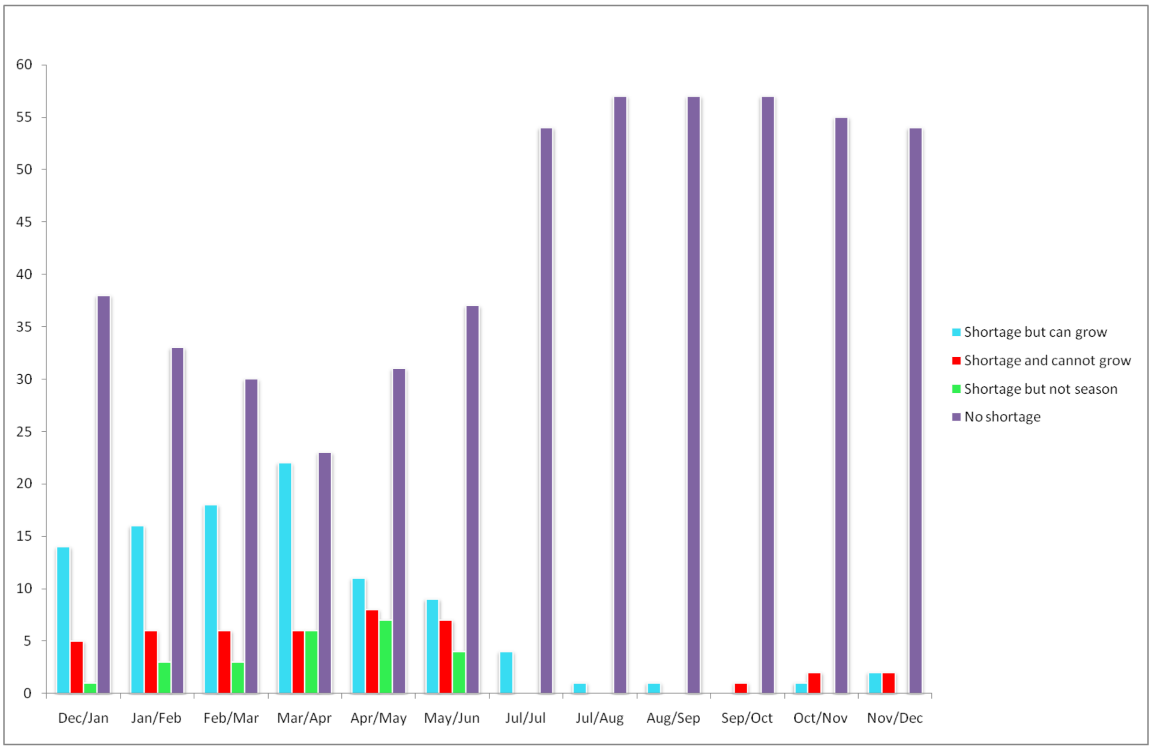


Figure 10: Irrigation water shortage over one year

3.1.4 Cultivated crop and cultivation period

The performed survey shows that the main crops cultivated are rice and corn which are cultivated by 80% of all asked farmers, followed by wheat which 69% grow. Millet and vegetables both with 41% are the next main products, but it must be considered that “vegetables” comprise all seasonal vegetables (cucumber, potatoes, radish, cauliflower, spinach, bitter melon, tomatoes, (soy) beans, onion, garlic, cabbage) (Figure 11).

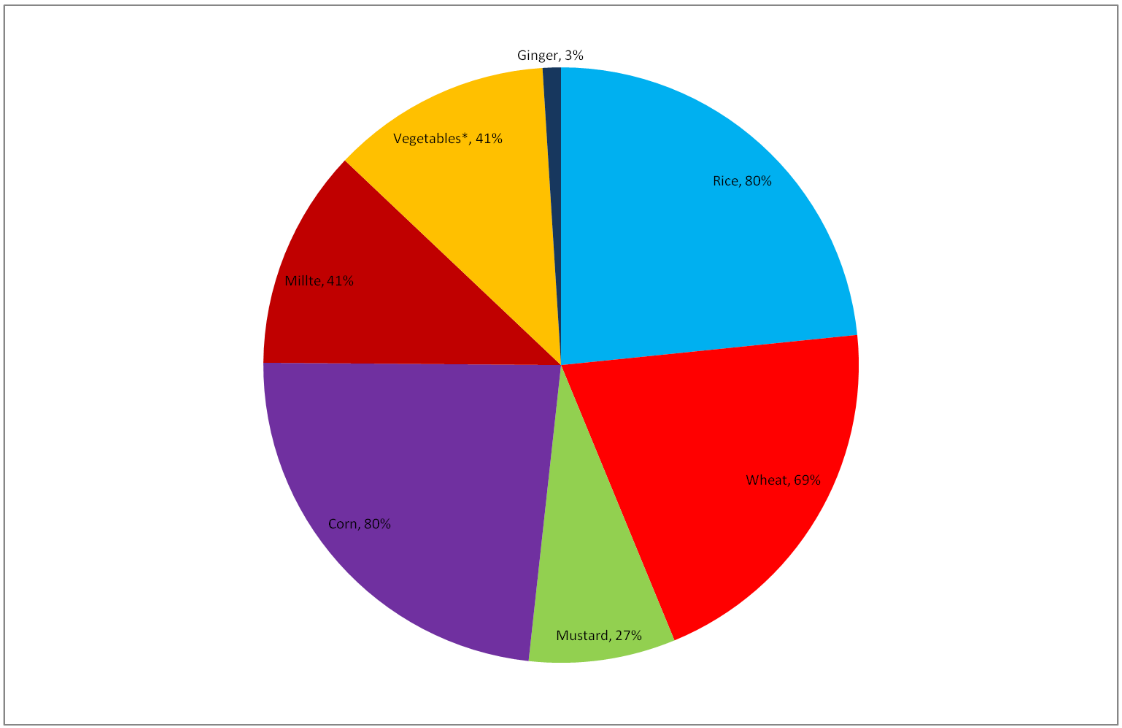


Figure 11: Amount of cultivated crop by all farmers in Jitpur Phedi (%)

Rice is mainly cropped from mid June till mid November, sometimes starting a month earlier or ending a month later. Furthermore the main cultivation period is 5 months but also rice species with a 6 month growing period are popular. Wheat is usually grown for 6 month per year during the time from mid November until mid April. For cultivation corn, 5 month from mainly mid April till mid August shows to be the most favorable ones. Starting between mid July and ending mid January is the usual time to grow millet for 5 month. Vegetables can be grown all year long with no specific season, because the actual period depends on the vegetable itself. Focusing on mustard, it can be seen that it is cultivated between the time of mid June and mid January sometimes twice during this period (Figure 12).

Important to notice is the fact that in the time of the most severe irrigation water situation wheat is the main crop besides some farmers which also grow vegetables, mustard and millet might be in its last month of growing period. Corn, millet and other more water intensive crops like rice are only cultivated in the time from mid May to mid December in which water scarcity barely occurs. Based on these results it can be said that a better or longer cultivation period with a higher amount of available water could be accomplished.

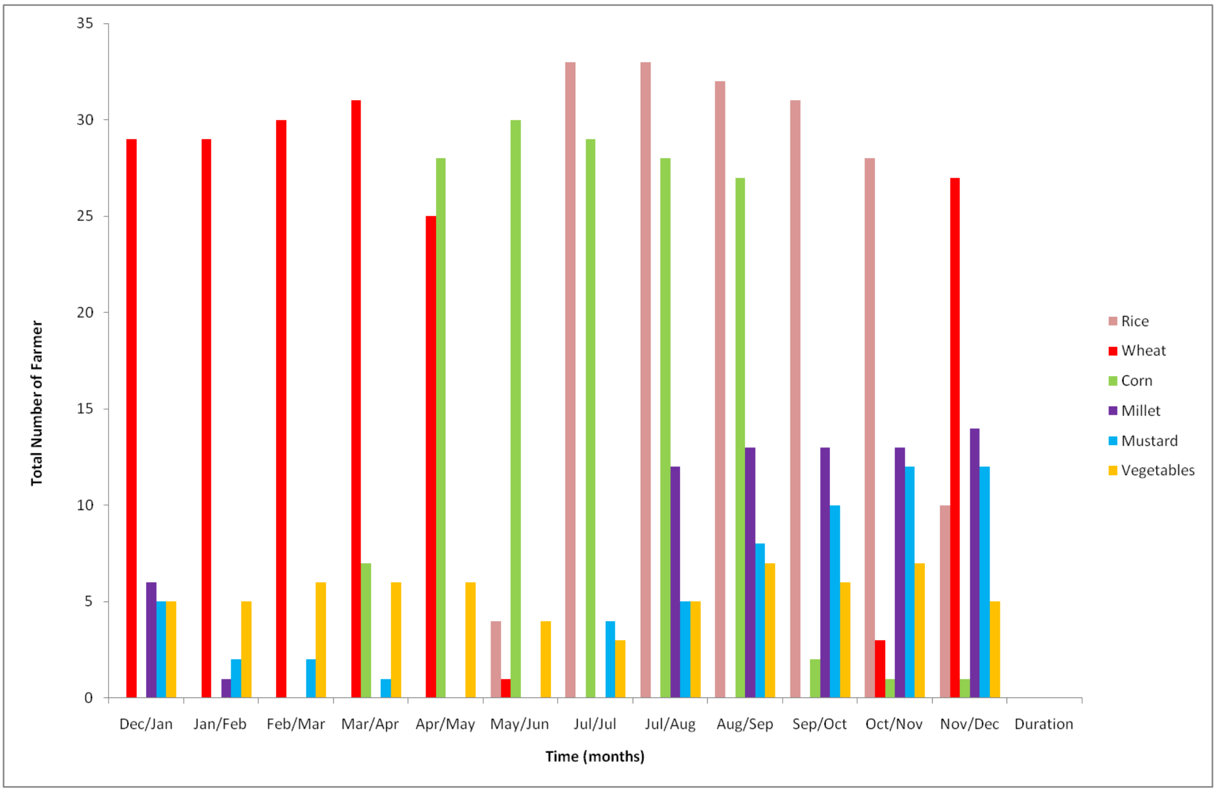


Figure 12: Cultivation period of different crop in Jitpur Phedi

3.1.5 Irrigation water demand examples

In order to determine if RWH is a feasible solution as an alternative water source calculations are made. The period of main water shortage and water scarcity is taken into account, which are, in case of Jitpur Phedi, around the same time from Feb/Mar until end of Jun/Jul. Throughout this time mainly wheat is cultivated and therefore picked as an example. The actual water demand of all the crops is provided in Appendix VI. As water shortage period the time where most farmers face irrigation water shortages is described, while scarcity period is defined as the time where most farmers have not enough water to cultivate their fields. In case of Jitpur Phedi the field sizes are divided into four categories with the smallest one from 1526m² up to 19841m² (Table 2). All results for the irrigation water demand of the other crop during the water scarcity period are listed in Appendix VII.I.

Table 2: Average field sizes in Jitpur Phedi

Total households	Field size (ropani)	Field size (m²)
328	3	1526
164	7	3561
87	13	6614
25	39	19841

<u>Wheat:</u>

Table 3: Water requirement for wheat (scarcity period)

Shortage (cannot grow)	Total water demand per growing period (m³/m²)	Growing Period (days)	Precipitation (m³/m²)	Field size (m²)	WD min (m³)	WD max (m³)
Feb/Mar-end Jun/Jul	0.45-0.65	90-120	0.21	1526	366	672
Feb/Mar-end Jun/Jul	0.45-0.65	90-122	0.21	19841	4762	8730

As shown in Table 3 the minimum water demand for the smallest field sizes for wheat cultivation lies already at 366m³ for the total growing period, while the maximum demand with 672m³ is almost 300m³ higher. Looking at the biggest field size the minimum demand lies at 4762m³ and at 8730m³ for the maximum demand. Besides the mentioned results in Figure 13 it can be clearly seen that already the second field size has a water demand above 1000m³. As for the other crops, millet has the same water demand as wheat, while corn and rice have an even higher water demand and only mustard and vegetables require less water. These demands exceed the pre-condition of a maximum storage tank capacity of 200m³ by far.

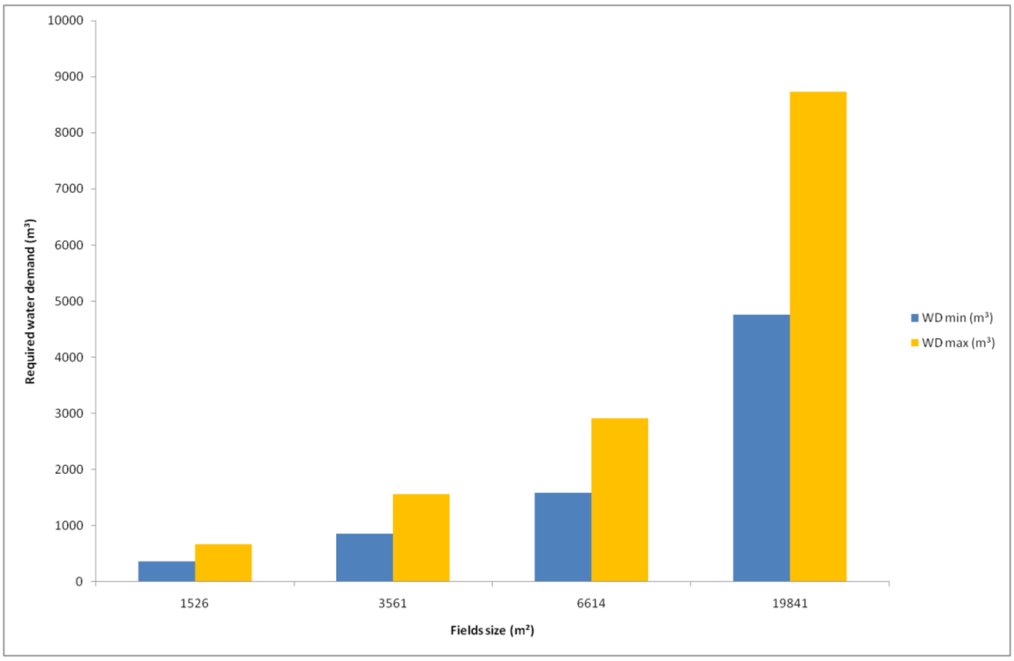


Figure 13: Required water demand (m³) for wheat cultivation (scarcity period)

Wheat:

Table 4: Water requirement for wheat (shortage period)

Shortage (can grow)	Total water demand per growing period (m³/m²)	Growing Period (days)	Available water (m³/m²)	Field size (m²)	WD max (m³)
Feb/Mar-end Jun/Jul	0.45-0.65	90-120	0.45	1526	305
Feb/Mar-end Jun/Jul	0.45-0.65	90-122	0.45	19841	3968

For all farmers who can cultivate in the time from Feb/Mar-end Jun/July (shortage period), the natural available water is at least 0.45m³/m² as the meteorological data states(the minimum demand for wheat cultivation) (Table 4). Therefore just the differences between the minimum and maximum requirements must be met. In the case of wheat an additional 305m³ of water are needed to provide the capacity for maximum water demand. The same numbers apply for millet too, which has the same water demand as wheat. Nevertheless for the biggest field sizes a total amount of 3968m³ are needed and also for the other intermediate sizes the required water capacity lies about 500m³ (Figure 14). Thus in this case the maximum storage tank capacity of 200m³ is topped.

Having a closer look at the alternative crops it becomes clear that only vegetables have a lower need for extra water with 198m³ on the smallest field size, than wheat and millet. This is exactly the maximum possible storage tank capacity. Mustard cultivation should be possible without any extra water, because its maximum demand is the same as the available water. Corn and rice require higher values of additional water, whereby the minimum demand for corn for the two smallest field sizes are relatively low, but to guarantee a proper harvest, the maximum demand should be met, which lies above 534m³ (Appendix VII.II), exceeding the 200m³ limit as well.

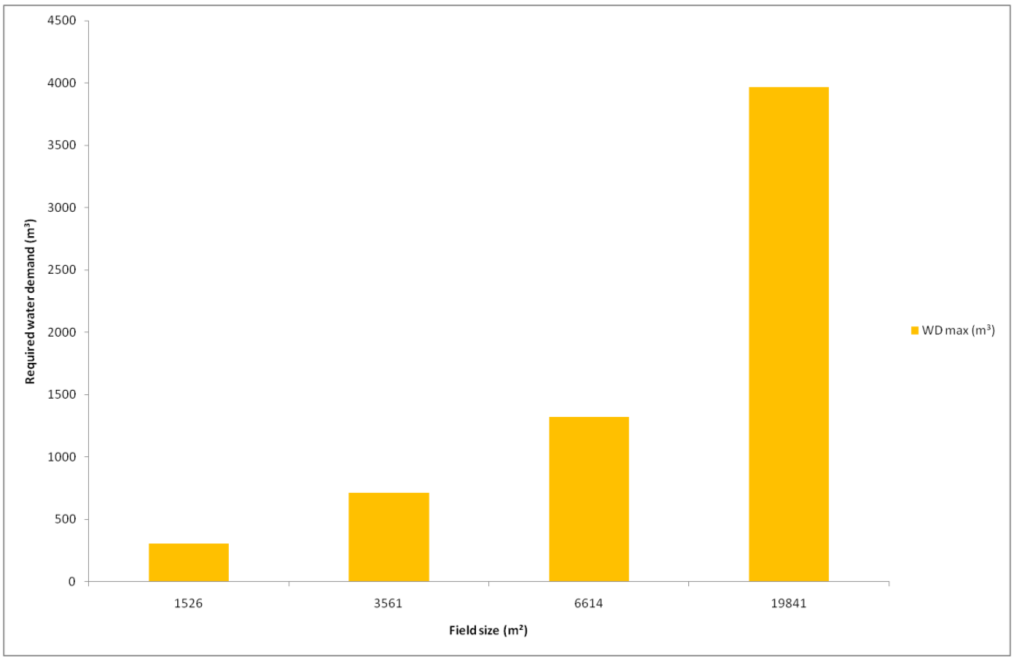


Figure 14: Wheat, maximum water demand for all field sizes (shortage period)

3.2 Taluwa

3.2.1 Observation

At this moment there are no rainwater harvesting systems used, but the villagers of Taluwa use in some cases reservoirs filled by the direct outflow of the sources in the area which are connected to further irrigation channels to irrigate their land. Those reservoirs are filled by channels which are connected to little streams fed by the main water source in these areas. Approximate capacities of these reservoirs are between 18m³ (and less) and 60m³. Variations of designs can be found from properly constructed cement reservoirs to more basic catchment basins only existing of a brick wall and normal soil as the bottom. The performance of the survey in Taluwa took place at the end of the wet season and beginning of the dry season. This leads to the fact that in a lot of areas still enough water is available and an impression of the situation during the most severe month of the dry season cannot be achieved. Nevertheless a main idea of the overall situation is given, showing that the wards in the upper part of the VDC (Ward 1, 2, 4 and 8) are drier then the wards located on a lower altitude, confirming the information gained by the interviewed households.

In all wards the distribution of the fields are similar. Fields used for rice cultivation are often clustered together at points where irrigation via irrigation channels is possible and thus further away from the most homes. Nevertheless the stage of those irrigated fields differs between the wards. In some of the upper wards, especially seen in ward 5, the rice fields suffer from irrigation water shortage and therefore only low production or even loss in crops appear. In the upper wards there is often even only a small number of rice fields present while in the lower wards, especially in ward 6, 7 and 5 many rice fields are found. On the other hands fields that are used for cultivating vegetables and crops with a low water demand are often located next to the houses, especially for vegetable cultivation, or everywhere spread over the ward mostly not further then 20min away. These fields also make a dry impression.

Another important observation is that traditionally people in the Taluwa VDC are using irrigation channels to water their fields. Irrigation channels can be found in all kind of areas always connected to some sources or tanks. Even though it is a common method to use irrigation channels, all of them are just small ditches dug into the road or paths. Sometimes the paths are the irrigation channels or at least parts of it. The irrigation channels are fed by different sources, most of them are directly connected to a source, while others are filled by reservoirs and a small part is distributed from the taps where the overflow goes into the channels and then leads to some fields close by. A common technique for the irrigation channels is to have a lot of branches departing at different locations from a main channel and if the water is needed or the schedule allows it, they close the main flow with some earth and stones and open the side branch letting the water flow into their fields. In this way one main irrigation channels is used by a various number of farmers.

