Adaptation to Climate Change

Zooming in on Rainwater Harvesting in the Thar Desert, India

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Abstract

Global warming is one of the major threats to humans and ecosystems, especially in already fragile areas like that of the Thar Desert in Rajasthan, India. People living there depend on rainwater for the every day life. This study aimed at investigating whether the there will be any influence on the existing rainwater harvesting structures in the future due to climate change and examining the adaptation factors needed to increase the resilience of the systems based on the perspectives of the persons maintaining and using these systems. This was done by literature reviews on climate change in the Thar Desert and interviews with villages and experts. My result showed that resilience of the rainwater harvesting structures lies upon several intertwined factors and having sustainable water supply is equivalent to having a resilient rainwater harvesting structure. In detail, these factors are social, institutional, economic, physical and technical. Understanding the factors and the links between them is vital to precede global work and consensus regarding adaptation to climate change and for securing water supply for people living in water scarce areas.

Keywords: *Climate change, Rainwater harvesting, Resilience, Adaptation, Social factors, Institutional factors, Economic factors, Physical factors, Technical factors.*

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1. Introduction

Water is the medium that connects society and nature and is essential for all socio-economic development and for maintaining healthy ecosystems. All over the world, people depend on water for a huge array of ecosystem services and the safeguarding of daily life (Keys *et al.*, 2012, p.734). However, global warming due to anthropogenic increases in green house gas concentrations in the atmosphere is causing vigorous change in the global water cycle as well as the climate system. As a consequence, a significant impact on hydrological parameters like runoff, evapotranspiration, soil moisture, ground water and precipitation sheds are expected combined with increasing global mean temperatures (IPCC, 2013, p.13; Bindoff *et al.*, 2013, p. 868). In particular, there is evidence of an anthropogenic influence on atmospheric moisture content. Warm air holds more water vapor and therefore increases evaporation of surface moisture. If there is little or no moisture in the soil to evaporate, the incident solar radiation raises the temperature, which could contribute to more severe droughts. Also, with more moisture in the atmosphere, rainfall tends to be more intense (Seneviratne *et al.*, 2012, p.143; Goyal, 2004, p.2).

Today, nearly 1 billion people over the globe lack access to safe drinking water (Gilbert, 2012, p. 256). Rural communities in arid and semi-arid areas are likely to be the most deeply affected by impacts of climatic change because of their reliance on their near environment for their livelihoods, which increases exposure and decreases the adaptive capacity to climate impacts (FAO, 2011, p. 5; Denton *et al.*, 2014, p.9). Where there are scarce water resources, the matter of sustainable water supply is of great concern (Government of India, 2011, p. 12). The issue of water scarcity and distribution of water is thus steadily moving upwards on the world's political agenda as its management incorporates some of the most important segments for human development and the environment (FAO, 2011, p.7). Globally, management strategies of water and ecosystems are changing. Where earlier management focused on the aspiration to control change there is now a move towards a perspective that strives for sustaining and improving the capacity of both human and natural systems to cope with and adapt to the change (Moberg & Galaz, 2005, 3; GWSP, 2011, p. 7).

This study was conducted in the Thar Desert, located in the western state of Rajasthan, India. Its location is shown in figure 1. It is the most densely populated desert in the world with a density of 84-90 people per square km (Mall *et al.*, 2006, p. 1610). Its ecosystem is fragile due chronic water scarcity, which makes the Thar Desert more sensitive to a changing global climate than other climate regions (Poonia & Rao, 2013, p.78). People living here are smallholders, depending on rainwater for their livelihoods and are thus vulnerable to climate change (FAO, 2011, p.7). Life in the Thar Desert has evolved with extreme life conditions. For example, summer temperatures often reach up to 50 °C. On average, the Thar Desert receives less than 200 mm of rain annually and the evapotranspiration is four to five times higher than that of rainfall in the region. The region is therefore suffering from meteorological drought, which in a broad sense means that the area is permanently dry as (Agarwal & Narain, 2008, p. 314; Narain *et al*, 2005, p. 3). The amount of rain is not evenly distributed. Of the annual rainfall, 80% is received during the short span of the summer monsoon, which comes in the time span of July to September and four out of every ten years on an average are severe drought years when there is little or close to no rain (Taygi & Attri, 2010, p.1). Land-use and life in a big part of the Thar Desert is dependent on precipitation due to the fact that the groundwater is saline and do also contain high levels of fluoride (Agarwal & Narain, 2008, p. 104). However, in the last 50 years, a threefold increase in the human population combined with a doubling of the livestock populations has put tremendous pressure on the existing water and land resources (Narain *et al.*, 2005, p.2). Research on different solutions on the water issue is thus of great importance.

When India gained independence in 1947, government supply of water focused on technical solutions as the state replaced the municipal as first provider and manager of water. The focus was on groundwater exploitation, which led to aquifer depletion and falling groundwater tables and the loss of indigenous knowledge of managing natural environments (Agarwal & Narain, 2008, p. 315; Glenfenning & Vervoort, 2010, p.331; Mall *et al.*, 2006, p. 1610; Narain *et al.*, 2005, p.9). Indigenous, or traditional, knowledge is the knowledge that people in a given society or culture has developed over time and continues to develop (Mbilinyi et al, 2005, s.793). Research on adaptation strategies states that adaptation to climate change will only work on the ground if they fit local conditions, including cultural traditions and knowledge and the physical landscape (Wilk & Wittgren, 2009, p.19).

In 2008, a National Action Plan on Climate Change, NAPCC of India, was created. The purpose was to improve the understanding of climate science, mitigation, adaptation, energy efficiency, natural resource management and conservation. Regarded the water issue, it was stated that "with water scarcity projected to worsen as a result of climate change, the plan sets a goal of a 20% improvement in water use efficiency through pricing and other measures" (NAPCC, 2008). An action plan for the state of Rajasthan was produced in 2011 with the aim to achieve sustainable development by reducing vulnerability to climate change impacts and enhancing resilience of ecological, economic and social systems (TERI, 2011[1]). In line with over all global management consensus, trans disciplinary approaches including bottom-up strategies and awareness of traditional knowledge was given considerable momentum in the report as a key to adapt to climate change and to solve the severe water crises in the state.

One of the focuses in the report is on traditional rainwater harvesting. The term rainwater harvesting encloses the capture, storing and redirection of rainfall, runoff, and groundwater for uses at a later time in the same vast area where the rain falls (Pandey *et al.*, 2003, p. 52; Mbilinyi *et al.*, 2005, p. 793). Rainwater harvesting, RWH, can guard against droughts and provide drinking water as well as social equity, it should be possible to provide safe drinking water in India with an annual precipitation of 100 mm if it just harvested properly and where the rain falls (Agarwal & Narain, 2008, p. 314). RWH is not however a new phenomenon in the Thar Desert. On the contrary, research has shown that the timing of rainwater harvesting system construction corresponds to changes in climate, which supports the theory that people "responded" with rainwater harvesting and staying in their homelands, rather than with migration (Pandey *et al.,* 2003, p. 53; Agarwal & Narain, 2008, p. 125; Batchelor *et al.*, 2002).

Against this background, there has been work done on revival and enhancing rainwater harvesting structures in the Thar Desert with the result that some villages now are self sustained with water, hence they have water almost all year round. However, the consequences of climate change are a threat to the water supply in the Thar Desert. To secure sustainable livelihoods and increasing the resilience to impacts of climate change, it is vital to study the rainwater harvesting systems and the potential of adaptation factors.

Aim of the study

The overall aim of the thesis is to examine whether there will be any influence on the existing rainwater harvesting structures in the future due to climate change and examining the adaptation factors needed to increase the resilience of the systems from the perspectives of the persons maintaining and using these system. In order to do so I will first examine what the climate change scenario for the Thar Desert look like and how it interferes with the water availability. This is done by a literature review. Secondly, interviews are performed with people in villages benefitting from secured water supply along with experts working on safeguarding water supply in the Thar Desert. The scenarios and the perception from villagers and experts are thereafter analyzed and discussed in relation to the analytical framework, which is based on theories and ideas on resilience and adaptation.

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[1] This report has no page numbers.

[2] Definitions of long and short term are dervied from the report "Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate

The study is the result of a Minor Field Study scholarship financed by SIDA, Swedish International Development Cooperation Agency. Delimitations in my study regard the actual study area, which is located in the outskirts of the Thar Desert, close to the city of Jodhpur and in the outskirts of the desert.

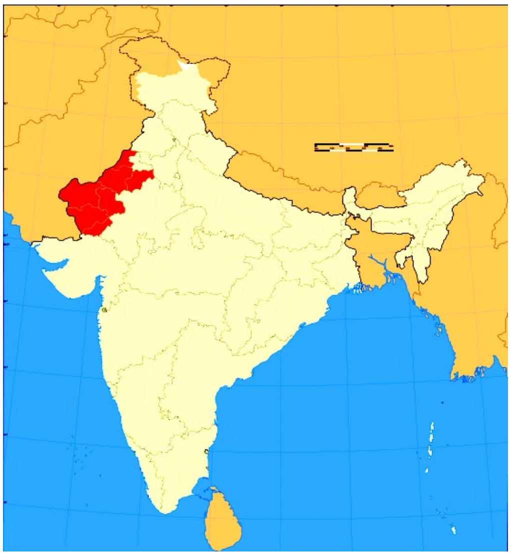

Figure 1. Location of the Thar Desert (Wikia, 2014)

Relevance to environmental science

Climate change is recognized as the greatest challenge facing the planet (Falkenmark *et al.*, 2001). This study touches upon several issues that are relevant to the environmental science field, by using the latest research about the climate system and the effects from anthropogenic sources and putting it in relevance to water scarcity, water management and adaptation theories.

The need for a broadened approach towards water management will increase as populations grow in regions that are water scarce. Climate change will, inter alia, worsen the element of uncertainty and surprise, with increased frequency of water related events such as dry spells, droughts and floods (FAO, 2011, p. 5). Locally established systems of water harvesting can not only ease the effects of chronic water shortage but can also provide a solution to the problem, thus improving the efficiency of rainwater harvesting structures by uncovering adaptation potential could impact millions of people in the poorest dry land communities and improve ecological systems in arid areas.

2. Methodology

The empirical material for this study was collected by three means: a literature study, that served as the basis for the regional climate scenarios, interviews with people from two target villages and experts and field observations. The project has been using a mixed methodology approach (Esaiasson *et al.*, 2012) as that type of methodological approach is able to host the project's interdisciplinary ambition, hence to reflect both the social and natural science perspectives of rainwater harvesting as water management is a multi criteria endeavor. The empirical material using the means of field observation and interview was collected at 4 different occasions. To answer my research questions the result consists of three sections: regional climate change, interviews and analyses. I was based outside the city of Jodhpur. Figure 2 shows a large-scale map of the study area where as figure 3 shows the villages location in detail.

2.1 Climate change and its consequences

To get an overview of predicted climate scenarios a literature review concerning climate change scenarios for the Thar Desert was conducted. It is today virtually impossible to produce any detailed predictions for local scale, as global climate predictions are subjects to various sources of uncertainty due to internal variability and complex response factors of forcing agents. On a regional level however, climate change and its consequences are somewhat examined. (Kirtman *et al.*, 2013, p.978; Handmer *et al.*, 2012, p.238; Chaturvedi *et al.*, 2013, p. 801; Goyal, 2004, p.3). To capture the worst-case scenario, the results are based upon studies using a "business as usual" scenario. This means that nothing or little is done to mitigate the emissions of green house gases, GHG.

Three focus areas were selected, i.e. the climate factors that are of relevance for the rainwater harvesting systems, focusing on the consequences of climate change that brings the most effect to rainwater harvesting systems. The focus areas are temperature, evapotranspiration and precipitation. Only reviewed studies were used in the literature study.

Figure 2. A map over Rajasthan. The study area is marked by an X. (Hello India Travel, 2014)

2.2 Interviews

I interviewed people who were using the rainwater harvesting systems as a source of drinking water and experts to get a heterogenic empirical material. This method is called triangulation (Esaiasson et al., 2012). The experts were from Jal Bhagirati Foundation, JBF. JBF is an NGO that for 10 years have been working with the enhancement of traditional rainwater harvesting structures, working accordingly after the principles of *Integrated Water Resource Management*, IWRM, see section 2.3. They work in collaboration with the villages, especially on enhancement of existing rainwater harvesting structures. They served as my supervisor in the field.