For the water usage in general it can be pointed out that a lot of water is lost due to infiltration either by the taps which are usually running all the time and the overflow is not caught, as well as by the irrigation channels which are not properly constructed and therefore are a weak point in the water chain.

For the personal drinking water supply a complex pipe system is developed by the local people of Taluwa, saving them the time to walk to the sources to fetch drinking water and also sometimes using it for irrigation in fields close to the houses. These pipes are also identified as weak point, since often some leaks appear on the way creating a great water loss. Moreover the pipes are not always properly guided underground and therefore are vulnerable to any kind of ruptures when people or cattle walk over them. For the maintenance of the storage tanks for drinking and irrigation water as well as the taps it is difficult to say. Some of the tanks and reservoirs look very good while other definitely show a lack of maintenance or even completely neglected. Therefore it can be said that the maintenance should be improved to prevent any rate of water loss.

Even though the majority of the local people have a tap or a pipe for drinking water close to their house, they face problems during the dry season because the taps run dry. Although the dry seasons just started already a number of dry taps are detected as well as taps where only a trickle of water is flowing out. Additionally it is important to point out that many of the visited alternative sources are very difficult to reach and only accessible via small, steep footpaths.

Evidence pictures for all observations are provided in Appendix VIII.

3.2.2 Meteorological conditions

The VDC of Taluwa as an average annual precipitation of 1800mm with its peak during the monsoon season from Mai until end of September. During this time a maximum precipitation of 466.8mm in July is reached. The months November till including February can be pointed out as far driest month during the year, with a minimum rainfall of 11.2mm in January (Appendix V).

Having a closer look at the yearly average temperature the greatest difference is only 12°C. The highest temperatures are found during the months of May till end September with temperatures above 20 °C and a maximum temperature of 22.2°C in July. January is the coldest month in this area with an average temperature of 10.3°C. All found temperatures and precipitation patterns are typical to the monsoon climate and during the month with the highest temperature and also highest rainfall and vice versa (Figure 15). Based on this climate information it can be said that the required pre-condition of 50mm precipitation per month is met during the seven month from April till end of October, or a minimum annual rainfall of 300mm is reached too. Thus for the main time of the year and in total the environmental rainfall pre-conditions enabling a successful RWH are given Nevertheless during a five month period (November till end March), the monthly amount of rainfall lies below the 50mm border which might negatively influence the possibility to successfully harvest rainwater during that time of the year. In order to avoid any results showing higher harvesting rates as possible these months will be neglected during the actual calculation leading to an overall effective annual rainfall of around 1700mm.

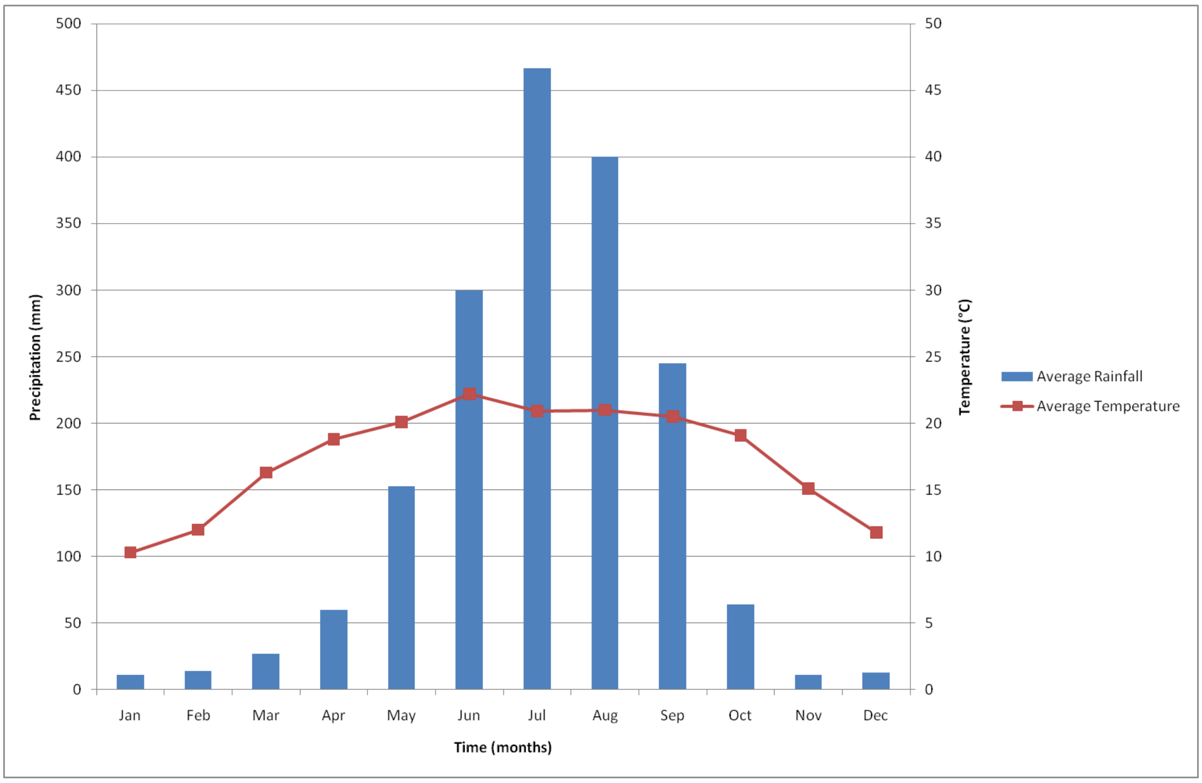


Figure 15: Climate diagram Taluwa (Okhaldhunga)

3.2.3 Irrigation water shortage

The found results for irrigation water shortages in the Taluwa VDC presented in Table 5, clearly point out that all interviewed farmers face irrigation water shortages and of those 83% have even a lack of irrigation water prohibiting growing any crop on their fields. The additional 16% face irrigation water shortages decreasing the amount of yield produced during this time.

Table 5: Survey results of irrigation water shortage Taluwa

Farmer	Total (households)	Percentage (%)
Water shortage (total)	**90**	**100**
• Lack of water	75	83
• Only shortage	14	16
No water shortage	0	0
Only water shortage outside of season	0	0
Others	1	1

Irrigation water shortages appear over a period of 2 up to 11 months per year with an average of 5.8 months in the Taluwa VDC. Hereby the months where water shortage and off season intersect are neglected. As indicated in the graph (Figure 16) from mid November until mid April the water scarcity is most severe. During this period most farmers cannot cultivate their crop due to a lack of water. Until mid July also a high number of farmers face irrigation water shortages decreasing their yield noticeably. Thus it is obvious that at the present time there is a great need for additional irrigation water sources in Taluwa. An important aspect to notice is that in the time from mid December to mid June the number of farmers who cannot cultivate exceed the amount of farmers who can cultivate on one or all their fields where only during five months per year there are more fields used then suffering shortages underlining the sobriety of the situation.

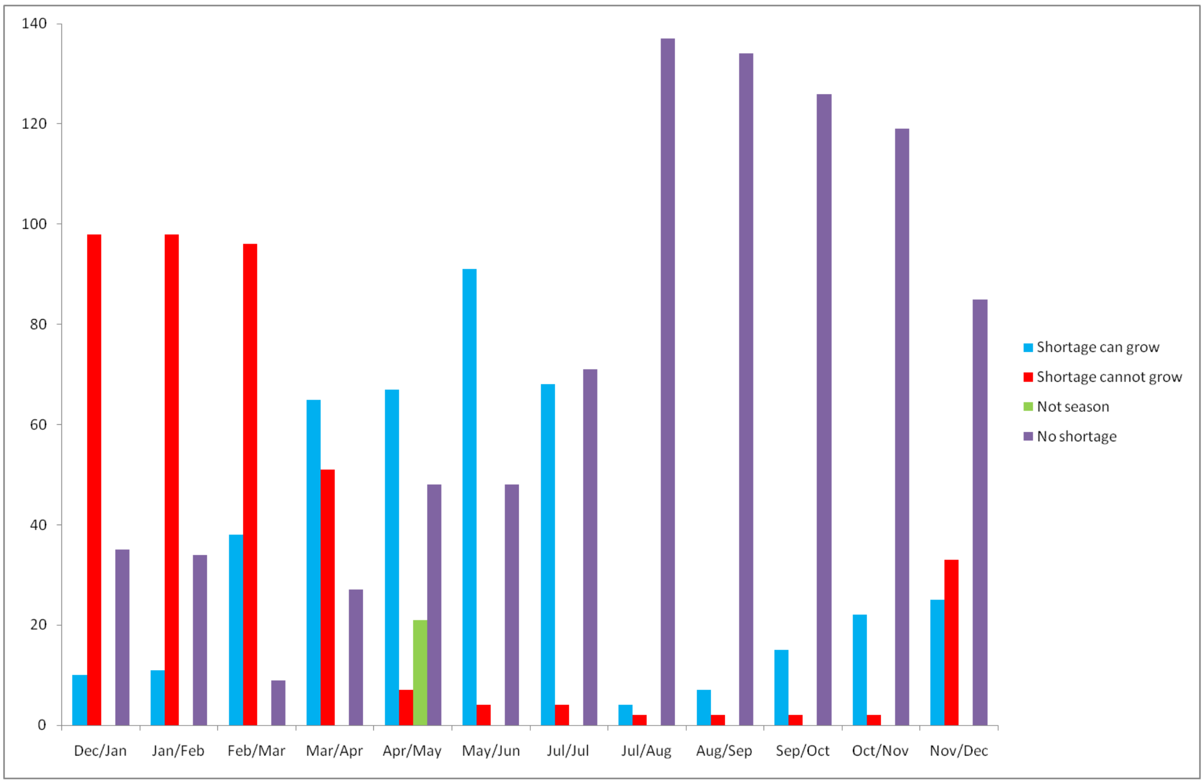


Figure 16: Irrigation water shortage in Taluwa VDC

3.2.4 Cultivated crop and cultivation period

The survey shows that the main crops cultivated in Taluwa are corn and rice together with a variety of vegetables (Figure 17). All farmers cultivated these crops, the second most cultivated plant is millet produced by 98% of all farmers where rice is only on the third position with 74%, already indicating that a lot of farmers do not have enough water to cultivate rice on their fields. The other crops grown by the most farmers in Taluwa are wheat (56%), buckwheat (39%) and tobacco (3%).

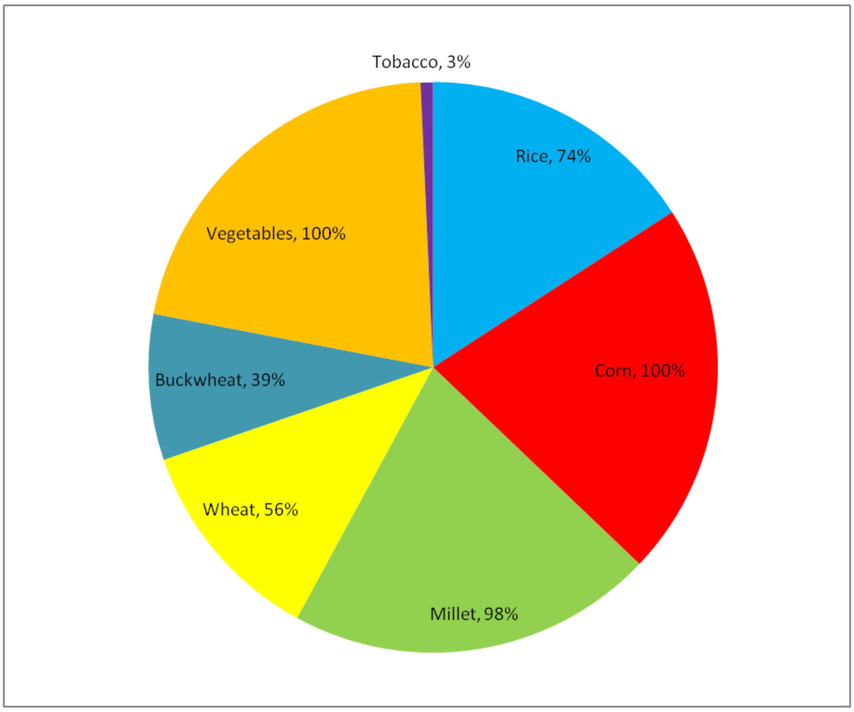


Figure 17: Amount of cultivated crop by all farmers in Taluwa (%)

Rice is mostly grown in the time from mid July till mid November while some farmers are also able to grow rice in the time from mid March to mid July. Vegetables are cultivated all year long with the peak season from mid July to mid April. Wheat is usually planted from mid November to mid April and millet in the period from mid July until mid December. For the buckwheat the main cultivation time is mid August to mid December (Figure 18).

Comparing the period of water shortages and lacks with the cultivation period of the different crop it is clearly visible that during the month with low water availability mainly wheat and vegetables are cultivated. When a little water is available, only enough for cultivation but to less for a high yield, crop like corn has its peak season. With more available water a shift to a better variety of cultivation period might be achieved.

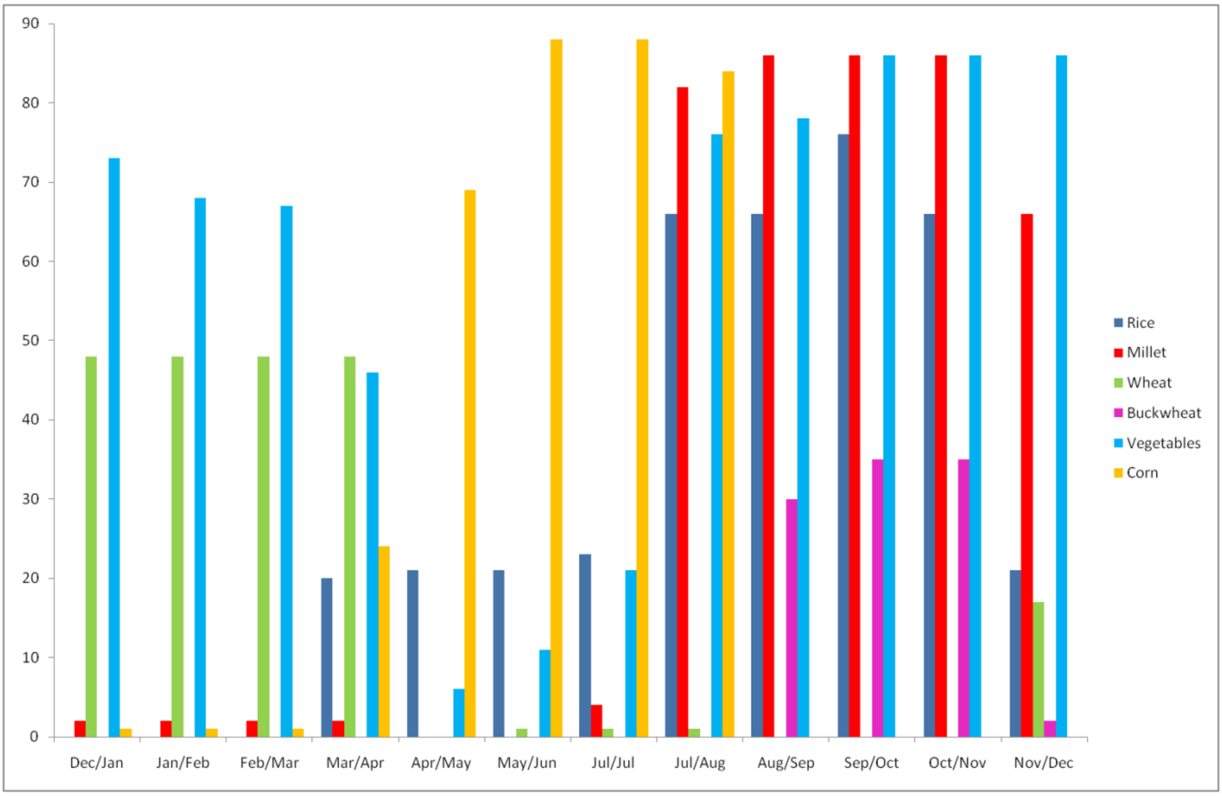


Figure 18: Cultivation period of different crop in Taluwa

3.2.5 Examples for irrigation water need

After assessing during which time and for how long irrigation water needs are occurring in Taluwa calculations are made. In this sub-chapter only a few examples are given, to present the possible amount of alternative water that is required during the time where most of the farmers cannot cultivate their fields due to a lack of water and throughout the period where the majority of the farmer is able to cultivate but has irrigation water shortages. Wheat and corn, used for the example calculations, are the ones, mainly cultivated during the chosen period. Moreover the biggest and the smallest field size of all nine Wards where picked to give a good contrast between the actual needed amounts. All further results for different field sizes and crop are presented in Appendix IX.I.

Wheat:

Table 6: Wheat water demand details (scarcity period)

Shortage (cannot grow)	Total water demand per growing period (m^3/m^2)	Growing Period (days)	Precipitation	Field size (m^2)	WD min (m^3)	WD max (m^3)
Nov/Dec- end Mar/Apr	0.45-0.65	110-130	0.10	91573	32051	50365
Nov/Dec- end Mar/Apr	0.45-0.66	110-130	0.10	509	178	280

The calculated amount of required water, besides the actual precipitation during the water scarcity period, is ,with a minimum of 32051m³ and a maximum of 50365m³ (Table 6) for the biggest field size, tremendously high. But, also in other Wards where the biggest fields are smaller, only one Ward has a demand lower than 5000m³ for its minimum demand. Moreover none of the maximum demands underscores the 5000m³ boarder, thus leading to a problem considering the necessary storage tank size which exceeds the limit of maximum 200m³(Figure 19). Having a closer look at the results for the smallest field sizes occurring in the nine Wards in Taluwa (Figure 20), a great difference for the additional needed water demand, compared to the big field sizes, can be observed. Nevertheless only two out of the nine Wards have a minimum demand lower than 200m³ while the lowest maximum demands are around 300m³. Most of the Wards have a minimum score around 400m³ – 500m³ and a maximum need of 600m³ and higher. Thus, as already mentioned beforehand, a problem for the storage tank size (maximum 200m³) occurs, when considering wheat cultivation during the scarcity period from Nov/Dec- end Mar/Apr.

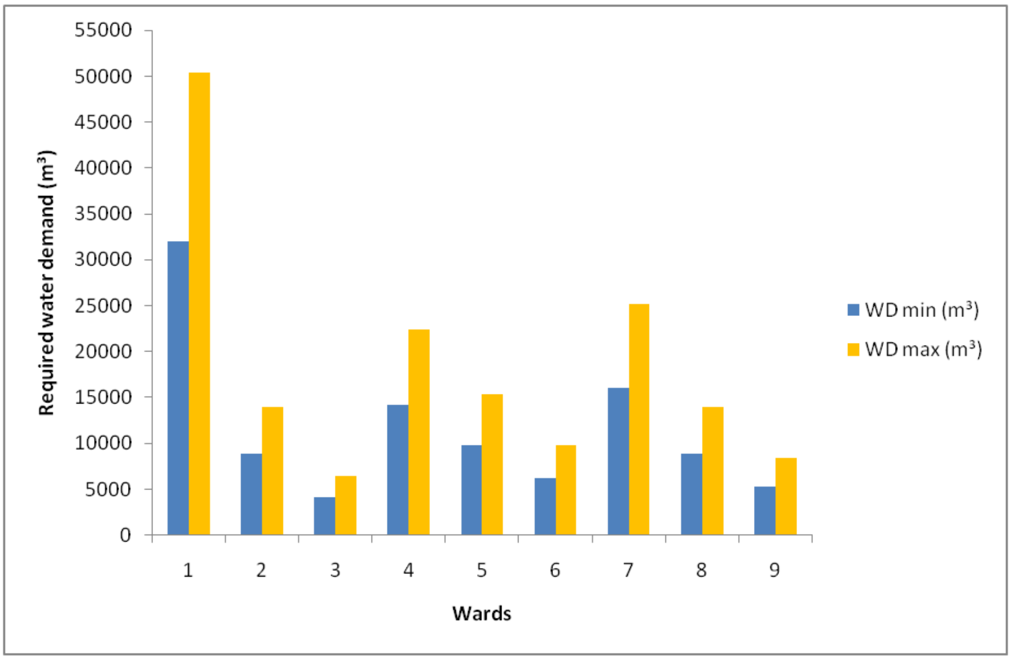


Figure 19: Required water demand (m³) for wheat cultivation on biggest field sizes per Ward

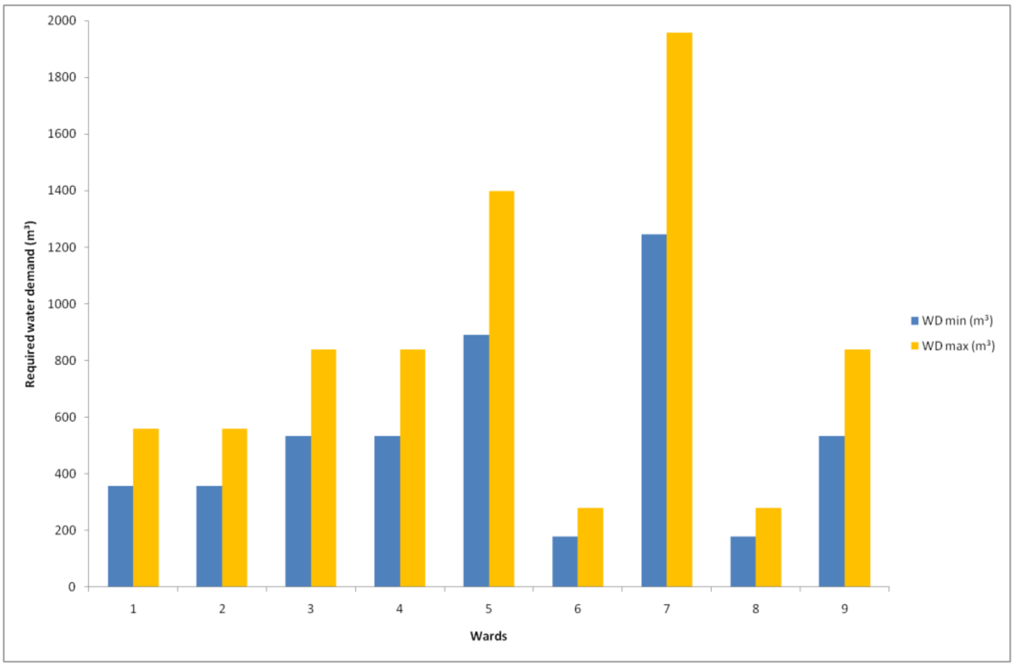


Figure 20: Required water demand (m³) for wheat cultivation on smallest field sizes per Ward

Furthermore bearing in mind the other possible crop (rice, corn, millet, mustard and vegetables) (Appendix IX.I), it becomes clear that all of the crop require a huge demand of additional water to guarantee a successful cultivation and a rich harvest. The only crop which has a slightly lower water demand, alternatively to wheat, is mustard. Here an average demand of 534m³ for maximum water demand for a small field and 11732m³ of additional water need for a big field is calculated. Besides the problem of construction and placing a proper storage tank able to hold the required water demand there is also a problem of collecting the necessary water. With an average precipitation of 1800mm per year a catchment area of around 330m² is needed to achieve a harvested amount of 534m³. For the entire other crop this numbers are even higher creating problems in the realization process.

Corn:

Table 7: Wheat water demand details (shortage period)

Shortage (can grow)	Total water demand per growing period (m³/m²)	Growing Period (days)	Precipitation (m³/m²)	Field size (m²)	WD max (m³)
Feb/Mar-end Jun/Jul	0.5-8.8	90-120	0.78	91573	1831
Feb/Mar-end Jun/Jul	0.5-0.8	90-120	0.78	509	10

During the time of irrigation water shortages the obligatory additional water amount for the big fields are very high too. Only one ward has a need of around 200m³ for proper corn cultivation in the time from Feb/Mar-end Jun/Jul, while most of the other results lie between 350m³-850m³ and even above (Figure 21). On the other hand the amount for additional water needs on the small fields is around 10m³-70m³ (Figure 22) which are appropriate demands.

Moreover having a closer look at the other results for the water shortage period it is important to mention that only corn (Table 7) and rice have water requirements which exceed the available precipitation during this time. Rice on its own however still requires lots of water (Appendix IX.II). Nevertheless for the small field sizes only as much as 60m³- 427m³ are missing, with the most fields below the restriction of 200m³. In these cases for both crops the small field sizes have possibilities to use the given circumstances to meet the additional water demands.

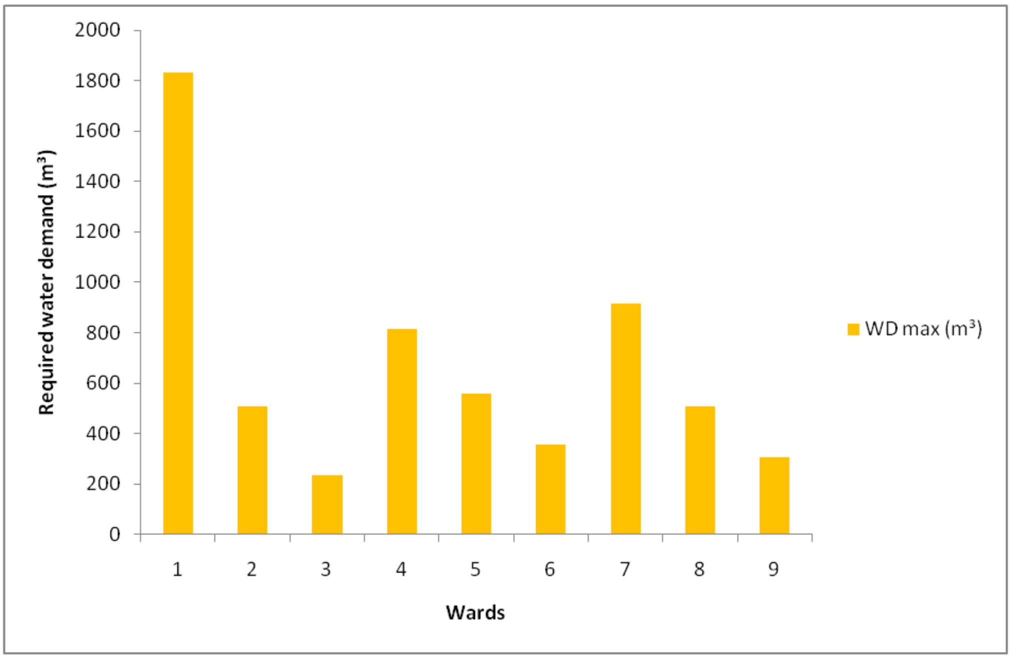


Figure 21: Required water demand (m³) for corn cultivation on biggest fields per Ward

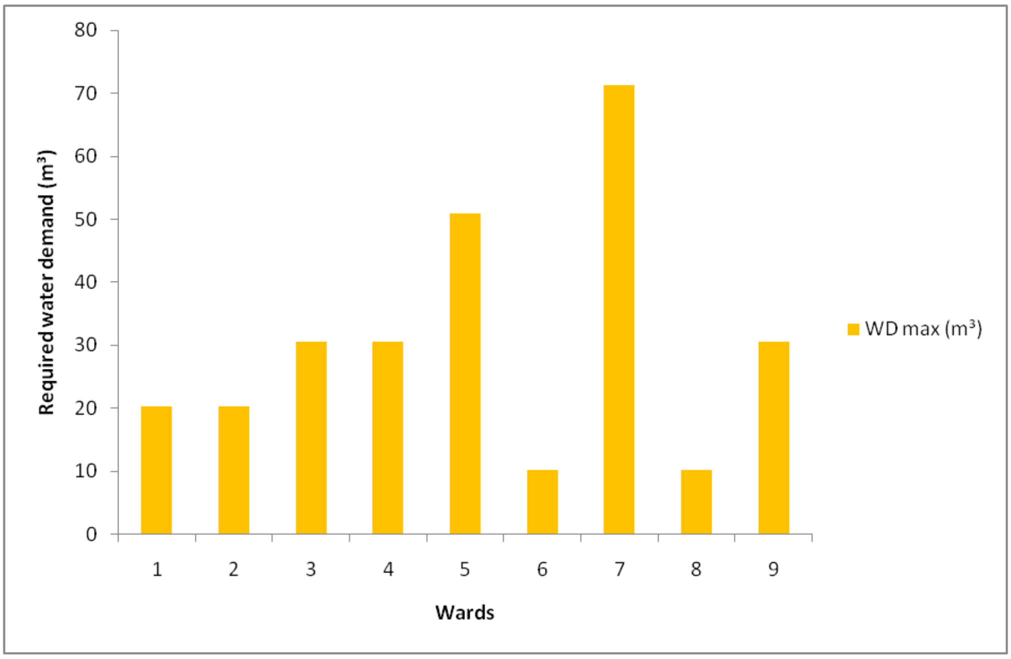


Figure 22: Required water demand (m³) for corn cultivation on smallest fields per Ward

3.2.6 Drinking water shortage

In the following tables and bar charts examples of two Wards are given, illustrating the one with the severest drinking water conditions (Ward 1) and with the least threatened water situation (Ward 6). The results are based on the total amount of households facing drinking water threats and the time period of the shortage. Additionally the results of whether or not the minimum amount of 15l-25l (Worm & Hattum, 2006) drinking water per person per day can be met. All results of the other wards are listed in Appendix X.

Table 8 clearly indicates that the drinking water situation in Ward 1 is extreme. Nine out of the surveyed households face drinking water shortages for a minimum period of five month and maximum length of twelve month. The total distribution of water shortages over the year is presented in the bar chart (Figure 23), showing that only during the middle of the monsoon season and bit after wards the number of households opposed to drinking water shortage is below the 50%, while during all other month at least five or more households face drinking water shortages. Moreover it must be pointed out that all surveyed households theoretically meet the pre-conditions to harvest at least 15l per person per day and of these six households could even meet the 25l per person per day mark (Table 9).

Table 8: Results drinking water shortage Ward 1

Ward 1

Water shortage	Time (month)
shortest	5.0
longest	12
average	9.1
Total households	9

Table 9: Meeting water demand Ward 1

Harvested amount (l)	Total Households
25 l (1)	6
15 l (2)	3
No (3)	0

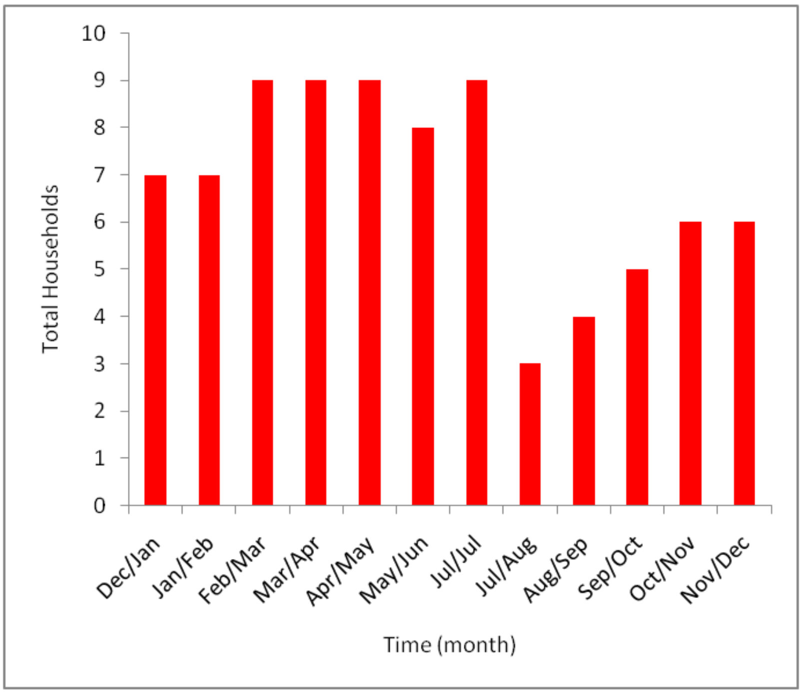


Figure 23: Drinking water shortages Ward 1 (one year period)

The following bar chart (Figure 24) and tables (Table 10; 11) visualizing the found results in Ward 6. In this Ward only one out of ten households is facing drinking water problems. The shortage appears over a period of four month, beginning at the end of the dry season until mid of monsoon season. Considering the ability to collect enough rainwater as an additional water source, this one household is able to meet the demand of 25l per person per day.

Table 10: Results drinking water shortage Ward 6

Ward 6

Water shortage	Time (month)
shortest	4.0
longest	4.0
average	4.0
Total households	1

Table 11: Meeting water demand Ward 6

Harvested amount (l)	Total Households
25 l (1)	1
15 l (2)	0
No (3)	0

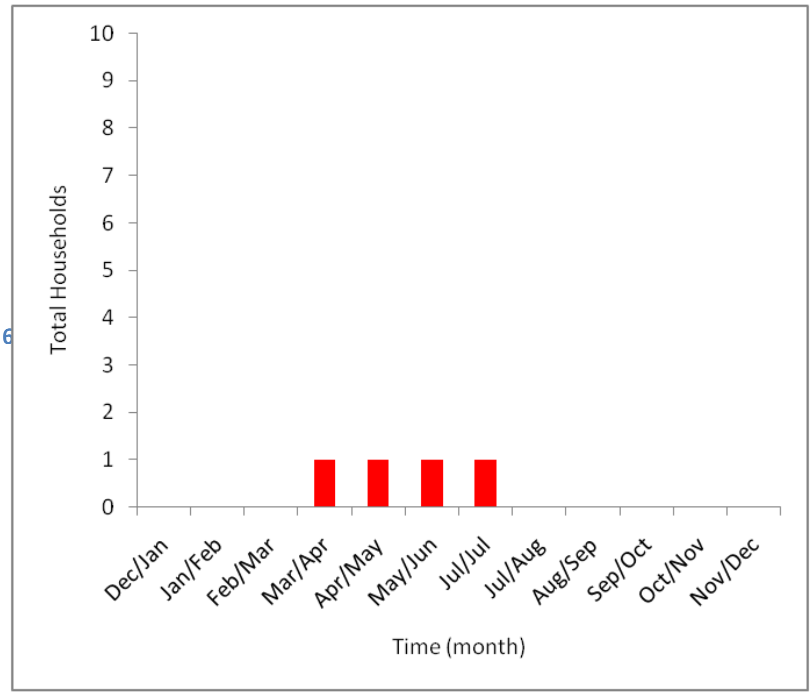


Figure 24: Drinking water shortage Ward 6 (one year period)

These two wards, number 1 and 6, show the extreme differences between different areas in the Taluwa VDC. Comparing the two mentioned wards, it becomes clear that different priorities should be given to the different wards when starting to implement RWH-systems. A ranking of the wards based on the number of households facing drinking water shortages, and the length of the average shortage period (Table 12), is illustrated beneath. It shows the wards from the most severe to the least severe with ward 5 as the most impacted and Ward 6 as least affected one.

Table 12: Ward ranking based on drinking water scarcity

Ward	Households	Average shortage period (month)
5	10	6.3
1	9	9.1
8	9	8.6
7	9	4.7
4	8	6.8
2	7	5.7
9	5	2.8
3	4	4.8
6	1	4.0

3.2.7 Feasibility evaluation

Adding all outcomes from the nine wards together following results occur. Of the 90 surveyed households, 62 households are facing drinking water shortages. Of these 62 households the given circumstances allow 30 households to harvest at least 25l of rainwater for drinking purposes, 15 households could fetch the minimum of 15l water per person per day. Only 17 of the surveyed households cannot meet the required demand hence to an insufficient catchment area. This leads to a total amount of 45 households (72%) (Figure 25) for which it is feasible to harvest rainwater and meet the required water demand during the shortage periods.

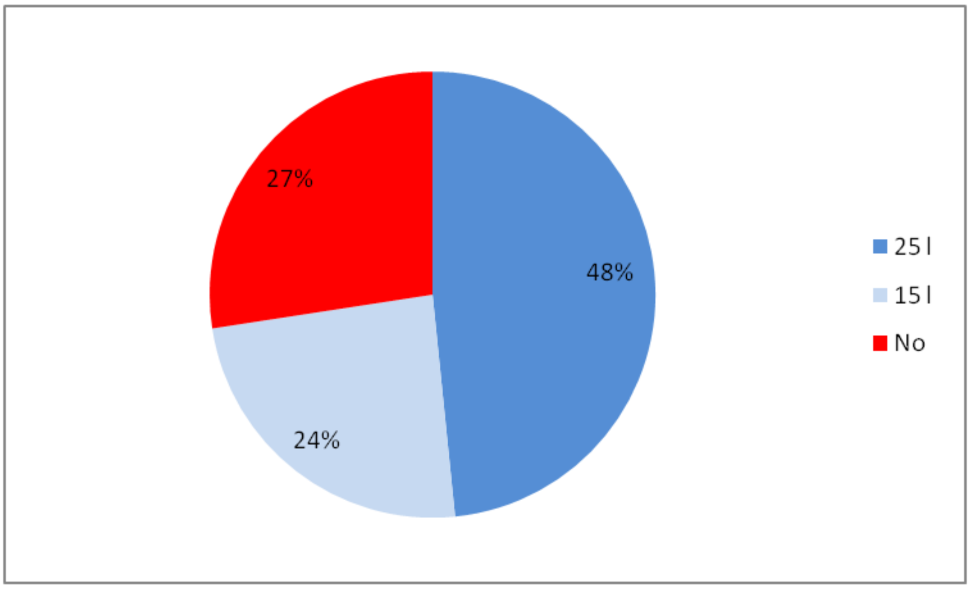


Figure 25: Meeting needed water demand (all Wards, Taluwa)

4. Conclusion

4.1 Irrigation water Jitpur Phedi

The survey showed that for the farmer who cannot grow any crop during the main water scarcity period, a tremendous amount of water is needed which exceeds the possible storage tank capacities. Furthermore a great catchment area would be needed to gather the needed extra water. On the other hand there is the opportunity for the farmer who can cultivate but face irrigation water shortages to use RWH-systems to collect some additional water for an enhanced vegetable cultivation. The results indicated that vegetables need the smallest additional amount of water and could be therefore used as target crop.

4.2. Irrigation water Taluwa

Under the given environmental circumstances, field sizes and crop water demand, it is not feasible to only use rainwater harvesting systems to collect the total amount of additional required water throughout the water scarcity period (Nov/Dec- end Mar/Apr). The demand of water exceeds the realizable storage capacity and catchment capacity needed by each farmer per field.

In addition to the time where a lack of water leads to cultivation stop, the period of water shortage shows a different outcome. During the period from Feb/Mar-end Jun/Jul, the main time of irrigation water shortages, the actual precipitation is so high that most of the cultivated crop (wheat, millet, mustard and vegetables) already meets its water demand. Besides these findings the results moreover indicate that rainwater harvesting would be a feasible alternative to meet the needed water demand for corn cultivation on all small field sizes. For the corn cultivation on all big fields the requested demand is too high, as well as for any rice cultivation.

4.3 Drinking water Taluwa

Based on the outcomes during the area survey it becomes clear that RWH as an alternative drinking water source is a reasonable method. With 72% a great number of households and local people can be positively affected by giving them the chance to collect rainwater. Not only would they be given the convenience of a water source directly at their house, but they can also safe up to one and a half hours of hard labor everyday over several months per year. The actual problem that occurs for drinking water collection is that most of the houses have an organic roof, being a potential hazard for the drinking water quality. Therefore it is inevitably to include proper filter devices, like a first flush and grids, as well as a pretreatment before drinking, like the “SODIS™ method (solar water disinfection)” (Dahlin & Sheehan, 2010) or boiling of the water before consuming.