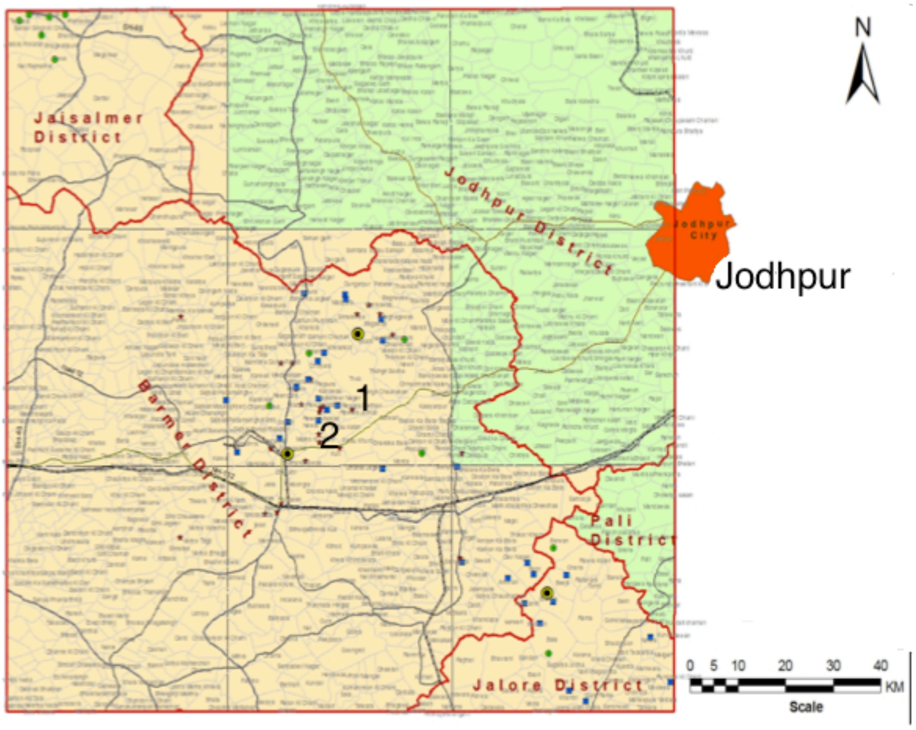

Figure 3. The villages' location in relation to Jodhpur. **1.** Rewada Jaitmal village **2.** Newai village
Source: Jal Bhagirathi Foundation.

2.2.1 Village interviews

Focus villages for interviews were selected upon availability and type of rainwater harvesting structure. I chose to conduct semi-structured interviews in villages where they had a functioning system that provided drinking water for most of the year. 2 villages were identified, Newai and Rewada Jaitmal, their location being on 26°18 N latitude and 73°1 E longitude, see their exact location in figure 3. The villages mainly income is from agriculture and animal husbandry and they rely on their rainwater harvesting systems for drinking water. If there are remaining needs, these are satisfied from buying external water from water tankers. Due to external circumstances, I was only able to go there on one occasion.

The interviews were preceded by a pilot interview, with the aim to test my questions and be able to change them if something did not turn out as expected. Worth mentioning is that the test interview was performed in a village where there was no functioning water harvesting system.

In every village collaborating with JBF there was a Water Committee, in the local language called a *Jal Sabha*. The *Jal Sabha's* responsibility is to overlook and plan for the maintenance of the rainwater harvesting structure. As it consists of a few people in every village with more knowledge about the schemes, members of the *Jal Sabha* were selected for the interviews. To capture the variability in indigenous knowledge and to capture the variability among the people in the study villages, emphasize was put on getting a broad selection of people. As cultural factors prohibited men and women to talk in the same room, two separate interviews were undertaken at each occasion. In total, 8 people took part in the interviews.

The overall agenda was to find out 1) how the in situ system worked 2) what the main advantages and risks were 3) if the people think that they will have drinking water even with a changing climate 4) if they could enhance the system's capacity in some way 5) other important factors for sustainable water supply.

As the interviews did not follow a specific form but were of an informal nature, all answers were considered but the coherent answers were emphasized in the presented result. The statements in the results derive from the interviews.

2.2.2 Expert interviews

To increase my understanding about the implemented rainwater harvesting systems I was brought along on filed visits to 6 different villages on two different occasions. With me was a person working at JBF, who held informal in situ lectures about the capacity, construction, and maintenance of the schemes. During the field visits, I was able to pose questions and discuss problems related to the specific structure. The questions and answers were noted and used as empirical material.

In addition to the field visits, two formal interviews were made. The first one was with Mr. an engineer from JBF, Mr. Thanvi, was interviewed. He works with the planning and implementing the schemes. The second one was with Mr. OP Sharma, who is country director of Wells for India, an organization who in similarity with JBF works with sustainable water supply in Rajasthan. The focus for this interview was the physical and biological factors for a sustainable rainwater harvesting system. The overall agenda was to find out 1) what the main advantages and risks of the systems were 2) how will they be affected by climate change 3) what other factors play an important role and why 4) if some factors will be more important in the future?

The coherent answers were presented as the results. The statements in the results were highlighted in the interview. However, discussions with the experts regarded not specifically the target villages of my study, but were more of a general character.

2.3 Analytical framework

The results are analyzed based on a flexible analytical framework, built on global water management discourses on climate change adaptation. This framework is used to interpret, discuss and understand my results (Esaiasson *et al.*, 2012).

According to Chaturvedi *et al.* (2013, p. 801), scenario-based projections of future climate should be used for climate change adaptation, CCA, planning. Where vulnerability is high and adaptive capacity relatively low, changes in extreme climate and weather events can make it difficult for systems to adapt without larger transformational changes. Adaptation strategies aim to increase resilience (Noble *et al.*, 2014, p.2). Resilience is a term for the ability of a system to return to normal functioning after a disturbance, buffer large and sudden external impacts or to withstand change (Boorse & Write, 2011, p.121). The concept of resilience can also be applied on human communities, and as nature and society are linked, the expression socio-ecological resilience is commonly used. In a broad sense, social-ecological systems resilience is the capacity to absorb disturbances and changes that affect them without a qualitative change in the system's function, and by system meaning the intertwined relationship of social, economic and ecological factors that shape the function (Moberg & Galaz, 2005, p. 2). For RWH systems, the crucial task is to improve the ability to co-manage water supply and environment so that overall resilience is achieved (Noble *et al.*, 2014, p.2). For this there is a need to ensure that inter alia social, economic, technical and institutional factors are able to interact with environmental factors, to support long-term resilient systems.

Local management will depend on the nature of the RWH structures, historical traditions of the area, local sociopolitical realities and water supply (Agarwal & Narain, 2008, p.325). The systems are often tested over centuries of usage and are adapted to the local culture and environment and can therefore initiate improved accountability in integrated risk decision-making that helps to break unsustainable development relations (Mbilinyi *et al.*, 2005, p.793; O'Brien *et al.*, 2012, p. 470).

However, Wilk and Wittgren (2009, p.19) argue that even if traditional practices, knowledge and adaptation measures would prove to be insufficient in the face of the climate change challenge, they serve as the starting point on which to build to ensure local engagement, commitment and willingness to adopt and integrate new approaches into adaptation strategies. These strategies include, inter alia, recognizing water quantity and quality linkages, protecting and restoring natural systems and including consideration of climate change (Wilk & Wittgren, 2009, p.7).

A common term for these strategies is *Integrated Water Resources Management,* IWRM. It is a concept that was first presented at the International Conference on Water and Environment in Dublin 1992 and in Agenda 21 the same year (Agenda 21, 1992). It is based on four principles, which are often used when developing national and regional water management policies:

1. Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.
2. Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
3. Women play a central part in the provision, management and safeguarding of water.
4. Water has an economic value in all its competing uses and should be recognized as an economic good.

IWRM is used to enhance socio-ecological resilience. The Government of India recognizes that water management projects need be of an inter-disciplinary nature with establishment of a collective decision and policymaking process. A multi-disciplinary approach should to be brought about by having a team of experts and workers of the associated disciplines into the management to increase resilience (Government of India, 2011).

Constrains involved with implementation and maintaining of rainwater harvesting structures are often of socio-economic character (Falkenmark *et al*., 2001). Social factors have been identified as the key to success, people have to be aware of the need to play an active role and frameworks are needed for their participation. (GWP, 2013, p. 30; Falkenmark *et al.*, 2001). Though, participatory water management cannot by itself address problems without complementary government action. Government actions include allocation of property rights, subsidies and resource augmentation (GWP, 2013, p.27). Funding is central, but economic incentives such as water charges and taxes are also of importance.
Provision of water and its management must be applied in combination with other processes shaping societies, economies and the environment. Ambitions of water security involve protecting and living with the water cycle and relying on responsible engineering schemes, developing risk awareness and preparedness (GWSP, 2011, p.7). Accordingly, Björklund et al. (2009, p.22) claim that physical land planning, institutional and human capacity and awareness, among others, should be the foundation of long-term adaptation strategies. Hence, to be able to strengthen CCA it is essential to develop a better understanding of the resilience of these water harvest systems.

With these dynamics in mind, I will analyse my results in section 3.3 and 3.4, interviews with villages and experts, and put them in relation to the result in 3.2, to be able to discuss whether the there will be any influence on the existing rainwater harvesting structures in the future due to climate change and examining the adaptation factors needed to increase the resilience of the systems.

3. Results

This section presents my findings from literature reviews, interviews and analyses.

3.1 Rainwater harvesting structures

There are many was to collect and store rainwater. The existing rainwater harvesting structures in the villages were *talabs* and *tankas.*

A *talab* is a pond, dug at a natural depression in the land to collect water from a large catchment area at village level. A catchment area is an extent of land where water from precipitation drains into a body of water. The *talab* is uncovered and its storage capacity is calculated to fit the need of the village, see figure 4. It is located at walking distance from the village.

A *tanka* is a covered underground tank for storing runoff water from natural or artificial catchments, or from a rooftop. The *tankas* in the villages had no catchment but were instead refilled manually, see figure 6. The *tankas* are usually located in relation to the house and are run and financed by a household. People transfer water from the ponds to *tankas* for storage and to reduce evaporation and seepage loss.

In one village there was a recharge well next to the *talab,* which is a shallow well that allows percolated water to refill the well. In dry periods, this was the major source of drinking water.

Figure 4. A *talab* used for drinking water for humans and livestock. Photo: by author.

Figure 5. Small part of a catchment area surrounding a *talab*. Photo: by author.

Figure 6. A *tanka* that can only be refilled because it has no inlets. Photo: by author.

3.2 Climate change and its consequences

This section elaborates on the consequences of climate change, due to increasing levels of GHG in the atmosphere in the Thar Desert - focusing on temperature rise, evapotranspiration and precipitation.

3.2.1 Temperature

The Thar Desert will be among the first areas in India to react to stronger forcing from GHG in the atmosphere (Chaturvedi *et al.*, 2012, p.797). If the warming continues at the present rate, the temperatures in the Thar Desert will likely increase by 2.3 to 4.0 ºC in the long term future[2] (2050-2100) from the current mean annual temperatures, which are 22-26 ºC during summer and 4-10 ºC during winter. But, the temperature could exceed that limit and move towards an increase of 6 ºC as well (Poonia & Rao, 2013, p. 73-75; Chaturvedi *et al.*, 2012, p.797; Krishna Kumar *et al.*, 2011, p. 320-322).

Near-term climate scenarios (2021-2050), projects increase in temperature of 2.0-2.5 ºC. Figure 7 shows the projected increase in average temperature in the near-term future (2035). The minimum temperature increase will be relatively greater than maximum temperature increase. This means that mean winter temperature will increase more, relatively, than mean summer temperatures (TERI, 2011; Chaturvedi *et al.*, 2012, p. 797; Krishna Kumar *et al.*, 2011, p.320-322; Collins *et al.*, 2013, p. 1031).

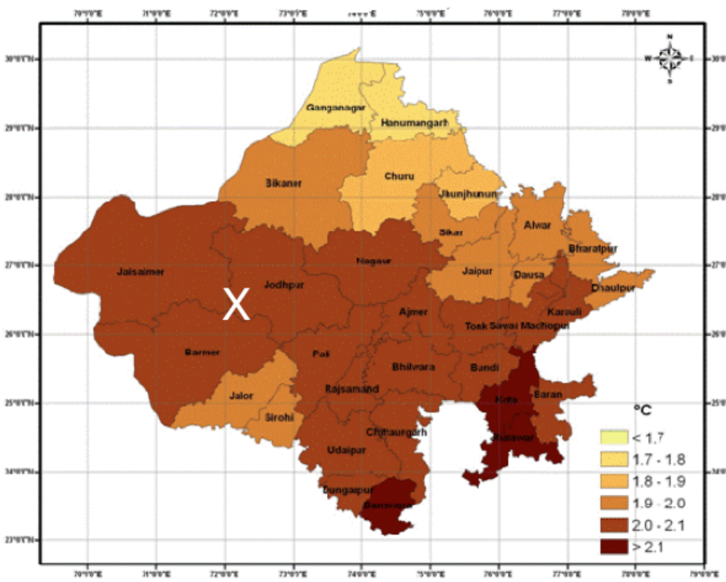

Figure 7. Projected increase in average temperature in the near-term (2035) future for Rajasthan, which shows an increase in 2.0-2.1 ºC The X shows the study area. (The Energy and Resources Institute, TERI, 2011).