5. Solutions

5.1 Irrigation water collection for Jitpur Phedi and Taluwa

As the inquiry showed, most of the cultivated fields are not located close to the house but further away, only small vegetables fields can be find next to the houses. A roof dependent RWH-system is therefore not the first choice, but a combination of land catchment and RainSaucers is more suitable.

If an open reservoir is used the reservoir itself already functions as a catchment area, hence decreasing the need for additional catchment areas. Combined with channels catching the surface runoff a maximum demand of 200m³ could be collected under the given circumstances. In case the collected surface runoff is not sufficient or due to geographical conditions unable to construct, additional RainSaucers can be implemented to increase the catchment area.

Besides the implementation of RWH-systems, which is only partly feasible, general water saving method can be conducted. In both communities, Jitpur Phedi and Taluwa, an incredible amount of available water is wasted due to uncontrolled runoff, percolation into the soil and outdated irrigation methods. Huge impacts could be made if proper irrigation channels would be constructed, averting percolation of water into the soil on the transportation way. Moreover there are great chances to collect and store water from the gravity fed taps, which are running all day long spilling precious water which just seeps into the soil around the tap creating big mud puddles. This water could effectively be guided via transportation channels into different storage tanks, eventually making additional RWH-systems unnecessary. Also the competent use of natural sources like small streams and springs could noticeably enhance the irrigation water situation in both communities. Most of the smaller streams are reliable sources and with a proper collection of this water, for example in small irrigation ponds alongside the stream, fields located close to this natural source, might not have as severe irrigation water shortages anymore.

Despite the construction of new channels or tanks an important factor is to increase the maintenance of the existing devices. A lot of water is lost due to broken irrigation channels, leaking tanks or pipes, which easily can be avoided eventually making new constructions redundant.

5.2 Taluwa drinking water collection

The most feasible solution for drinking water collection in Taluwa is the roof-dependent RWH-system. This method provides the water right at the house and using the given circumstances (roof) as the catchment area, whereby the construction of a catchment area becomes unnecessary.

Different examples of the various part of a roof-dependent RWH-system are presented in Appendix XI. It is important to notice that most of the houses in Taluwa use organic material as roof topping, increasing the possibility of hazardous bacteria as well as the probability of containing more pollutants like leaves, insects or other pollutants. Therefore it is crucial to include any kind of first flush device (Appendix XI.V) to prevent contamination of the drinking water. A very useful measure to avoid insects like mosquito breeding in the storage tank is to place a mosquito screen between the storage tank and the downpipe. Furthermore the water should be treated before drinking by either UV penetration or by boiling.

For the storage tank various opportunities are feasible. First of all depending on the needed amount of additional drinking water different types of tanks are more suitable. For smaller amounts up to 10m³ plastic tanks or ferro cement tanks are practical. In case of the need for a lager storage capacity either several smaller storage tanks could be used or one big underground tank can be constructed. If more than one roof is available for proper rainwater harvesting, a connection with gutters can be constructed to effectively use both catchment areas for rainwater collection.

In case the required amount of 15l per person per day is only missed by a few liters, it would be also possible to construct additional RainSaucers for extra catchment area. Under these circumstances RWH could be feasible for more households then actual found so far.

6. Discussion

During the survey of the two target areas many problems occurred. Some of them account for both communities others were area specific but in general there must be mentioned that for both survey areas the climate data is not precise. There are huge differences of the climate even in the communities based on the fact that first of all they face big differences in altitude. Second there is only one measurement point per community which, in case of Taluwa lies 15Km away from the actual surveyed area. Due to these circumstances the preciseness of the rainfall data is questionable and only provides a rough idea of the possible precipitation in the different wards. This problem also got confirmed by the statements given by the inquired households where some wards were claiming to have a very low rainfall over the year, while other wards did not face that problem. Moreover it also must be kept in mind that during years with a low precipitation the aimed amount of harvested water might not be reached. For example the lowest amount of rainfall in Jitpur Phedi (Appendix V) in the last ten years lies 200mm underneath the average rainfall and a difference of even 400mm is documented leading to a different outcome for the feasibility.

In addition also the collected data of the field sizes are imprecise. Most of the collected information in Taluwa were guesses since none of the farmer exactly knew how big their fields are. In the case of Jitpur Phedi none of the surveyed farmers knew their field sizes. Thus the used data for the field sizes origin from the VDC Village Profile and are also only approximate results.

Another difficulty that occurred concerns the required water demand of the crop. The provided data is a mixture of different sources, which might have used other methods to evaluate the water demand. Moreover the water demand per crop is influenced by the evapotranspiration rate, which is swayed by environmental circumstances like wind, temperature, total hours of light etc. Thus it must be kept in mind that the provided results might vary from the actual situation affecting the actual capacity of the additional water needs.

Besides that a further factor strongly impacting the water demand is the soil composition of the irrigated area. Different soil textures have different water storage capacity and therefore another demand. Unfortunately this information is not available for the surveyed sites. In order to make a more precise estimation of the actual water demand, the soil composition must be established first.

Moreover in the result chapter buckwheat is mentioned as a popular crop in Taluwa, unfortunately no information about water demand or similar could be found and therefore it was neglected during the final calculations. Nonetheless based on all the outcomes buckwheat did not play a very crucial role.

Last but not least one of the mentioned solutions enhancing the irrigation water availability is to include the natural sources stronger. This solution must be seen as an idea, since no data is provided about the amount of alternative sources, the reliability and actual flow rate. The idea is based on personal observation and experiences.

7. Advices

This report is the first part of a possible bigger program to successfully construct RWH-systems in Jitpur Phedi and Taluwa. All results, problems and conclusions must be seen as first impressions and ideas on which further, more specific, researches can be build on. To finalize the project several steps and activities have to be accomplished. Below some major follow up activities are listed on which future researches and decisions can be made.

1. Presenting the results to the organization in charge (VIN) to see if further interests is given
2. Display all findings to community officials (by VIN)
3. Form User Committees to create guidelines and divide the responsibilities
4. Approach to other organizations (governmental, non-governmental) for funding
5. Contact specialists from involved sectors (engineers, agriculture profession, irrigation specialists)
6. Make more specific research to fill in missing data like soil composition, actual meteorological conditions, availability of alternative sources (streams, springs) to identify real water need in the different areas of the communities→ adjust results of feasibility
7. Create a cost-efficiency plan
8. If feasible, plan the construction

Bibliography

ACO Building Drainage. (2011, November). *ACO Building Drainage* . Retrieved October 14, 2013

Agriinfo. (2011). *My Agriculturel Information Bank.* Retrieved September 20, 2013, from http://www.agriinfo.in/?page=topic&superid=1&topicid=16

Arab Forum for Environment and Development. (2013). *AFED*. Retrieved December 2013, from http://www.afedonline.org/water%20efficiency%20manual/PDF/6Chapter%205_Agriculture.pdf

Arkitrek. (2013, April 1). *Arkitrek - First Flush Diverter.* Retrieved October 14, 2013, from http://arkitrek.com/http:/arkitrek.com/first-flush-diverter/

Dahal, R., Ban, J., Makaju, S., Shrestha, R. S., & Dwa, N. (2010, November). *Rainwater Harvestin (RWH) in Nepal.* Retrieved August 10, 2013

Dahlin, K., & Sheehan, C. (2010). *Water Wells For Africa; Polluted to Potable: Trusted TM Water Filtration Method.*

GDRC. (2013). *The Global Development Research Center - An Introduction To Rainwater Harvesting.* Retrieved October 4, 2013, from http://www.gdrc.org/uem/water/rainwater/introduction.html

Google Maps. (2013). *Google Maps.* Retrieved September 17, 2013, from https://maps.google.de/

Greenplan. (2013). *Greenplan sustainable house designs for everyone* . Retrieved September 20, 2013, from http://www.greenplanhomes.com/pages/Rainwater-Harvesting.html

isp. (2013). *International Flood Initiative.* Retrieved October 12, 2013, from http://cecar.org/groups/ifi/wiki/8e2e4/

Karki, R. (2013, October). Meteorological Data Jitpur Phedi and Okhaldunga. Nepal.

Khoury-Nolde, N. (2013). *Rainwater Harvesting - European Rainwater Catchment Systems.* Retrieved September 16, 2013, from http://www.rainwaterconference.org/uploads/media/Rainwater_Harvesting_-_an_overview_.pdf

Luong, T. (2013). *Harvesting the Rain - A Construciton Manual for Cement Rainwater Jars.* Bankok, Thailand: UNICEF East Asia and Pacific Regional Office .

Madhya Pradesh Pollution Control Board . (2013). *Madhya Pradesh Pollution Control Board .* Retrieved October 12, 2013, from http://www.mppcb.nic.in/RWH.htm

RainSaucers. (2009). *RainSaucers.* Retrieved September 16, 2013, from http://rainsaucers.com/

Spring Association of reasonal planers. (2013). *Village Profile Jitpur Phedi.* Kathmandu.

TECA. (2013). *TECA Technologies and practices for small agricultural producers.* Retrieved September 16, 2013, from http://teca.fao.org/read/7387

Visit Nepal. (2013). *Visit Nepal*. Retrieved from http://www.visitnepal.com/travelers_guide/when_to_come.php

Water Harvesting. (2013). *Water Harvesting*. Retrieved September 3, 2013, from http://www.rainwaterharvesting.org/methods/modern/gwdams.htm

Wikipedia. (2013, June 9). *Wikipedia.* Retrieved September 17, 2013, from http://en.wikipedia.org/wiki/Okhaldhunga_District

Wikipedia. (2013, May). *Wikipedia Nepal*. Retrieved from http://en.wikipedia.org/wiki/Nepal

Worm, J., & Hattum, T. v. (2006). *Agrodok 43.* Retrieved August 10, 2013, from http://journeytoforever.org/farm_library/AD43.pdf

Appendix I - Questionnaire

I.I Farmer - Irrigation

1) What crop is cultivated?
2) What is the current cultivation period?
3) If there is a gap, why is it impossible to cultivate?
4) What is the current irrigation system?
5) Is there a water shortage during the cultivation period?
6) How far away from the house is the field located?

I.II Citizens-Drinking water

1) Is there a drinking water scarcity?
2) For how many months do you face drinking water scarcity?
3) How many family members do you have?
4) What is your current/additional water source?
5) For which purposes do you need additional water?

Appendix II – VDC maps

II.I Jitpur Phedi VDC map

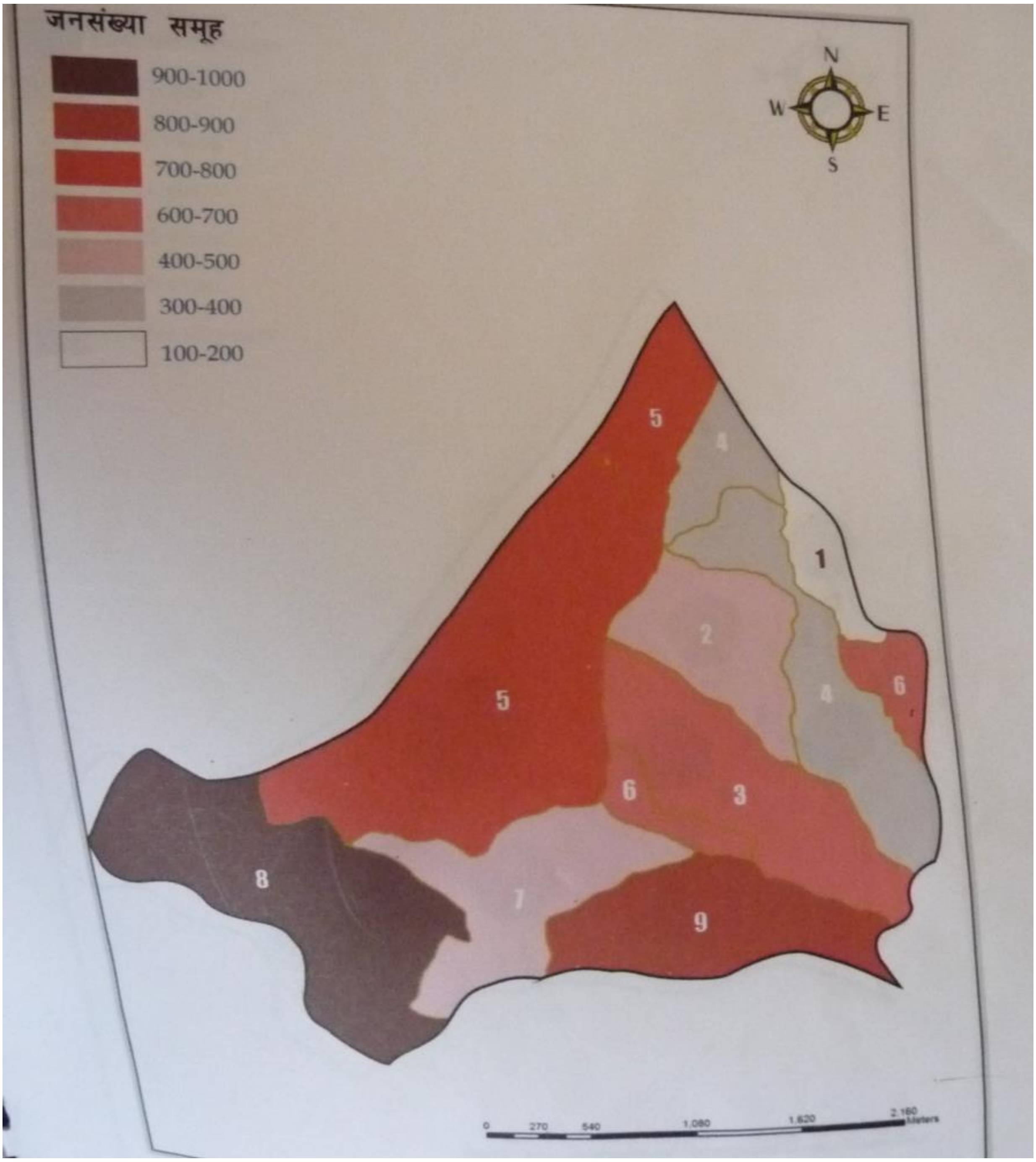


Figure 26: Map displaying all Wards of Jitpur Phedi VDC

II.II Taluwa VDC map

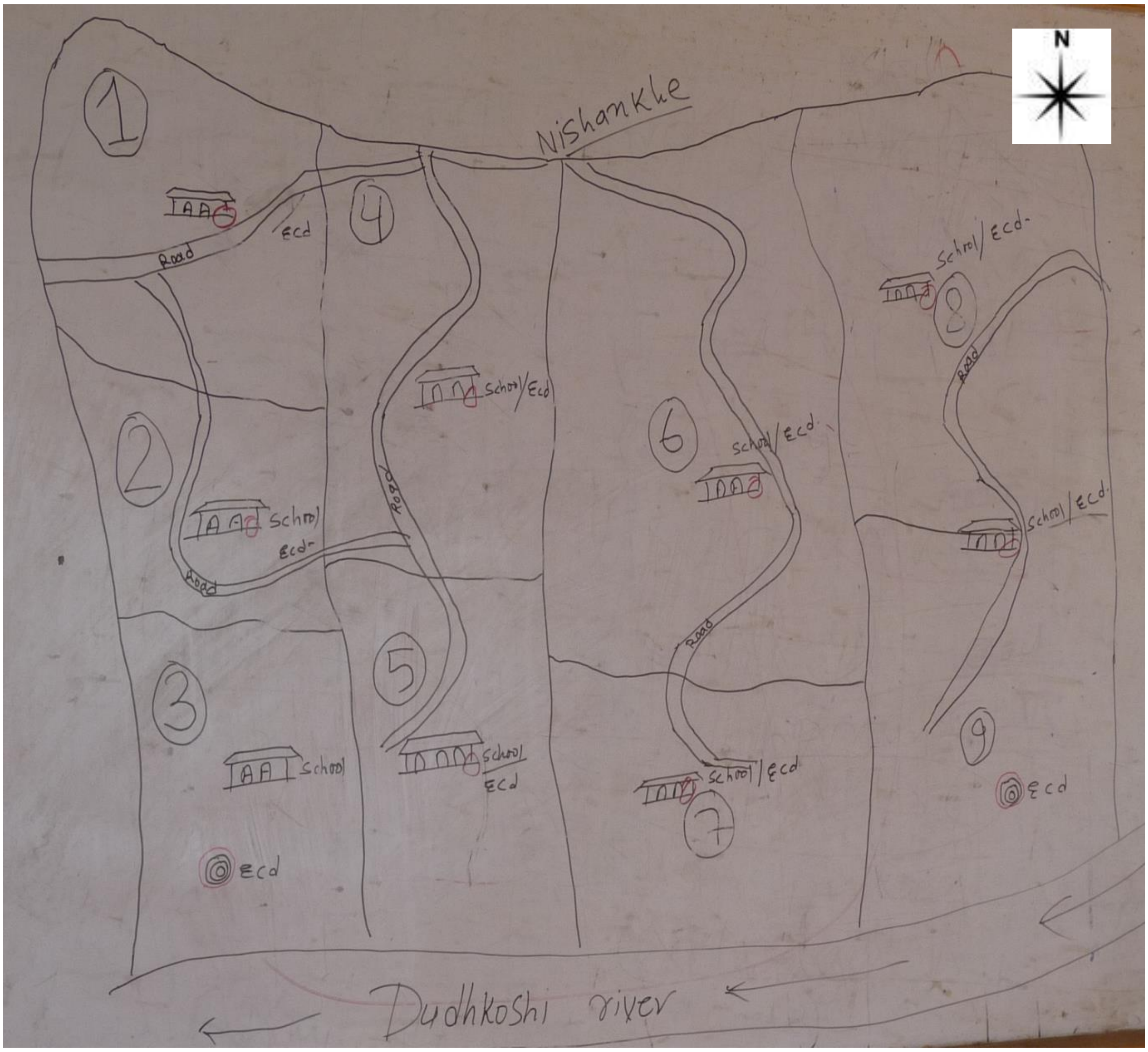


Figure 27: Sketched map of all Ward of Taluwa VDC

Appendix III – Observation tools

1. How is the area geographical looking?
2. How are the main fields distributed?
3. How are the irrigation channels looking
4. Is the water used carefully? E.g. are taps running all day long? High loss to infiltration?
5. How are taps, irrigation channels and storage tanks maintained?