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[2] Definitions of long and short term are dervied from the report "Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change".

3.2.2 Evapotranspiration

Increases in temperature will increase the capacity of air to hold water vapor and therefore increase the evapotranspiration, ET, rate (Mall *et al*, 2006, p. 1622-1623; Goyal, 2004, p.3). ET is the second major component of the hydrological cycle and accounts for over two-third of water losses from surface water bodies in arid and hot regions. Increase in ET in the Thar Desert has been identified as one of the key impacts on water resources due to climate change and could cause tremendous annual water losses (Goyal, 2004, p. 7; TERI, 2011). If there is little or no moisture in the soil to evaporate, the incident solar radiation raises the temperature, which could contribute to more severe droughts and increasing soil erosion (Collins *et al.*, 2013, p.1084; Mall *et al.,* 2006, p. 1613).

A temperature increase of 1%, which is 0.42°C based on normal maximum temperature of Rajasthan today, could result in an increase in ET by 15 mm. The expected long-term temperature increase of 4 degrees would therefore alone result in an increase of annual ET of +8%, a total change of +146 mm (Goyal, 2004, p.7). Adding other affecting factors could result in an ET increase of 12-16% during monsoon and 17-22% during winter by the end of the century (Poonia & Rao, 2013, p.76; Goyal, 2004, p. 5, Mall *et al.*, 2006, p.1623; TERI, 2011). Today, the Thar Desert experiences meteorological drought every 3rd year. The chance of occurrence of a meteorological drought in the state is now 47% and climate change is projected to increase drought occurrence (TERI, 2011). The consequences of climate change will approximately increase the in situ water need by 12-23% in summer, and by 13-47% during winter (Poonia & Rao, 2013, p.78).

3.2.3 Precipitation

Precipitation is the major component of the hydrological cycle (Goyal, 2004, p.2). As global warming is expected to lead to faster warming over land, monsoon circulations will also become stronger in summer (Seneviratne *et al.*, 2012, p.153). This means the rain pattern will change to various degrees. There is medium confidence that the increase of the Indian summer monsoon rainfall and its extremes throughout the 21st century will be the largest among all monsoons (Christensen *et al.*, 2013, p. 1219).

For the Thar Desert, characteristics of daily rainfall have already been undergoing changes during recent years. The frequency and intensity of heavy rainfall events are increasing, whereas events with low rainfall are showing a decline in their frequency (Krishna Kumar *et al.*, 2011, p.313; Mall *et al.*, 2006, p. 1621). For example, during recent years, parts of Rajasthan have twice received their annual rainfall in only two days (Agarwal & Narain, 2008, p. 314).

In the short-tem future (2021-2050), precipitation during monsoon is expected to show a slight increase of 5-10% (Kirtman *et al.,* 2013, p. 987; Krishna Kumar *et al.,* 2011, p. 320-322, TERI, 2011).

In the long term (2050-2100), mean annual rainfall is predicted to decrease with around 40 mm in the Thar Desert, whereas extreme rainfall is expected to increase in frequency and intensity (Poonia & Rao, 2013, p. 74; TERI, 2011). The number of rainy days is expected to decrease in the long-term (2050-2080) with the reference period 1961-1991 (Krishna Kumar *et al*, 2011, p. 320-322). Due to increased extreme events precipitation, there will be an increase in runoff by 10-20 (Kirtman *et al.*, 2013, p. 987).

3.3 Findings from village interviews

This section is categorized in two parts relating to my research questions. The first part, 3.3.1, focuses on the current system and how it works where as the second part, 3.3.2, focuses on if and why the existing systems will be able to handle future climate change.

3.3.1 How and why it works

The villages get most of their drinking water from the *talab*. The village works as one unit and mobilization of the community is important to sustain the water structure. The Water Committee, the *Jal Sabha*, plays an important role. It is a village level forum where people in the village meet, discuss problems, seek solutions and assert priorities for the local water supply. The *Jal Sabha* also develops and implements projects of water and natural resource development in the village. For example, one contribution can be to enlarge the *talab* or initiatives to change the use of the structure.

Every year before the monsoon they have a joint a cleaning of the catchment area, where the area is cleaned from plastics, defecation and invasive species. Cleaning of the catchment area is a part of a religious manifestation; a clean catchment area pleases the gods and there is usually a temple next to the *talab* for praying. This was brought up as a motivation to maintain the *talab*. In one village there was a women working with collecting open defecation as the livestock was drinking from the *talab.* To prevent people from walking or in other ways degrade the catchment area, are reasons to why they are kept tidy according to the villages.

The government provides the catchment area, and the area is earmarked solely for this purpose. The villages were aware of that they play an active role in the management, but they argued that the knowledge that the catchment area is legally protected against settlement contributed to security. However, they wanted the government to take on a bigger role than today.

Economic incitements were seen as important. As the *talabs* have water all year round other villages are entitled to purchase the surplus. The money goes in to a water fund. The money is used solely for capacity enhancement of the village water structures. Pricing of the water is one of the responsibilities of the *Jal Sabha* as well as allocation for construction work of the structures. The villages were proud over the fact that they were earning money on their RWH structures.

The relationship with JBF provides technical expertise and most of all economic funding for enhancing work or for building new RWH structures. JBF pays 70% of the costs and the village 30%. The households in the village raise the 30% and this was brought up as the reason why there is joint responsibility in the village.

The *tankas* can be refilled by water collected from the *talab* or by roof top rainwater harvesting. Not all households have tankas as they are privately financed. The villages said that they provided a safety at household level, as the water in the *tankas* is cleaner and easier managed. The women who had tankas did not have to walk everyday to the *talab* to collect water, which gave them more time to rest.

Regarding the physical part the villages argued that the optimal shape for a *talab* is oval shape with a deepening in the middle, this was also the original shape before the capacity enhancement.

3.3.2 Future perspectives

The villages had observed that climate change was already happening. The argument they brought forward was that the start of the monsoon, which normally is in July, has now been postponed about two weeks. All of the people I talked to testified of a warmer climate and more erratic rainfall since the past decade. The biggest concern was yet not the survival of the *talabs* and *tankas*, but the climate change's effect on agriculture as all agriculture is rain fed. The yields were already badly affected and further changes would prevent planning of sowing and harvest, which is crucial for forth living in the area.

The increased water demand coming from increasing population and consequences of climate change was not seen as a big problem, even though there were discussions on some safety measures to increase the water security. As last years rains were scanty, none of the villages had much water. But one village, yet decreasing water tables, was anyhow selling some water to nearby villages with less water as they emphasized the act of sharing. One of the most important ones that were emphasized was the separation of livestock and human drinking source to uphold a good water quality even in a warmer climate as today the cattle defecate in the *talab.* Only one village had two separated *talabs* for humans and cattle. This can be done by creating a smaller pond connected to the bigger *talab* through a small canal for the overflow water.

Another measure mentioned was the capacity enhancement of the *talab.* The villages had already used all the possible surface area for their *talab*, but were discussing the possibilities of making it deeper, but not too deep, as the rocky ground would allow the water to percolate faster. The deepening should be done during the dry period, before the monsoon. The established relationship with JBF was pointed out as a factor for the structures survival. Even though the villages are self-sufficient when it comes to water supply, JBF provides support and expertise.

3.4 Findings from expert interviews

This section is categorized in two parts relating to my research questions. The first part, 3.4.1, focuses on the current system and how and why it works where as the second part, 3.4.2, focuses on if and why the existing systems will be able to handle future climate change.

3.4.1 How and why it works

The experts argued that community involvement should be emphasized at every step of the process of either creating a RWH system or enhancing existing ones as it gives a sense of ownership. As the village people pay 30% of the total cost, the sense of ownership is secured.
Each system is designed based on the given physical conditions, and is therefore site specific. The catchment area should be kept clean and invasive species removed. The most common one of the invasive species is the *Prosopis juliflora*. It is a thorny, sturdy shrub, which is difficult to remove due to its ability to regenerate from its roots. It has a large water demand that allows it to overtake native plants. The livestock, if consuming large quantities, may become poisoned.

According to the experts, much is known about favourable factors for a well functioning catchment area. Before the implementations or enhancements of structures, measurements are taken and the site assessments are made. As there are high levels of fluoride in the ground, soil tests are used to assess the future water quality. A test pit is dug and filled with water to reveal the soil conditions on the site. Over the years, the systems are continuously evaluated.

The systems featured in this study have a catchment area with a mild slope, consisting of a few shrubs to maintain the soil moisture. According to the experts these are favourable conditions. A good catchment should be aware of the capacity needed, the number of rainy days and the amount of rain. It is assumed that evaporation losses will be 75% in the catchment area, so the effective water supply to the *talab* is 25% of the rainfall. This quote is by one of the experts at JBF:

> A good catchment should be aware of the capacity needed, the number of rainy days and the amount of rain.

A lot of emphasize was put on the *beras*, recharge wells that recharged by percolated water from the *talab*. Even if the *talab* dries out, the well will still have water as it is recharged from the percolated water. The *talab* has a strong vertical boundary to handle pressure from the water, which is also important.

When it comes to the *tankas* the experts highlight that they are important because the water is cleaner and as they are covered the water does not evaporate. The first rain of the monsoon is used to flush away silt and dust. According to the experts, the shape and the material is important, the *tanka* has to be completely round. Today, the material used is cement, which is somewhat sensitive to heat. Therefore the water should cover 50% of the total volume as this allows the water to evaporate, which creates a humid inside that prevents the cement from cracking.

The pricing system is a way for the village to raise funds for the maintenance of the *talab*. The fact that more money can be earned if the prospects are maximized is an important incentive. Here, the *Jal Sabha*, plays an important role.

What was also brought up was the importance of sanitation projects. As people in the villages become more aware of the importance of personal hygiene and toilets, the overall environment for the RWH systems improves. That is why JBF also focuses on sanitation projects and building toilets.

3.4.2. Future perspectives

Overall, there was a great confidence that the systems would last for a long period of time; with the motivation that they already had survived the recent climate changes of increased temperature and rainfall irregularity. A lot is known of the best physical factors and as experience is gained over the years, the better it gets. The measurements taken are by the experts interpreted as sufficient from a water supply perspective in the future, including a possible population increase as well as increasing runoff and evaporation. Though, they argued that further technical research is needed on how to reduce evaporation and seepage. This quote is by Mr. Thanvi, technical engineer:

> Some structures that we built five or ten years ago are still working and are serving their purpose. Even if we have had a temperature rise during this time, they have worked. So I believe that they will work even in 50 years time. But we need maintenance of the structures, for example that you do a cleaning of the catchment every three to five years.

Sustainable water supply allows the population to grow. Due to population increase, assessment of to what extent the *talab* can be expanded is needed. If there is no scope for extension, focus should be put on water pricing, which is a kind of water management. The experts argued that in the future, people would have to be even more encouraged to follow the maintenance rituals of the RWH systems. The quality of the catchment area can be improved by digging canals, to direct the water down to the *talab*. If there is no outlet for overflow water, this should also be prioritized.

A future perspective of the *tankas* was also part of the discussions. As the water inside is not evaporating to such a fast extent as in the talabs, they conserve the water better. Also, the quality is better. For the villagers that have a well functioning system round the *talabs*, the next step is to focus on the *tankas* and ways to harvest rainwater into *tankas*. But as *tankas* mostly are privately owned, focus should always be on the *talabs* to begin with. The experts argued that the most important thing is water availability and that the villages become self-sustained, water quality is regarded as the next step in the water practise. The experts thought that JBF was an important component even if the villages they had worked with became self-sustained.

3.5 Analyses

When presenting my results regarding future consequences of climate change, there was a prevailing consensus amongst villages and experts that the RWH systems were resilient and would survive the forthcoming changes. Hence, the adaptation capacity was seen as sufficient. The consensus was that when there is sustainable water supply embodied in both a physical, social, institutional and economic part regarding the RWH systems there is an assurance that the water supply will be sufficient as long as the different parts interact. Overall, the view on many perspectives was the same as well as the awareness of climate change and necessary adaptation measures.