Appendix IV – Observations Jitpur Phedi

Figure 28: Area overview east and south Jitpur Phedi

Figure 29: Small vegetable fields next to the house, Jitpur Phedi

Figure 30: Irrigation channel, Jitpur Phedi

Figure 31: Gravity fed tap, Jitpur Phedi

Figure 32: Example of fields in Jitpur Phedi

Appendix V- Meteorological data

V.I Jitpur Phedi

Table 13: Average Rainfall (mm) – Jitpur Phedi (2001-2009) (Karki, 2013)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
13.3	23.4	34.0	72.2	137.1	215.0	517.6	454.8	270.8	68.4	4.9	5.3	1816.9

Table 14: Minimum Rainfall (mm) – Jitpur Phedi (2001-2009) (Karki, 2013)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0.0	0.0	16.7	15.5	148.0	79.5	622.1	486.5	148.2	64.5	0.0	4.0	1585.0

Table 15: Average Temperature (°C) – Kathmandu Airport (Karki, 2013)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10.8	13.0	16.7	19.9	22.2	24.1	24.3	24.3	23.3	20.1	15.6	12.0

V.II Taluwa

Table 16: Average Rainfall (mm) - Okhaldhunga (1981-2010) (Karki, 2013)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
11.2	14.1	26.8	59.6	152.8	299.8	466.8	399.9	245.3	63.7	11.3	12.8	1764.1

Table 17: Minimum Rainfall (mm) – Okhaldhunga (1981-2010) (Karki, 2013)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
10.4	10.0	23.4	70.0	98.6	367.4	322.5	231.9	177.8	72.2	0.0	27.2	1411.4

Table 18: Average Temperature (°C) – Okhaldhunga (1981-2010) (Karki, 2013)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10.3	12.0	16.3	18.8	20.1	22.2	20.9	21.0	20.5	19.1	15.1	11.8

Appendix VI- Crop water demand

Table 19: Details of crop growing period and water demand (Arab Forum for Environment and Development, 2013), (Agriinfo, 2011)

Crop	Total water demand per growing period (mm)/m²	Growing Period (days)	Plants per m²	Min. water demand per m² (m³)	Max. water demand per m² (m³)	min per ropany	max per ropany
Rice	900-1500	100-120	150.00	0.90	1.50	457.87	763.11
Corn	500-800	90-120	8.00	0.50	0.80	254.37	406.99
Wheat	450-650	110-130	150-200	0.45	0.65	228.93	330.68
Millet	450-650	105-140	170-250	0.45	0.65	228.93	330.68
Buckwheat	/	60-70	/	/	/	/	/
Mustard	350-450	90-125	80-120	0.35	0.45	178.06	228.93
Tobacco	980.00	130-160	/	0.98	0.98	498.57	498.57
Bean	300-500	75-110	/	0.30	0.50	152.62	254.37
Cabbage	300.00	70-90	2.00	0.30	0.30	152.62	152.62
Onion	350-550	70-95; 150-210	/	0.35	0.55	178.06	279.81
Pea	350-500	90-100	/	0.35	0.50	178.06	254.37
Potato	500-700	100-150	/	0.50	0.70	254.37	356.12
Soybean	450-700	100-120	/	0.45	0.70	228.93	356.12
Tomato	900-1400	40-60	/	0.90	1.40	457.87	712.24
Cauliflower	470.00	55-120	2.00	0.47	0.47	239.11	239.11
Radish	300.00	40-60	/	0.30	0.30	152.62	152.62
Lentils	400.00	90-100	/	0.40	0.40	203.50	203.50
Vegetables avg	/	/	/	0.43	0.58	219.78	296.09

Appendix VII- Irrigation water needs Jitpur Phedi

VII.I Irrigation water needs scarcity period

Corn

Shortage (cannot grow)	Total water demand per growing period (m^3/m^2)	Growing Period (days)	Precipitation (m^3/m^2)	Field size (m^2)	WD min (m^3)	WD max (m^3)
Feb/Mar-end Jun/Jul	0.5-0.8	90-120	0.21	1526	443	900
Feb/Mar-end Jun/Jul	0.5-0.8	90-120	0.21	3561	1033	2101
Feb/Mar-end Jun/Jul	0.5-0.8	90-121	0.21	6614	1918	3902
Feb/Mar-end Jun/Jul	0.5-0.8	90-122	0.21	19841	5754	11706

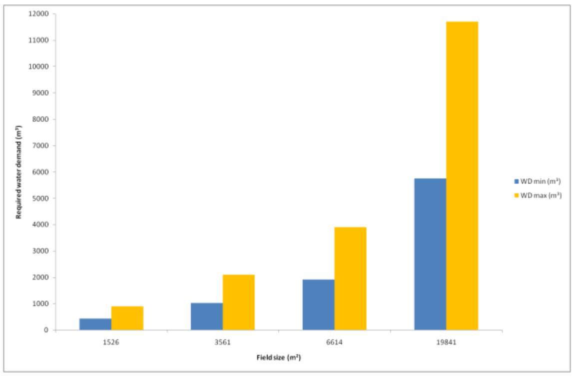


Figure 33: Corn min. and max. water demand for all field sizes, Jitpur Phedi (cannot grow)

Rice

Shortage (cannot grow)	Total water demand per growing period (m^3/m^2)	Growing Period (days)	Precipitation (m^3/m^2)	Field size (m^2)	WD min (m^3)	WD max (m^3)
Feb/Mar-end Jun/Jul	0.9-1.5	90-120	0.21	1526	1053	1969
Feb/Mar-end Jun/Jul	0.9-1.5	90-120	0.21	3561	2457	4594
Feb/Mar-end Jun/Jul	0.9-1.5	90-121	0.21	6614	4563	8532
Feb/Mar-end Jun/Jul	0.9-1.5	90-122	0.21	19841	13690	25595

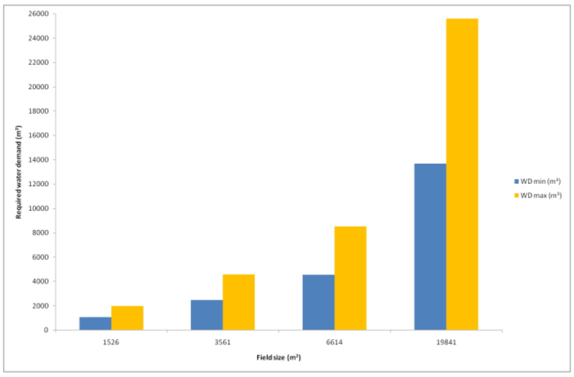


Figure 34: Rice min. and max. water demand for all field sizes, Jitpur Phedi (cannot grow)

Wheat/Millet

Shortage (cannot grow)	Total water demand per growing period (m^3/m^2)	Growing Period (days)	Precipitation (m^3/m^2)	Field size (m^2)	WD min (m^3)	WD max (m^3)
Feb/Mar-end Jun/Jul	0.45-0.65	90-120	0.21	1526	366	672
Feb/Mar-end Jun/Jul	0.45-0.65	90-120	0.21	3561	855	1567
Feb/Mar-end Jun/Jul	0.45-0.65	90-121	0.21	6614	1587	2910
Feb/Mar-end Jun/Jul	0.45-0.65	90-122	0.21	19841	4762	8730

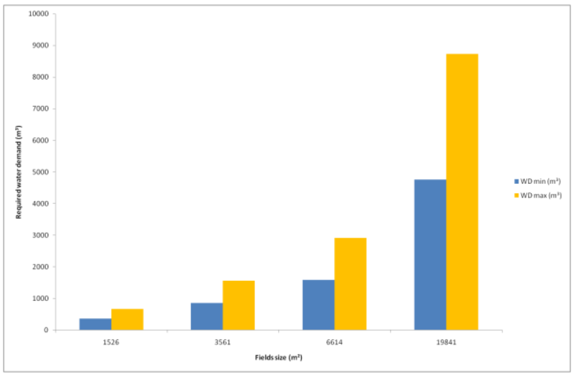


Figure 35: Wheat/Millet min. and max. water demand for all field sizes, Jitpur Phedi (cannot grow)

Mustard

Shortage (cannot grow)	Total water demand per growing period (m^3/m^2)	Growing Period (days)	Precipitation (m^3/m^2)	Field size (m^2)	WD min (m^3)	WD max (m^3)
Feb/Mar-end Jun/Jul	0.35-0.45	90-120	0.21	1526	214	366
Feb/Mar-end Jun/Jul	0.35-0.45	90-120	0.21	3561	499	855
Feb/Mar-end Jun/Jul	0.35-0.45	90-121	0.21	6614	926	1587
Feb/Mar-end Jun/Jul	0.35-0.45	90-122	0.21	19841	2778	4762

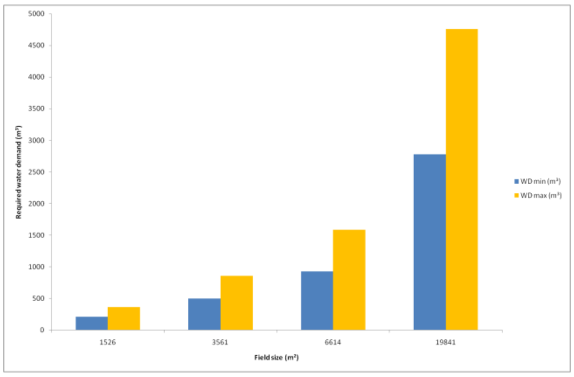


Figure 36: Mustard min. and max. water demand for all field sizes, Jitpur Phedi (cannot grow)

Vegetables

Shortage (cannot grow)	Total water demand per growing period (m^3/m^2)	Growing Period (days)	Precipitation (m^3/m^2)	Field size (m^2)	WD min (m^3)	WD max (m^3)
Feb/Mar-end Jun/Jul	0.43-0.58	90-120	0.21	1526	336	565
Feb/Mar-end Jun/Jul	0.43-0.58	90-120	0.21	3561	783	1318
Feb/Mar-end Jun/Jul	0.43-0.58	90-121	0.21	6614	1455	2447
Feb/Mar-end Jun/Jul	0.43-0.58	90-122	0.21	19841	4365	7341

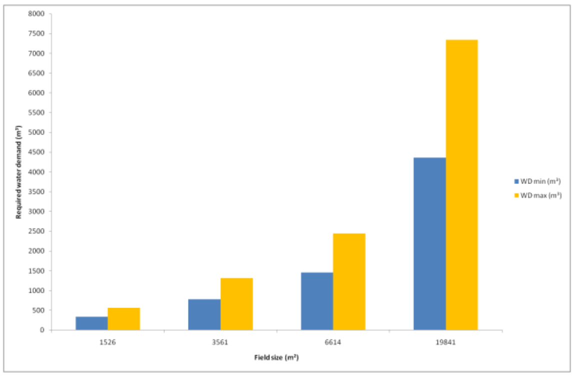


Figure 37: Vegetables min. and max. water demand for all field sizes, Jitpur Phedi (cannot grow)

VII.II Irrigation water need shortage period

Corn

Shortage (can grow)	Total water demand per growing period (m^3/m^2)	Growing Period (days)	Available water (m^3/m^2)	Field size (m^2)	WD min (m^3)	WD max (m^3)
Feb/Mar-end Jun/Jul	0.5-0.8	90-120	0.45	1526	76	534
Feb/Mar-end Jun/Jul	0.5-0.8	90-120	0.45	3561	178	1246
Feb/Mar-end Jun/Jul	0.5-0.8	90-121	0.45	6614	331	2315
Feb/Mar-end Jun/Jul	0.5-0.8	90-122	0.45	19841	992	6944

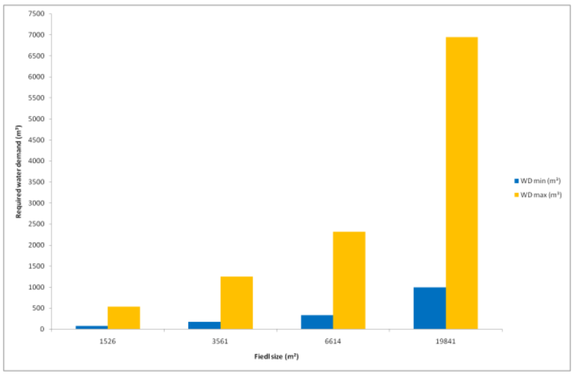


Figure 38: Corn min. and max. water demand for all field sizes, Jitpur Phedi (can grow)

Rice

Shortage (can grow)	Total water demand per growing period (m³/m²)	Growing Period (days)	Available water (m³/m²)	Field size (m²)	WD min (m³)	WD max (m³)
Feb/Mar-end Jun/Jul	0.9-1.5	90-120	0.45	1526	687	1603
Feb/Mar-end Jun/Jul	0.9-1.5	90-120	0.45	3561	1603	3739
Feb/Mar-end Jun/Jul	0.9-1.5	90-121	0.45	6614	2976	6944
Feb/Mar-end Jun/Jul	0.9-1.5	90-122	0.45	19841	8928	20833

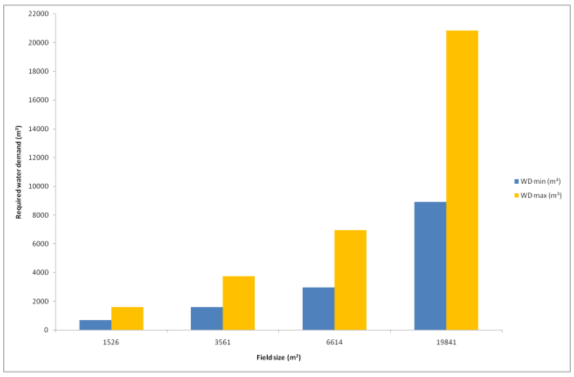


Figure 39: Rice min. and max. water demand for all field sizes, Jitpur Phedi (can grow)

Wheat/ Millet

Shortage (can grow)	Total water demand per growing period (m³/m²)	Growing Period (days)	Available water (m³/m²)	Field size (m²)	WD min (m³)	WD max (m³)
Feb/Mar-end Jun/Jul	0.45-0.65	90-120	0.45	1526	0	305
Feb/Mar-end Jun/Jul	0.45-0.65	90-120	0.45	3561	0	712
Feb/Mar-end Jun/Jul	0.45-0.65	90-121	0.45	6614	0	1323
Feb/Mar-end Jun/Jul	0.45-0.65	90-122	0.45	19841	0	3968

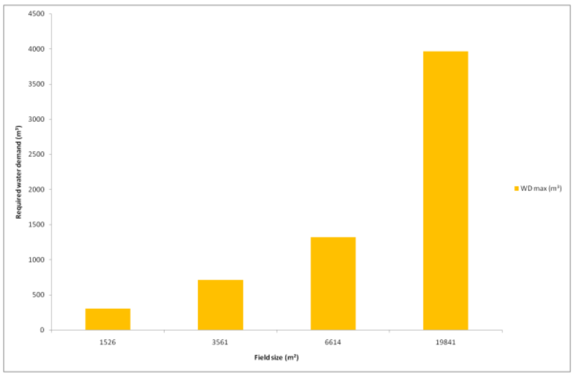


Figure 40: Wheat/Millet min. and max. water demand for all field sizes, Jitpur Phedi (can grow)

Mustard

Shortage (can grow)	Total water demand per growing period (m³/m²)	Growing Period (days)	Available water (m³/m²)	Field size (m²)	WD min (m³)	WD max (m³)
Feb/Mar-end Jun/Jul	0.35-0.45	90-120	0.45	1526	0	0
Feb/Mar-end Jun/Jul	0.35-0.45	90-120	0.45	3561	0	0
Feb/Mar-end Jun/Jul	0.35-0.45	90-121	0.45	6614	0	0
Feb/Mar-end Jun/Jul	0.35-0.45	90-122	0.45	19841	0	0

Figure 41: Mustard min. and max. water demand for all field sizes, Jitpur Phedi (can grow)

Vegetables

Shortage (can grow)	Total water demand per growing period (m^3/m^2)	Growing Period (days)	Precipitation (m^3/m^2)	Field size (m^2)	WD min (m^3)	WD max (m^3)
Feb/Mar-end Jun/Jul	0.43-0.58	90-120	0.45	1526	0	198
Feb/Mar-end Jun/Jul	0.43-0.58	90-120	0.45	3561	0	463
Feb/Mar-end Jun/Jul	0.43-0.58	90-121	0.45	6614	0	860
Feb/Mar-end Jun/Jul	0.43-0.58	90-122	0.45	19841	0	2579

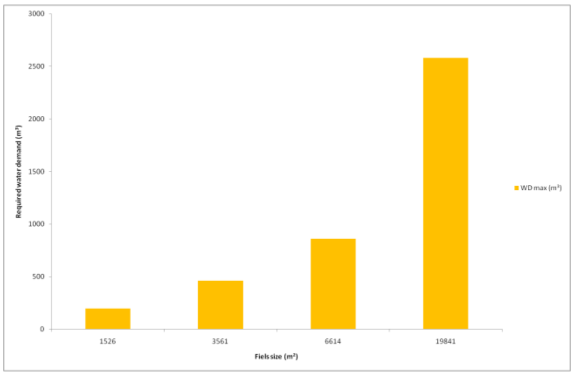


Figure 42: Vegetables min. and max. water demand for all field sizes, Jitpur Phedi (can grow)

Appendix VIII– Observations Taluwa

Figure 43: Existing irrigation water storage tank, Taluwa

Figure 44: Example of field location (Ward 4), Taluwa

Figure 45: Example of dried out rice field, Taluwa

Figure 46: Example of field location, Taluwa

Figure 47: Irrigation channel, Taluwa

Figure 48: Leaking house water pipes connected to tap, Taluwa

Appendix IX- Irrigation water needs Taluwa

IX.I Water demand (WD) for different crops during water scarcity period

Wheat:

Table 20: Wheat, irrigation water need details for all wards (scarcity period)

Ward 1

Shortage (cannot grow)	Total water demand per growing period (m^3/m^2)	Growing Period (days)	Precipitation (m^3/m^2)	Field size (m^2)	WD min (m^3)	WD max (m^3)
Nov/Dec- end Mar/Apr	0.45-0.65	110-130	0.10	91573	32051	50365
Nov/Dec- end Mar/Apr	0.45-0.66	110-130	0.10	1017	356	559

Ward 2

Field size (m^2)	WD min	WD max
25437	8903	13990
1017	356	559

Ward 3

Field size (m^2)	WD min	WD max (m^3)
11701	4095	6436
1526	534	839

Ward 4

Field size (m^2)	WD min	WD max (m^3)
40699	14245	22384
1526	534	839

Ward 5

Field size (m^2)	WD min	WD max (m^3)
27981	9793	15390
2544	890	1399

Ward 6

Field size (m^2)	WD min	WD max (m^3)
17806	6232	9793
509	178	280

Ward 7

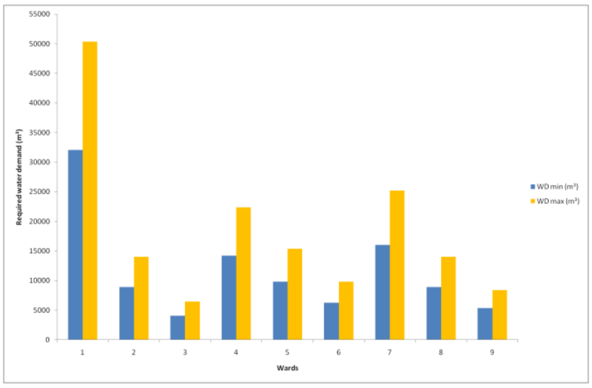
Field size (m^2)	WD min	WD max (m^3)
45787	16025	25183
3561	1246	1959

Ward 8

Field size (m^2)	WD min	WD max (m^3)
25437	8903	13990
509	178	280

Ward 9

Field size (m^2)	WD min	WD max (m^3)
15262	5342	8394
1526	534	839



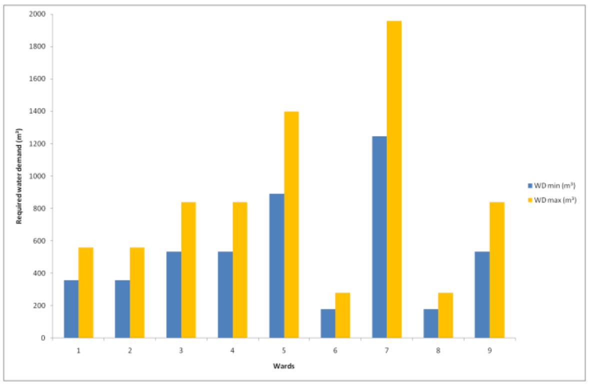


Figure 49: Water demand of wheat (scarcity period), big field (left) small field (right)

Corn:

Table 21: Corn, irrigation water need details for all wards (scarcity period)

Ward 1

Shortage (cannot grow)	Total water demand per growing period (m³/m²)	Growing Period (days)	Precipitation (m³/m²)	Field size (m²)	WD min (m³)	WD max (m³)
Nov/Dec- end Mar/Apr	0.5-0.8	90-120	0.10	91573	36629	64101
Nov/Dec- end Mar/Apr	0.5-0.8	90-120	0.10	1017	407	712

Ward 2

Field size (m²)	WD min	WD max (m³)
25437	10175	17806
1017	407	712

Ward 3

Field size (m²)	WD min	WD max (m³)
11701	4680	8191
1526	610	1068

Ward 4

Field size (m²)	WD min	WD max (m³)
40699	16280	28489
1526	610	1068

Ward 5

Field size (m²)	WD min	WD max (m³)
27981	11192	19587
2544	1018	1781

Ward 6

Field size (m²)	WD min	WD max (m³)
17806	7122	12464
509	204	356

Ward 7

Field size (m²)	WD min	WD max (m³)
45787	18315	32051
3561	1424	2493

Ward 8

Field size (m²)	WD min	WD max (m³)
25437	10175	17806
509	204	356

Ward 9

Field size (m²)	WD min	WD max (m³)
15262	6105	10683
1526	610	1068

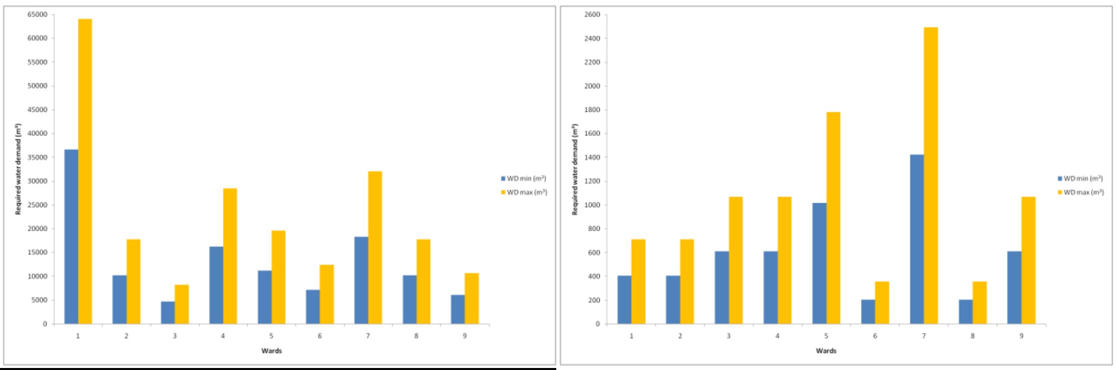


Figure 50: Water demand of corn (scarcity period), big field (left) small field (right)

Millet:

Table 22: Millet, irrigation water need details for all wards (scarcity period)

Ward 1

Shortage (cannot grow)	Total water demand per growing period (m^3/m^2)	Growing Period (days)	Precipitation (m^3/m^2)	Field size (m^2)	WD min (m^3)	WD max (m^3)
Nov/Dec- end Mar/Apr	0.45-0.65	105-140	0.10	91573	32051	50365
Nov/Dec- end Mar/Apr	0.45-0.66	105-140	0.10	1017	356	559

Ward 2

Field size (m^2)	WD min	WD max (m^3)
25437	8903	13990
1017	356	559

Ward 3

Field size (m^2)	WD min	WD max (m^3)
11701	4095	6436
1526	534	839

Ward 4

Field size (m^2)	WD min	WD max (m^3)
40699	14245	22384
1526	534	839

Ward 5

Field size (m^2)	WD min	WD max (m^3)
27981	9793	15390
2544	890	1399

Ward 6

Field size (m^2)	WD min	WD max (m^3)
17806	6232	9793
509	178	280

Ward 7

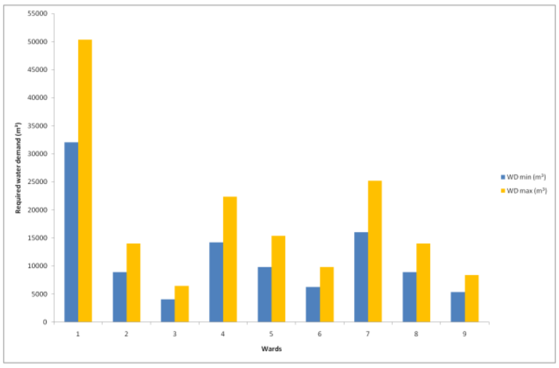
Field size (m^2)	WD min	WD max (m^3)
45787	16025	25183
3561	1246	1959

Ward 8

Field size (m^2)	WD min	WD max (m^3)
25437	8903	13990
509	178	280

Ward 9

Field size (m^2)	WD min	WD max (m^3)
15262	5342	8394
1526	534	839



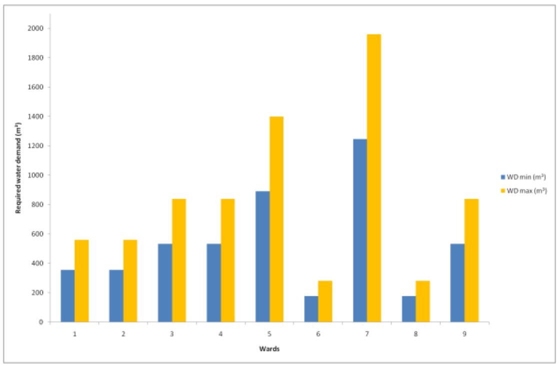


Figure 51: Water demand of millet (scarcity period), big field (left) small field (right)

Rice:

Table 23: Rice, irrigation water need details for all wards (scarcity period)

Ward 1

Shortage (cannot grow)	Total water demand per growing period (m³/m²)	Growing Period (days)	Precipitation (m³/m²)	Field size (m²)	WD min (m³)	WD max (m³)
Nov/Dec- end Mar/Apr	0.9-1.5	100-120	0.10	91573	73258	128202
Nov/Dec- end Mar/Apr	0.9-1.5	100-120	0.10	1017	814	1424

Ward 2

Field size (m²)	WD min	WD max (m³)
25437	20350	35612
1017	814	1424

Ward 3

Field size (m²)	WD min	WD max (m³)
11701	9361	16381
1526	1221	2136

Ward 4

Field size (m²)	WD min	WD max (m³)
40699	32559	56979
1526	1221	2136

Ward 5

Field size (m²)	WD min	WD max (m³)
27981	22385	39173
2544	2035	3562

Ward 6

Field size (m²)	WD min	WD max (m³)
17806	14245	24928
509	407	713

Ward 7

Field size (m²)	WD min	WD max (m³)
45787	36630	64102
3561	2849	4985

Ward 8

Field size (m²)	WD min	WD max (m³)
25437	20350	35612
509	407	713

Ward 9

Field size (m²)	WD min	WD max (m³)
15262	12210	21367
1526	1221	2136

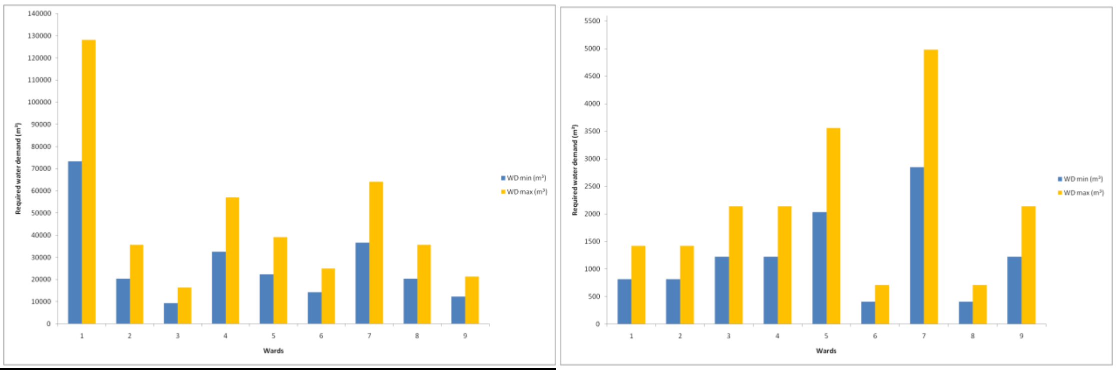


Figure 52: Water demand of rice (scarcity period), big field (left) small field (right)

Mustard:

Table 24: Mustard, irrigation water need details for all wards (scarcity period)

Ward 1

Shortage (cannot grow)	Total water demand per growing period (m³/m²)	Growing Period (days)	Precipitation (m³/m²)	Field size (m²)	WD min (m³)	WD max (m³)
Nov/Dec- end Mar/Apr	0.35-0.45	90-125	0.10	91573	22893	32051
Nov/Dec- end Mar/Apr	0.35-0.45	90-125	0.10	1017	254	356

Ward 2

Field size (m²)	WD min	WD max (m³)
25437	6359	8903
1017	254	356

Ward 3

Field size (m²)	WD min	WD max
11701	2925	4095
1526	382	534

Ward 4

Field size (m²)	WD min	WD max (m³)
40699	10175	14245
1526	382	534

Ward 5

Field size (m²)	WD min	WD max
27981	6995	9793
2544	636	890

Ward 6

Field size (m²)	WD min	WD max (m³)
17806	4452	6232
509	127	178

Ward 7

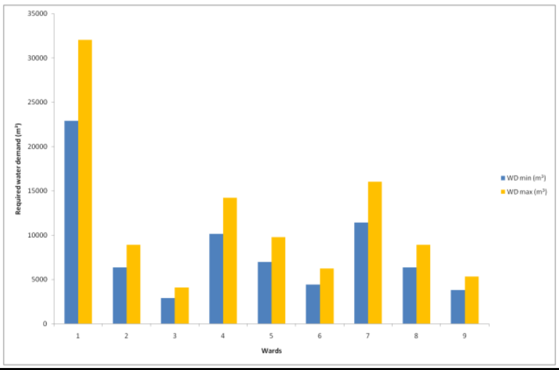
Field size (m²)	WD min	WD max (m³)
45787	11447	16025
3561	890	1246

Ward 8

Field size (m²)	WD min	WD max (m³)
25437	6359	8903
509	127	178

Ward 9

Field size (m²)	WD min	WD max (m³)
15262	3816	5342
1526	382	534



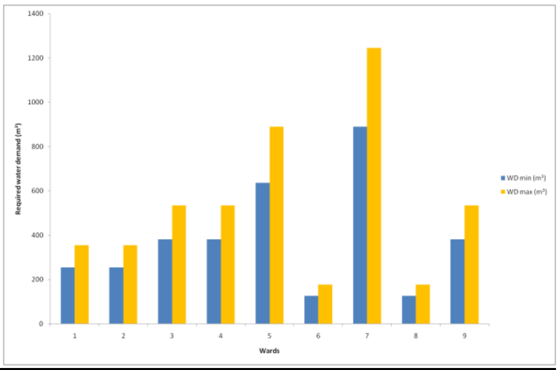


Figure 53: Water demand of mustard (scarcity period), big field (left) small field (right)

Vegetables:

Table 25: Vegetables, irrigation water need details for all wards (scarcity period)

Ward 1

Shortage (cannot grow)	Total water demand per growing period (m³/m²)	Growing Period (days)	Precipitation (m³/m²)	Field size (m²)	WD min (m³)	WD max (m³)
Nov/Dec- end Mar/Apr	0.43-0.58		0.10	91573	30219	43955
Nov/Dec- end Mar/Apr	0.43-0.58		0.10	1017	336	488

Ward 2

Field size (m²)	WD min	WD max (m³)
25437	8394	12210
1017	336	488

Ward 3

Field size (m²)	WD min	WD max (m³)
11701	3861	5616
1526	504	732

Ward 4

Field size (m²)	WD min	WD max (m³)
40699	13431	19536
1526	504	732

Ward 5

Field size (m²)	WD min	WD max (m³)
27981	9234	13431
2544	840	1221

Ward 6

Field size (m²)	WD min	WD max (m³)
17806	5876	8547
509	168	244

Ward 7

Field size (m²)	WD min	WD max (m³)
45787	15110	21978
3561	1175	1709

Ward 8

Field size (m²)	WD min	WD max (m³)
25437	8394	12210
509	168	244

Ward 9

Field size (m²)	WD min	WD max (m³)
15262	5036	7326
1526	504	732

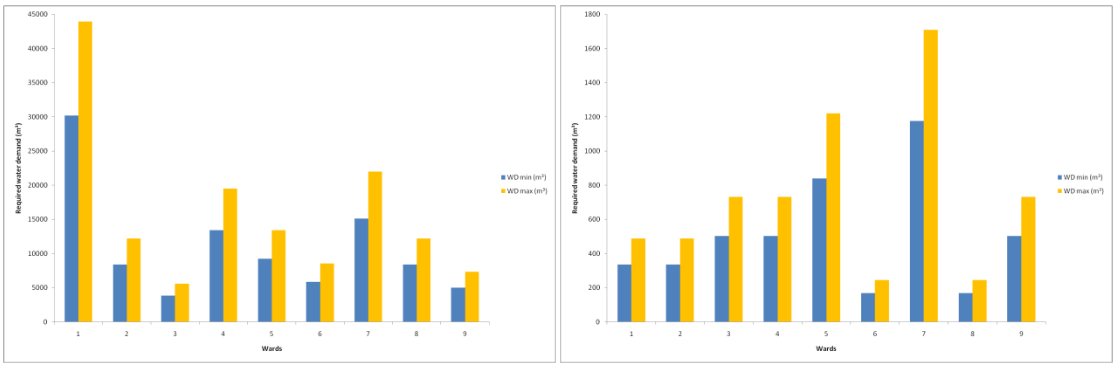


Figure 54: Water demand of vegetables (scarcity period), big field (left) small field (right)

IX.II Water demand (WD) for different crops during water scarcity period

Corn:

Table 26: Corn, irrigation water need details for all wards (shortage period)

Ward 1

Shortage (can grow)	Total water demand per growing period (mm)	Growing Period (days)	Precipitation (m^3/m^2)	Field size (m^2)	WD max (m^3)
Feb/Mar-end Jun/Jul	500-800	90-120	0.78	91573	1831
Feb/Mar-end Jun/Jul	500-800	90-120	0.78	1017	20

Ward 2

Field size (m^2)	WD max (m^3)
25437	509
1017	20

Ward 3

Field size (m^2)	WD max (m^3)
11701	234
1526	31

Ward 4

Field size (m^2)	WD max (m^3)
40699	814
1526	31

Ward 5

Field size (m^2)	WD max (m^3)
27981	560
2544	51

Ward 6

Field size (m^2)	WD max (m^3)
17806	356
509	10

Ward 7

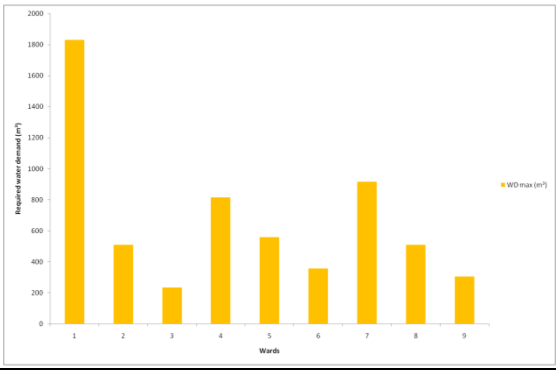
Field size (m^2)	WD max (m^3)
45787	916
3561	71

Ward 8

Field size (m^2)	WD max (m^3)
25437	509
509	10

Ward 9

Field size (m^2)	WD max (m^3)
15262	305
1526	31



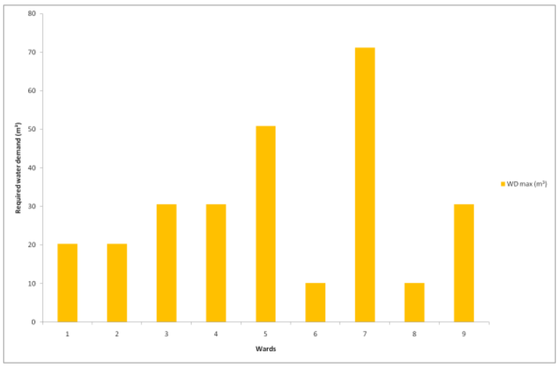


Figure 55: Water demand of corn (shortage period), big field (left) small field (right)

Rice:

Table 27: Rice, irrigation water need details for all wards (shortage period)

Ward 1

Shortage (can grow)	Total water demand per growing period (mm)	Growing Period (days)	Precipitation (m^3/m^2)	Field size (m^2)	WD min (m^3)	WD max (m^3)
Feb/Mar-end Jun/Jul	900-1500	100-120	0.78	91573	10989	65933
Feb/Mar-end Jun/Jul	900-1500	100-120	0.78	1017	122	732

Ward 2

Field size (m^2)	WD min	WD max (m^3)
25437	3052	18315
1017	122	732

Ward 3

Field size (m^2)	WD min	WD max (m^3)
11701	1404	8425
1526	183	1099

Ward 4

Field size (m^2)	WD min	WD max (m^3)
40699	4884	29303
1526	183	1099

Ward 5

Field size (m^2)	WD min	WD max (m^3)
27981	3358	20146
2544	305	1832

Ward 6

Field size (m^2)	WD min	WD max (m^3)
17806	2137	12820
509	61	366

Ward 7

Field size (m^2)	WD min	WD max (m^3)
45787	5494	32967
3561	427	2564

Ward 8

Field size (m^2)	WD min	WD max (m^3)
25437	3052	18315
509	61	366

Ward 9

Field size (m^2)	WD min	WD max (m^3)
15262	1831	10989
1526	183	1099

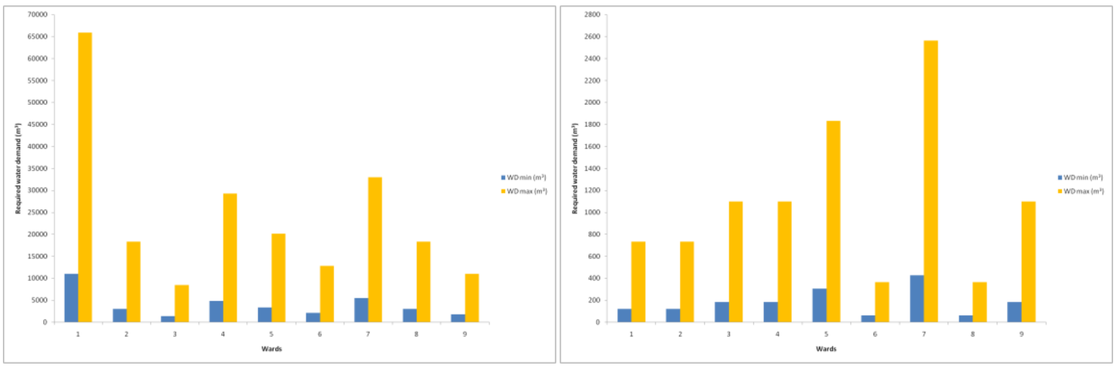


Figure 56: Water demand of rice (shortage period), big field (left) small field (right)

Appendix X- Drinking water shortage results

Ward 2

Water shortage	Time (month)
shortest	2.0
longest	12
average	5.7
Total households	7

Harvested amount (l)	Total Households
25 l (1)	5
15 l (2)	2
No (3)	0

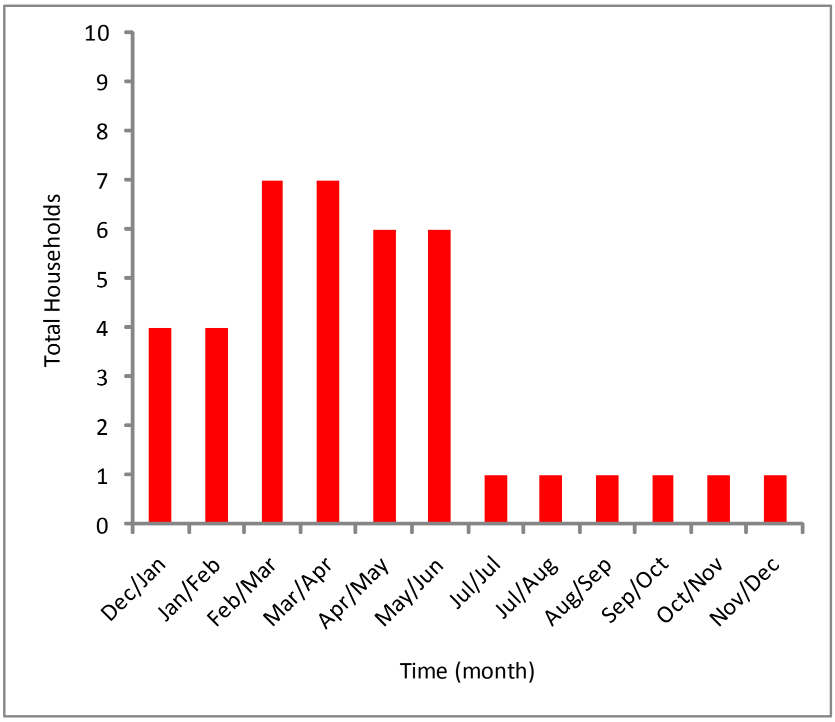


Figure 57: Results for drinking water shortage Ward 2

Ward 3*

Water shortage	Time (month)
shortest	1.0
longest	8.0
average	4.8
Total households	4