Both parts mentioned the economic factor, which correlates with the analytical framework. Without funding from JBF, the villages would not have the ability to financially implement any construction work and without economic incentives the self-sustainability would not be feasible. Both villages and experts also highlighted the water committee, *Jal Sabha*, as key unit manager of the water structure. A sense of ownership is hereby fulfilled and financial capital provides a big security measure.

Even though the government is the protector of the catchment area, the villages were wishing for more acknowledgements from the government. Both the experts and the villages raised the importance of JBF, as an intergovernmental support provider.

The experts were project oriented, discussing physical parameters and technical experiences gained whereas the villages exhibited religious motivations for the sustainability of the systems.

The biggest concern presented in the interviews regarded the crop production; both experts and villages highlighted this. According to the results in 3.2, evapotranspiration may increase with around 20 % by the end of the century; this affects the soil and plant moisture negatively which brings legitimacy for their worry.

The projected precipitation changes are expressed in more heavy rainfalls. As for precipitation, the result of the interviews correlated with the result in 3.2; characteristics of daily rainfall have already been undergoing changes during recent years and the frequency and intensity of heavy rainfall events have increased.

Heavy rainfall produces more silt, but the villages felt confident in the handling of an increasing silt level, both for the *talabs* and the *tankas*.

The key factors for resilient RWH structures according to my result are physical, economic, social, technical and institutional. They are pictured in figure 8.

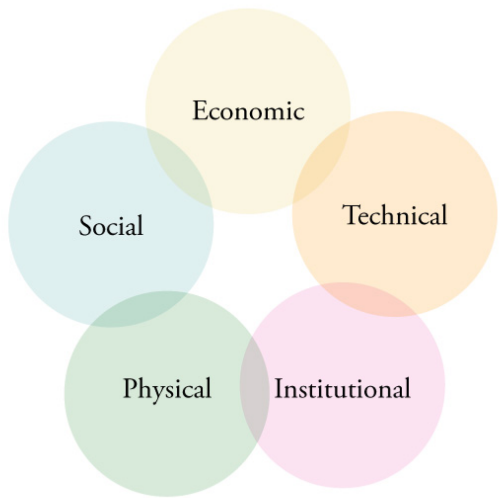

Figure 8. The intertwined factors affecting the resilience of RWH structures are economic, technical, social, physical and institutional.

4. Discussion

To secure sustainable water supply in the Thar Desert and increasing the resilience to impacts of climate change, it is vital to study rainwater-harvesting systems and potential of adapting factors as rainwater is the main water source. The aim of my thesis was to examine whether there will be any influence on the existing rainwater harvesting structures in the future due to climate change and examining the adaptation factors needed to increase the resilience of the systems.

Starting this research, I was mostly focusing on the physical parameters of an ecological resilient rainwater harvesting structure. However, progressing the research I found that the resilience of the RWH structures lies upon several intertwined factors and having sustainable water supply is equivalent to having a resilient rainwater harvesting structure.

In this section I will elaborate a discussion based on my results. When I write about resilient structures, I involve the adaption factors playing a part for resilience, as stated in the analytical framework. Even though previous research suggests that RWH practices improve resilience by enhancing socio-economic as well as ecological adaptability (Pandey *et al.*, 2003, p.56), given the circumstances of this study, where only a small number of interviews were executed, it is impossible to give a definite answer to whether the rainwater harvesting systems are resilient or not. However, adaptation to climate change is closely linked to water (Vohland & Barry, 2009, p.124). Focusing on villages that have sustainable water supply today and ask these villages if they think it will be sustainable in the future in relation to future climate change, has allowed me to find that the key factors are social, institutional, economic, technical and physical. In the following text I will discuss these factors in relation to climate change adaptation and the mitigation of the adverse effects in the Thar Desert.

4.1 Social factors

The analytical framework states that social factors are recognized as a key to success to enhance socio-ecological resilience. The villages were aware that their knowledge played a big role. They villages are familiar with their surroundings and used local experiences to i.e. discuss the optimal shape of the *talab*. One of the traditional maintenance activities that stretch far back in time is the cleaning of the catchment area, which the whole village do together. To clean it from bushes, plastics and defecation makes the waters way to the pond smoother and prevents contamination.

Indigenous knowledge has been recognized and accepted as a vital knowledge source. There is a need for local knowledge when it comes to construct and evaluate RWH systems as farmers hold a substantial amount of knowledge on RWH and identification of potential new sites (Mbilinyi *et al.*, 2005, p. 798; Cutter *et al.*, 2012, p.293; Björklund *et al.*, 2009, p.22). The knowledge base of the user communities should be utilized as they have first-hand knowledge and experience that no "experts" can match, according to Agarwal & Narain (2008, p.320).

According to the analytical framework I interpret religious manifestation as a social factor. The action of pleasing gods by cleaning catchment and actively working for sustainable water management should therefore be further encouraged to enhance the resilience of the RWH structures. Kumar & Kandpal (2003, p. 7) also recognizes religion as one key factor for "success".

Interventions related to climate change responses should aim to combine goals of sustainable development, climate change adaptation, and climate change mitigation into "win-win" approaches that highlight overlaps between these goals (Denton *et al.*, 2014, p.10). This is also a part of the IWRM practice. JBF do trainings in sanitation and they build toilets along with enhancement work on RWH structures as the social benefits gained in form of better health and sanitation brings awareness around these issues. It is also a matter of equity. As for the women, they do no longer have to walk long distances to fetch water, especially those who had a household *tanka*. It was only the women who brought up the time saving factor. Social equity can therefore be achieved as women get more social capital by saving time.

4.2 Institutional factors

The villages recognized JBF as one important institutional factor, serving as a link between sciences, implementation and government. More decentralized structures are needed for sustainable development (Falkenmark *et al.*, 2001). If for some reason the institutional support gets limited, there is a risk that the adaptive measurements taken dissolve. This involves the loss of expertise. Today, only one person at JBF provides most technical knowledge and this person is therefore a crucial link between today and future CCA. The water committee, *Jal Sabha,* is one crucial link for sustainable water supply. The *Jal Sabha* works as socio-institutional factor as it establish contact with other water committees in the area, discusses problems and solutions. At the same time, it is depended on a good social culture within the committee. The water committee is therefore essential for upholding resilience to climate change.