Harvested amount (l)	Total Households
25 l (1)	2
15 l (2)	1
No (3)	1

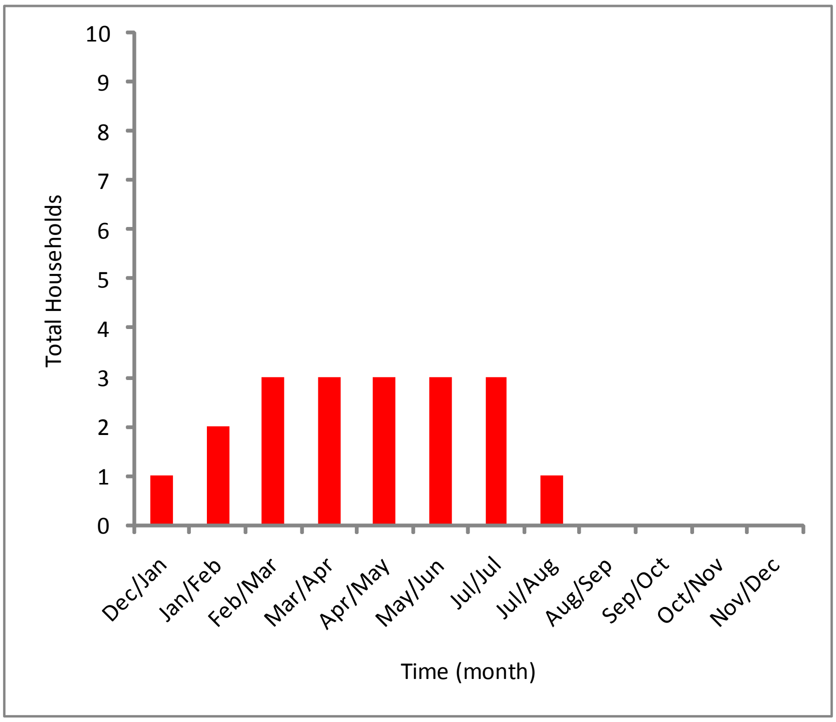


Figure 58: Results for drinking water shortage Ward 3

* only the roof of the house was taken into account, not additional roofs like sheds

Ward 4

Water shortage	Time (month)
shortest	4.0
longest	12
average	6.8
Total households	8

Harvested amount (l)	Total Households
25 l (1)	5
15 l (2)	2
No (3)	1

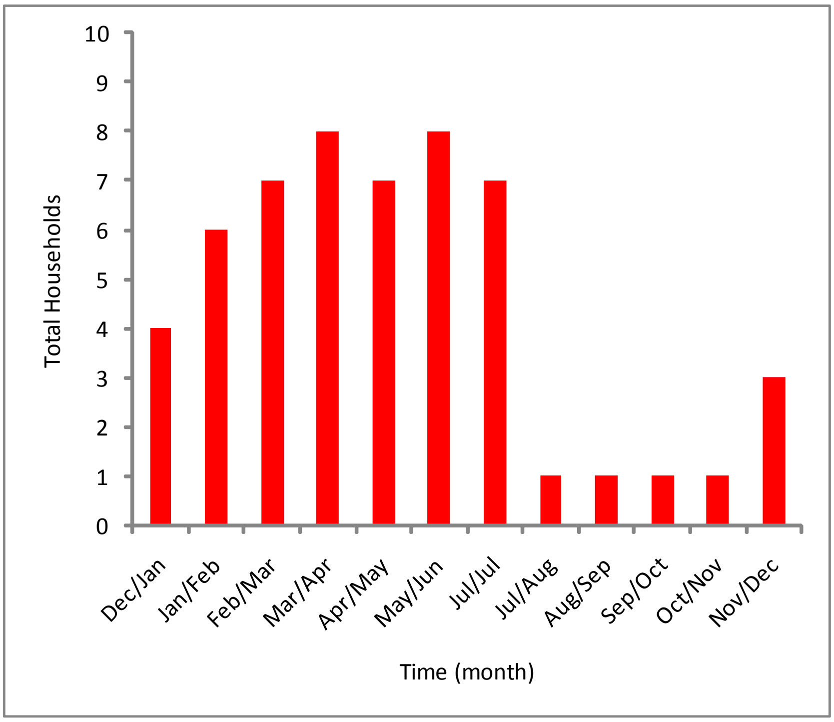


Figure 59: Results for drinking water shortage Ward 4

Ward 5*

Water shortage	Time (month)
shortest	4.0
longest	12
averag	6.3
Total households	10

Harvested amount (l)	Total Households
25 l (1)	1
15 l (2)	3
No (3)	6

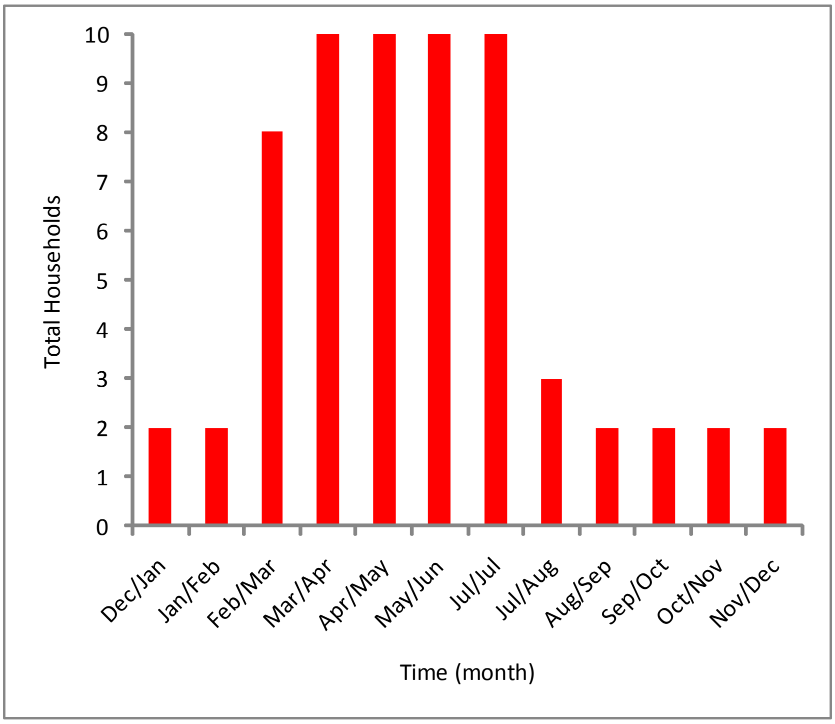


Figure 60: Results for drinking water shortage Ward 5

Ward 7*

Water shortage	Time (month)
shortest	2.0
longest	7.0
average	4.7
Total households	9

Harvested amount (l)	Total Households
25 l (1)	3
15 l (2)	2
No (3)	4

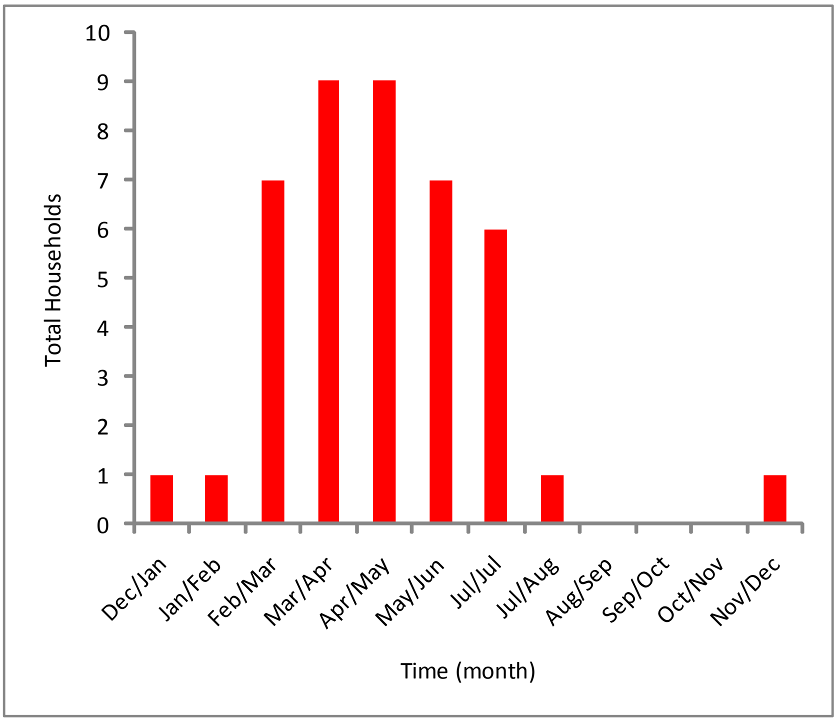


Figure 61: Results for drinking water shortage Ward 7

Ward 8

Water shortage	Time (month)
shortest	3.0
longest	12
average	8.6
Total Households	9

Harvested amount (l)	Total Households
25 l (1)	2
15 l (2)	2
No (3)	5

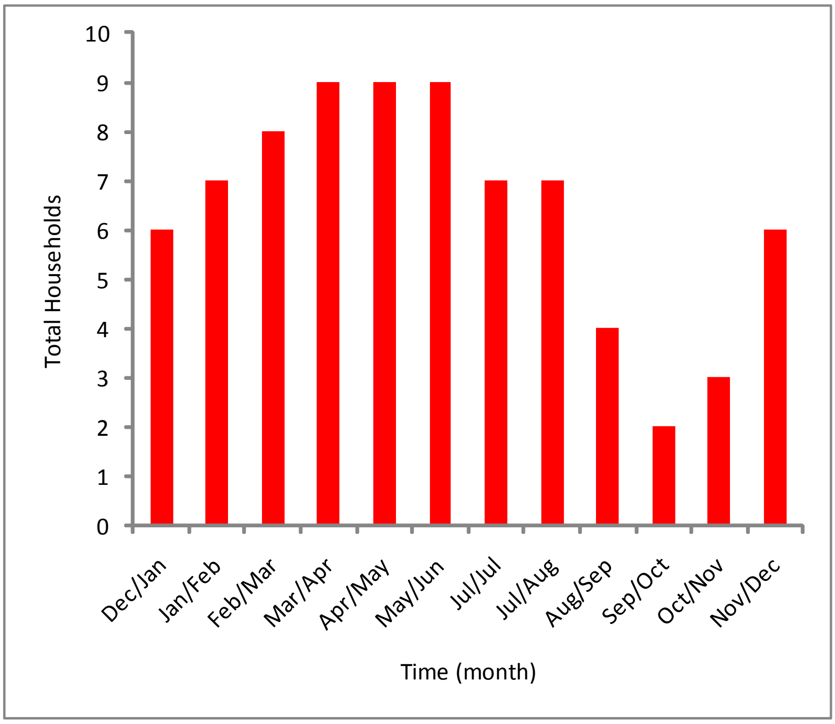


Figure 62: Results for drinking water shortage Ward 8

Ward 9

Water shortage	Time (month)
shortest	2.0
longest	3.0
average	2.8
Total households	5

Harvested amount (l)	Total Households
25 l (1)	5
15 l (2)	0
No (3)	0

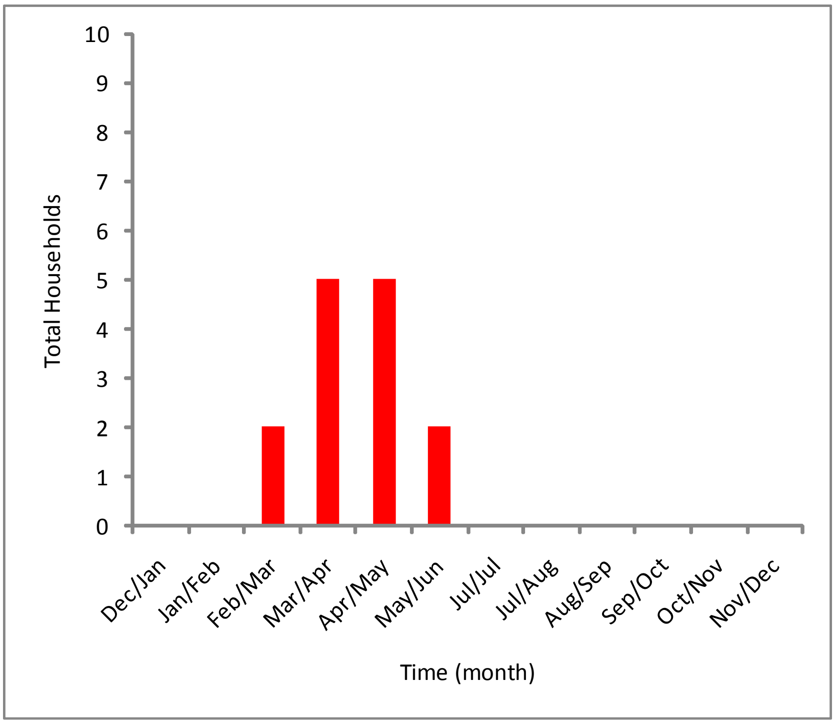


Figure 63: Results for drinking water shortage Ward 9

Appendix XI– Details of RWH-system parts

XI.I Catchment area

The most common method of fetching rainwater is to use the roof surface as catchment area for the precipitation. Therefore the roof material is a crucial aspect. Generally it can be said that any material used as a roof is acceptable for collecting water. However, if the water is collected to serve as drinking water, the roofing material plays an important role. It should be avoided to collect drinking water from roofs covered with asphalt or made of lead. Galvanised, corrugated iron sheets as well as corrugated plastic, flat cement or felt-covered roof on the other hand are preferable materials. “If paint is used, it should be non-toxic (no lead-base paints)” (Khoury-Nolde, 2013).

Of all the mentioned materials galvanised iron sheets seems be mostly used roof material in RWH-systems. The advantages are the high run-off coefficient with 0.9 (Worm & Hattum, 2006). Furthermore there is the positive effect by sunlight penetration which heads up the iron sheets and therefore kills bacteria which might be contaminating the harvested rainwater. Using natural material like wood or reed is also possible but this material enhances bacterial growth and the water quality must be monitored more strongly. Also are the run-off coefficients of natural material less than of galvanised iron sheets (Table 28) (Worm & Hattum, 2006).

Table 28: Run-off coefficients for traditional roofing materials (Worm & Hattum, 2006)

Type	Run-off coefficient
Galvanised iron sheets	>0.9
Tiles (glazed)	0.6-0.9
Aluminium sheets	0.8-0.9
Flat cement roof	0.6-0.7
Organic (e.g. thatched)	0.2

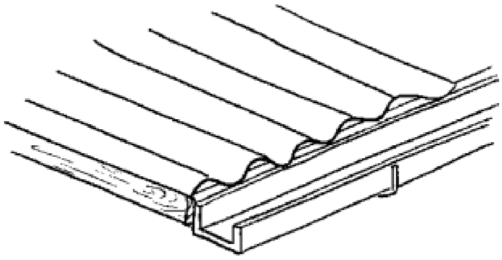
XI.II Gutters

The gutter describes the part of the RWH-system which is used to guide the rainwater flowing down from the roof into the surface tank. This component is often the weakest part in the RWH-systems (Worm & Hattum, 2006) and needs therefore special consideration.

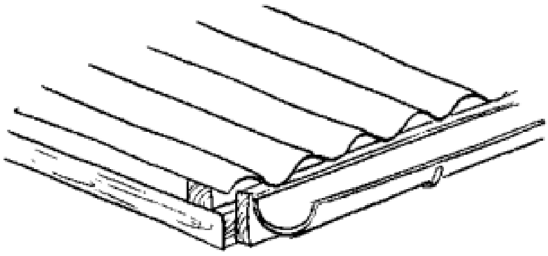
To construct the gutter different material can be used as for example galvanized metal, plastic (PVC), bamboo, aluminum or wood. If plastic is used it must be protected from direct sunlight to prevent quick failing of the material. As already mentioned in the previous chapter, natural material like bamboo can be used, but natural degradation of the material must be considered as well as they provide a favorable ground for bacterial growth. If using wooden gutters, the different parts of the wood can be joined by using a mixture of tar and lime, sometimes also plastic sheets can be used to cover the joints (Luong, 2013). In order to decide which material is the most suitable, the combination of cost efficiency, available material and purpose of water use must be gauged.

When the matter of material is decided the next important part is the shape of the gutter (Figure 64). Most common and cheap form is the V-shaped gutters which are easy to construct and cost efficient. Other forms are semi-circular or squared gutters. A disadvantage of the V-shaped gutters compared to semi-circular- or squared gutters are that they tend to be faster blocked by debris and leaves

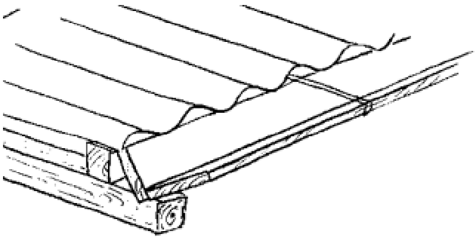
(Worm & Hattum, 2006). When using wooden gutters the V-shape is the most suitable and material saving form but can be also designed as square gutters. Bamboo gutters are naturally semi-circular shaped and iron gutters can be provided in any preferred shape.



semi-circular gutter



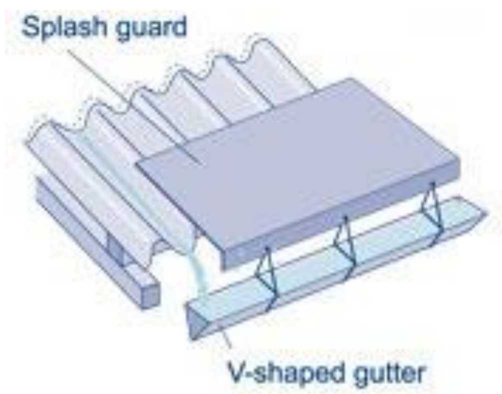
squared gutter



V-shaped gutter

Figure 64: Different gutter designs (Worm & Hattum, 2006)

Regardless which shape the implemented gutters will have the implementation of a splash guard is strongly advisable. Especially in a country like Nepal where rain showers often only last for a short period but with a high intensity it is an essential aspect to prevent a high rate of water over splashing and thus tremendous harvest loss. Special splash shield can be constructed to avoid this unnecessary loss. Splash guards (Figure 65) are designed as a “long strip of sheet metal 30cm wide, bent at an angle and hung over the edge of the roof about 2-3cm” (Worm & Hattum, 2006) which helps to channel all run-off to flow into the gutter and finally into the storage tank. Additionally it should be kept in mind to arrange the gutter in the way that the roof is hanging slightly over the gutter to ease the rainwater inflow.



The gutter is a key part of Rainwater Harvesting Systems and if properly designed it is capable of collecting up to 90% (Worm & Hattum, 2006) and more of the rainwater run-off per rain shower. To attain this amount of harvest the dimensions of the gutter is essentially and must be corresponding to the catchment area. As a rule of thumb it can be said that per 1m² of roof surface a gutter cross-section of 1cm² should be provided (Worm & Hattum, 2006) and the slope toward the storage tank should be increasing in the slope from 1:100 to 3:100 over the complete lengths to increase the potential water flow by 10-20 % (Dahal, Ban, Makaju, Shrestha, & Dwa, 2010). Furthermore the depth of the gutter should be one-half of its width (Luong, 2013). The dimension of the downpipe is supposed to be similar to the gutter to guarantee a constant flow into the storage tank and simultaneously avoiding overflow during heavy rainfall. Examples of appropriate dimensions are illustrated in Table 29.

Figure 65: Principle of a splash guard (smet, 2003)

Table 29: Appropriate Width of Gutter and Diameter of Outlet Drain and Various Roof Areas (Luong, 2013)

ROOF AREA, sq. m	GUTTER WIDTH, cm	OUTLET DRAIN dia., cm
50	12	6.5
60	13	6.5
70	14	6.5
80	15	7.5
90	16	7.5
100	17	7.5

After choosing a gutter design and calculating the necessary dimensions according to the local circumstances an appropriate fixture has to be applied. Also this problem can be solved with different solutions, again depending on the budged and local availability of materials.

A first method to fix any kind of gutter to the roof is using conventional gutter holders made of iron which are attached to the wooden eaves (Figure 66) over the total length of the gutter. This method can be conducted for all shapes and material.

An additional technique is to use wooden gutter holders. There are two main designs of wooden gutter holders, the first one is a “Cross-fixed wooden gutter holder” (Luong, 2013)(Figure 67). This design is applicable with semi-circular- and V-shaped gutters regardless which material they are made of. The Cross-fixed wooden gutter holders are fixed to all rafters of the roof. Secondly the Squared wooden gutter holders can be implemented. Best suitable for semi-circular - and Square shaped gutters they are attached to either all wooden rafters or to wooden eaves at an interval of 50cm (Luong, 2013) (Figure 68).

As a more unconventional and low budged method the “Tree Twig Gutter Holder” (Luong, 2013) is a capable solution to attach the gutters to the roof. All that is needed to apply this method are strong tree twigs which are fixed to the roof rafters with nails, ropes or iron wire (Figure 69). Most favorable gutter shapes for this technique are Square – and semi-circular shape gutters.

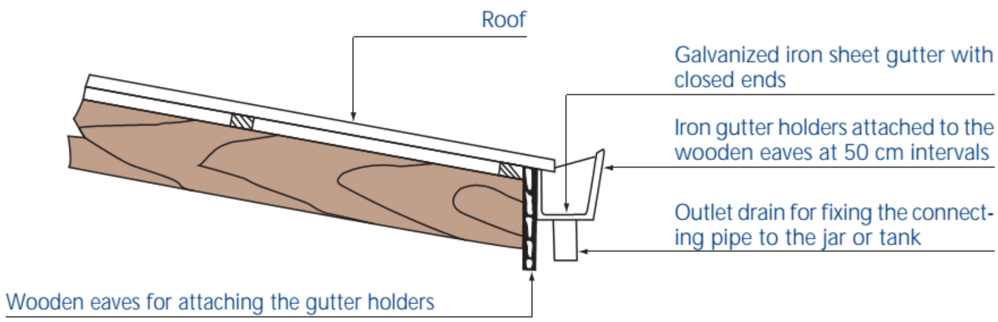


Figure 66: Iron gutter holders (Luong, 2013)

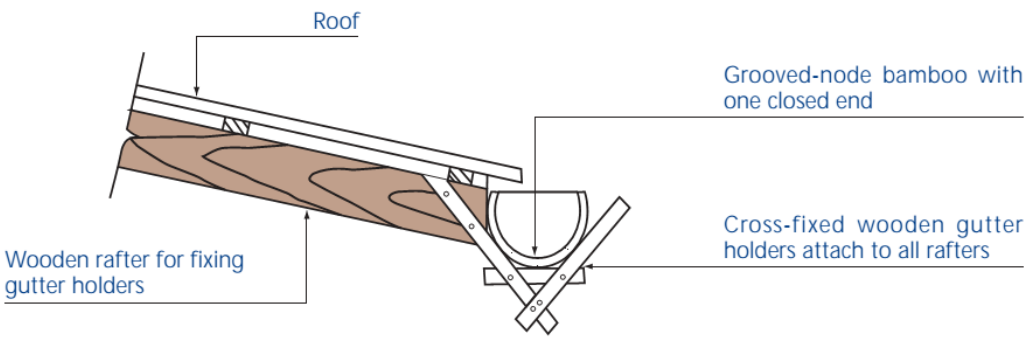


Figure 67: Crossed-fixed wooden gutter holder (Luong, 2013)

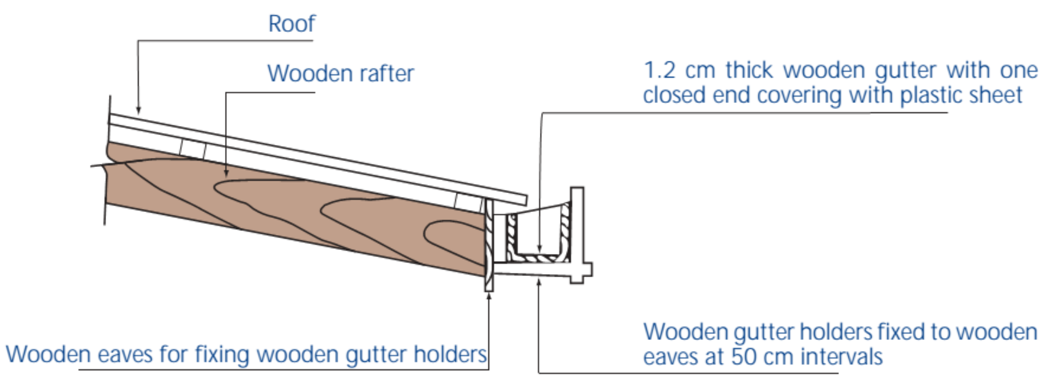


Figure 68: Squared wooden gutter holder (Luong, 2013)

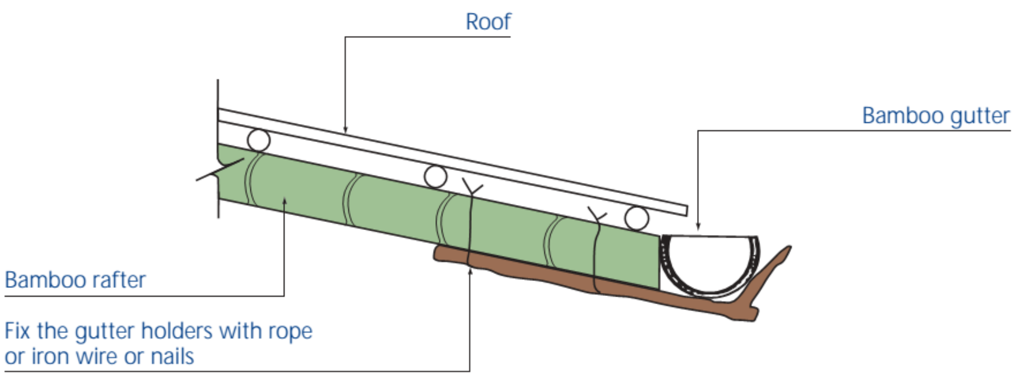


Figure 69: Tree-twig gutter holder (Luong, 2013)

If applying land surface catchment as the harvesting technique the gutter design is simpler than for the roof catchment. Depending whether the water shall be stored in an open reservoir like a pond or in a sub-surface tank different methods are used. When using a pond as a storage reservoir it is already sufficient to only build a channel leading the water from the catchment area into the pond and can be upgraded by adding normal pipes if necessary, also connected to eventual drain pipes placed in the catchment area. Using a sub-surface tank to store the collected water a manhole connected to the tank via a pipeline is the most common solution. Applying this technique it is crucial to guarantee that the pipeline is properly connected to the tank and the manhole which should be covered by a grid to avoid flushing more dirt then inevitably into the storage tank.

Designing a suitable gutter for the RainSaucer system depends on the size, amount and location of the saucers and storage tank. Using the saucer as a kind of funnel (Figure 70) directly connected to the storage tank the need for a gutter system is neglected. Applying designs containing two or more saucers (Figure 71) a proper gutter system must be set up, using downpipes which are joined at the end to have only one drainpipe inflow into the storage tank.

Figure 70: Single saucer collection method

Figure 71: Multiple saucers collection method

XI.III Storage Tank

After calculating the required storage capacity as described in Chapter 2.2.3 a decision for a design must be made. At first it should be argued whether a surface or a sub-surface tank is the most suitable solution. Usually surface tanks are most common in combination with a roof catchment system and the RainSaucers, where as in land surface catchment sub-surface tanks are often used. Sub-surface tanks may also be the more suitable solution for roof catchment systems, but this decision is highly connected to the local circumstances. There can be a few advantages and disadvantages of both methods pointed out (Table 30; 31).

Table 30: Advantages of surface and sub-surface tanks (Worm & Hattum, 2006)

Advantages	Surface Tank	Sub-surface Tank
	• Above-ground structure allows for easy inspection for cracks or leakage • Many existing designs to choose from • Can be easily purchased 'off-the-shelf' in most market centers • Can be manufactured from a wide variety of materials • Easy to construct with traditional materials • Water extraction can make use of gravity in many cases • Can be raised above ground level to increase water pres- sure	• Generally cheaper • Surrounding ground gives support allowing lower wall thickness • Requires little or no space above ground • Is not in the way (below the ground) / not as noticeable

Table 31: Disadvantages of surface and sub-surface storage tanks (Worm & Hattum, 2006)

Disadvantages	• Requires space • More easily damaged • Prone to erosion from weather • Failure can be dangerous	• Water extraction (to draw water or for cleaning) is more problematic – often requiring a pump • Leaks or failures are more difficult to detect • Contamination of the tank from groundwater is more common • Tree roots can damage the structure • There is danger to children and small animals if tank cover is left off • Flotation of the cistern may occur if groundwater level is high and cistern is empty • Heavy vehicles driving near a cistern can cause damage

Storage tanks can be constructed out of a huge variety of materials such as reinforced concrete, ferrocement, fiberglass or polyethylene. Moreover stainless steel, wood, metal or earth can be used as well. Polyethylene tanks are the most common tanks, since they are easy to clean and the connection to pipe systems is also easy to implement (Khoury-Nolde, 2013). In Asian countries and especially in Thailand "Cement Rainwater Jars" (Luong, 2013) are very common. They are simple to construct and do not require a high budget since they can be made mainly of locally available materials such as cement, sand and iron wire (Table 32).

Table 32: Materials needed for cement rainwater jars (Luong, 2013)

MATERIAL REQUIREMENTS	1,000-LITRE JAR	2,000-LITRE JAR
Cement	3 bags	4 bags
Sand	2 cubic metres	3 cubic metres
Aggregate	0.3 cubic metre	0.3 cubic metre
Wire, 0.04 inch (or 0.1centimetre) diameter	3 kilograms	4 kilograms
GS pipe, 3/4 inch (or 1.9 centimetres) inner diameter	0.8 metre	0.8 metre
GS socket, 3/4 inch (or 1.9 centimetres) inner diameter	2 pieces	2 pieces
Tap, 3/4 inch (or 1.9 centimetres) inner diameter	1 piece	1 piece
GS plug, 3/4 inch (or 1.9 centimetres) inner diameter	1 piece	1 piece
Aluminium or iron wire, 0.12 inch (or 0.3 centimetre) diameter	2 kilograms	2 kilograms
Nylon net	1 square metre	1 square metre
Jute cloth (like that used for rice sacks)	4 square metres	6 square metres
Big iron sewing needle	1 piece	1 piece
Wooden or aluminium cover	1 piece	1 piece
Skilled mason	2 days	2 days
Unskilled labourer	2 days	2 days

The shape of the tanks is highly variable from normal squared one, to oval cisterns up to round tanks. When choosing the shape it should be kept in mind that round tanks need the least amount of material to construct. Additionally it is also possible to construct either one jar meeting the required storage capacity or building a “Battery tanks” (GDRC, 2013).

Independent on which tank design is chosen in the end, if it is a surface or sub-surface tank, there are some rule of thumb which apply for all them.

1. The usage of inert material
2. Proper closure to prevent any entry of insects like mosquitoes or other animals polluting the collected water
3. The tank has to be opaque to prevent any kind of algal growth
4. A manhole must be included to enable proper cleaning
5. Adding of an extraction device or system which does not contaminate the stored water
6. Rainwater inlet should be as calm as possible to avoid unnecessary disruption of stored water leading to stirring up of settled sediments

XI.IV Taps and pumps

Independent whether the chosen storage tank is surface or sub-surfaces a water extraction device is needed. In case of surface tanks a simple tap can be used to extract the water. Since all particles or any other kind of small pollution settles on the bottom of the storage tank the tap must be, for drinking water purposes, at least 50cm above the tank bottom placed, if the water is only used for irrigation or washing purposes 15cm are sufficient enough (Worm & Hattum, 2006).

To avoid a big amount of “dead storage” (Worm & Hattum, 2006) for the drinking water taps, a second tap can be constructed on the bottom which is then be used to extract water for washing or irrigation purposes. Furthermore it would be advisable to place the tank on a little enlargement creating more space between the ground and the taps.

In case of a cistern a pump, or due to a lack of electricity, a bucket rope must be used. The advantage of a pump over a tap is simply the safety if the device breaks. A tap would leak and the precious water would be lost, while during a breakdown of a pump no water will be lost and the bucket rope can be used as long as the pump will be replaced.

XI.V First Flush

With this system the first rain that flows from the roof and through the gutter washing away all droppings and other pollutions and therefore is highly contaminated is not guided into the storage tank but put aside. Afterwards the water can flow without any fear of contamination into the storage tank. There are different design possibilities for the first flush, which then depends on the final budged and available material.

Two possible techniques for a first flush device are manual method and fixed volume method.

The manual method includes, as the name already mentioned, the manual diverting of the first flush and effectively harvested water. This can be either done by using a movable pipe disconnecting it from the storage tank during the first five minutes of every rainfall and afterwards connecting it again (Figure 72).

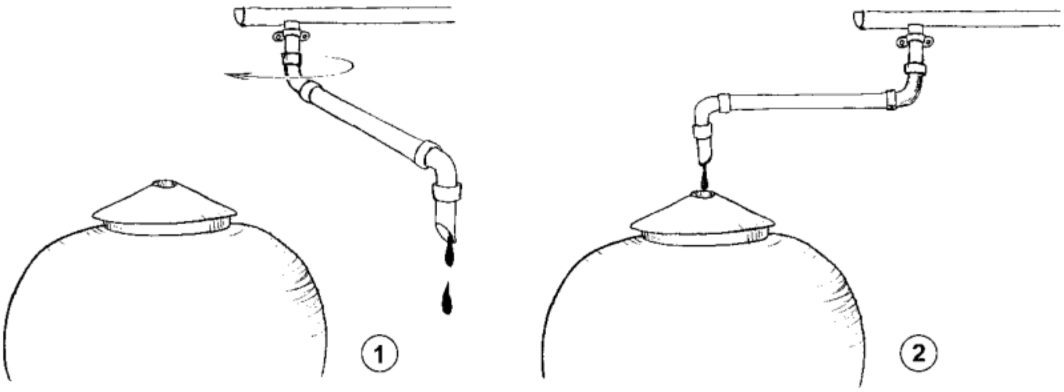


Figure 72: Manual first flush method, movable downpipe (Worm & Hattum, 2006)

Another option is to use a bucket as a weight to divert the first 10l into the bucket and by the added weight connecting the drain pipe back to the storage tank (Figure 73).

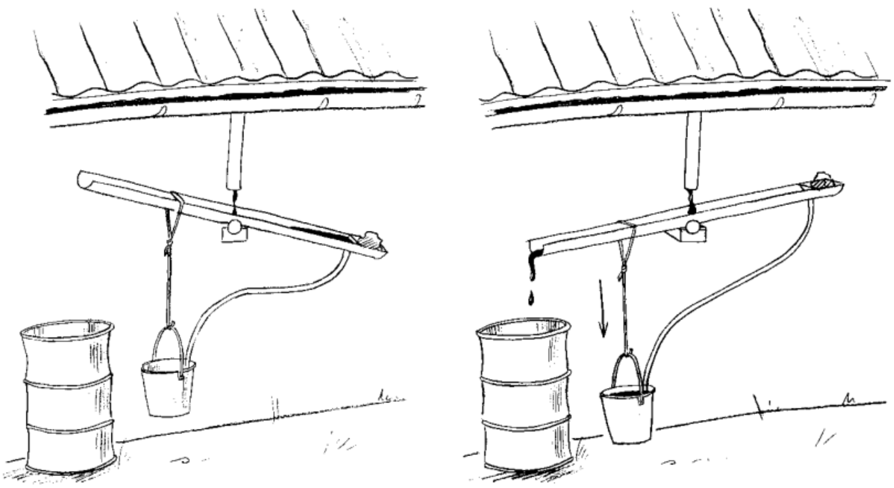


Figure 73: Manual first flush method, weight diverter practice (Worm & Hattum, 2006)

The disadvantages of these manual methods are that they require the present of a family member at the house at every rainfall, and also during the night to ensure the proper function.

Another technique, the fixed volume method is can be considered as a half automatic first flush device. This system consists of a smaller storage tank, like a drain pipe or similar, comprising a floating ball. When the rain starts the pipe fills up with the first water and the flushed dirt until it is full and the floating ball is ceiling it from the main drain pipe. In this way the dirty water is locked away while the clean water can flow into the storage tank afterwards. The only effort is to empty the flush tank after every rainfall. An example design is illustrated in Figure 74.

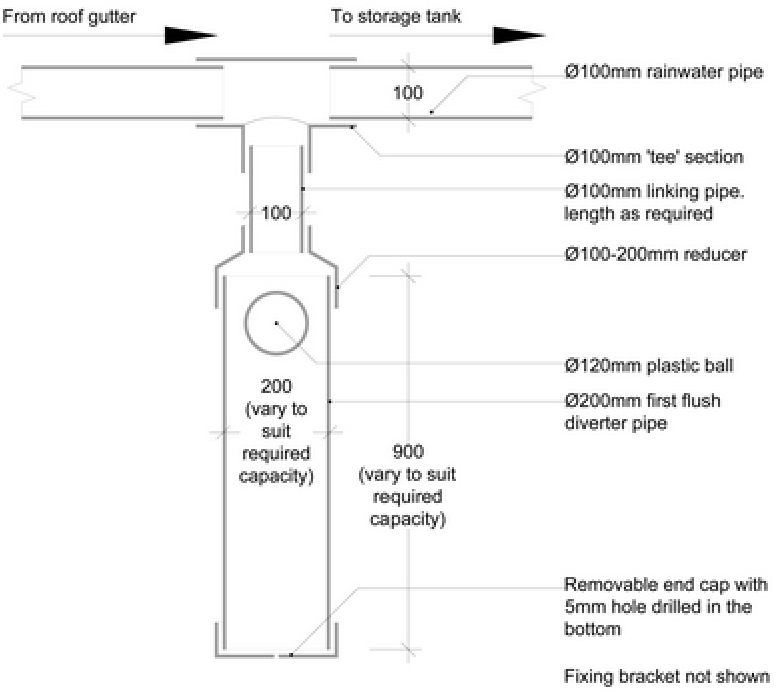


Figure 74: Half automatic first flush method, diverter pipe (Arkitrek, 2013)

XI.VI Water quality

Generally it can be said that atmospheric rainwater in rural areas meets the drinking water standards. Contamination only appears when any kind of industrial area or other highly air pollutant sources like volcanoes are close. The real threat for contamination in RWH-systems starts when the rainwater hits the roof. Bird and animal droppings as well as leaves, organic matter and dust pollute the rainwater. To avoid contamination several safety measures should be applied. Beside the first flush system mentioned previously (Appendix XI.V) grids to catch any kind of bigger pollution like leaves, bigger insects or big size particles can be either put on top of the gutter, at the bottom of the drainpipe or directly before the rainwater enters the storage tank. Independent of where the grid is installed it must kept in mind that an easy access is crucial for cleaning and maintenance of the grid, to avoid blocking of the system and wasting precious water.

Another important aspect is the prevention of any kind of insects, like mosquitoes to breed in the storage tank contaminating the water. A simple way of avoiding unwanted insects is to cover every open or vulnerable part of the rainwater harvesting system with an insect screen. Also if using the water as a drinking water source any unnecessary disturbance of the collected water has to be avoided to avert stirring up of settled sediments and thus water contamination.

Despite all this safety measures “a certain degree of microbiological and chemical contamination of roof rainwater run-off is inevitable” (Worm & Hattum, 2006). If the user still feels uncomfortable to use the collected rain water for drinking purposes, there is always the possibility to boil the water for a short time to make sure all bacteria are killed, or place it in any kind of clean plastic container in direct sunlight for a while. The sun heats up the water and also kills the bacteria.

Further steps to avoid any kind of contamination is to make sure to not use dirty containers or buckets, and keep the system well maintained, from regular checking and cleaning to proper fixing in case of damages (Worm & Hattum, 2006).