The villages had their catchment area given to them by the government and the catchment area was earmarked for this sole purpose. This was seen as an important factor, as it prevented settlement and contamination in the catchment area. There was a shared responsibility, which pleased the village people. However, the villages wanted more acknowledgements from the government. Governments at all levels do play an important role in advancing adaptation and enhancing adaptive capacity and resilience.
Noble *et al.* (2014, p. 3) argue that:

> Local institutions, including local governments, NGOs and civil society organizations, are among the key actors in adaptation, but are often limited by lack of resources and capacity and by continuing difficulties in gaining national government or international support, especially in developing countries.

Institutions, informal and formal, provide an enabling environment for implementing adaptation actions. Overall, there is a need for effective institutions to identify, develop, and pursue climate-resilient adaptation paths (Noble *et al.*, 2014, p. 9). The institutional factor is even more important in common pool property, as RWH structures are. This is because they due to climate change effects both the ecosystem and the resources that support the livelihoods of those communities dependent on them (Denton *et al.*, 2014, p.22). Based on the results, the government should take more concrete action, which will be discussed in the next section.

4.3 Economic factors

Socio-economic preconditions are considered to be at least as important as specific improvements of the RWH practices (Vohland & Barry, 2009, p.121). Economic factors for the villages include the fact that they through having water all year round can sell the surplus to near-by villages. Water is hereby recognized as an economic good, which can be traded, as stated in the analytical framework. Within this study there is thus no scope to evaluate the ethics on water pricing.

Yet, a sense of ownership is achieved. Private units, which the *Jal Sabha* and the village is when managing their water resources will according to the IPCC in the report "Climate Change 2014: Impacts, Adaptation, and Vulnerability" seek to protect and enhance their production systems by pursuing adaptation related opportunities. These objectives will help expand adaptation activities (Noble *et al*, 2014, p.3). The villages were very keen on embracing the possible adaptation measures, much due to the economical value of the water.

Experience show that successfully carried out projects usually are initiated by an NGO or individual with more capital and Falkenmark *et al.* (2001), which is coherent with my results. As JBF is an NGO, their funding is dependent on donations. As the government raises the need of understanding and adapting to climate change in both the NAPCC and the Regional Climate Action Plan for Rajasthan, and doing so by focusing on traditional rainwater harvesting structures, enhancing resilience could be done by more funding from the government so that all villages in the Thar Desert could achieve sustainable water supply in the short and long term. Though, this brings up the issue of the economic incentive as today the villages earn money by selling water to nearby villages without all year round water, if all villages had sustainable drinking water this incentive would get lost.

One of the most challenging aspects of resilience is that it exists in distinctive local contexts. Evidence is emerging that rainwater harvesting, if used inappropriately can lead to inequitable access to water resources and hence to unreliable drinking water supplies (Batchelor *et al.*, 2002). The villages in my study were all self-sufficient but this did not imply that the surrounding villages were. Denton *et al.* (2014, p. 12) argue that resilience cannot be achieved in a few privileged places if it is not achieved in other connected places. As one village was selling its water even though they hardly had enough to survive the dry period, this can be seen as an act of collective thinking, ranked above economic motivation that could increase the overall resilience on a bigger scale than just regarding separate villages.

4.4 Physical and technical factors

For drinking water supply and good quality physical factors are vital. Strong boundaries, an effective slope and other measures including soil and water chemistry to reduce evaporation and contamination were seen as keys to success. When calculating on catchment size, it is assumed that evaporation losses will be 75% in the catchment area, so the effective water supply to the *talab* is 25% of the rainfall. These calculations were seen as efficient even if the ET rate would increase due to temperature rise. An undulating slope makes the water travel over a longer distance, which gives it more time to percolate down, thus decreasing the runoff. A gentle and continuous slope will produce a better runoff (Agarwal & Narain, 2008, p. 137). Soil physical characteristics are important in arid ecosystems to extend the runoff area so that sufficient water amounts collects at RWH structures (Vohland & Barry, 2014, p.121). In situ RWH practices have an overall positive effect on landscape functions; hydrologic improvements concern the recharge of aquifers and increase in soil water (Vohland & Barry, 2009, p.124). The experts highlighted that technical expertise was important and the villages also discussed this topic, showing awareness and knowledge about their physical surroundings.

Narain (2005, p.23) argue that the traditional systems of water harvesting prevalent in the region are cost-effective and therefore should be improved and utilized on a large scale to meet the required drinking needs. This was highlighted in the interviews as a way to enhance the resilience of the systems. Scopes for extensions were discussed amongst experts and villages. However, little is known about the effects of up scaling RWH structures. Noble *et al.* (2014, p.28) discuss that the there are risk involved with up scaling without fully regarding interactions and feedback between systems. Precautions are therefore essential.

4.5 Climate change

It is important to highlight that climate change is already happening. The projected precipitation changes are expressed in more heavy showers and irregular rainfall. As for precipitation, the result of the interviews correlated with the result of the literature review; characteristics of daily rainfall have already been undergoing changes during recent years and the frequency and intensity of heavy rainfall events have increased. For example, Rajasthan have twice received their annual rainfall in only two days. The coherence increases the validity of my study.

To be considered when studying climate scenarios is that we do not know how much GHG and other anthropogenic forcing factors there will be in the near- or long- term future. Though we can say with almost 100% certainty that there will be an increase in temperature (Chartuvedi *et al.*, 2012, p.797).

The literature review on future rainfall scenarios indicates that there will likely be an increase in heavy rainfall in the future. According to my results the resilience is high when it comes to weather events, with motivation that if they have sustainable water supply now, they will have so tomorrow. According to the regional action plan for Rajasthan, TERI (2011), there are not many vulnerability risk mapping and climate modeling analysis studies available for the Thar Desert. Especially rainfall, temperature and wind extremes should be further in-depth studied in detail to be able to advance scenario projections. Even though the villages and experts were confident that the systems as they are working now would endure climate change adaptation measures should consider climate scenarios. If the drought frequency increases, it is important to be able to collect water for two years ahead during the monsoon.

There will most likely be a temperature increase with the result of increased evapotranspiration. Mean winter temperature will increase relatively more than mean summer temperature. Evapotranspiration can increase as much as 22% during the winter. These specific figures were not discussed during the interviews; rather a broader perspective was used including increased evapotranspiration, of which all were familiar. The answer to increased evaporation was to enhance the *talabs* and putting a higher price on the water, making people use less. Covering the water, as in the example of the *tankas*, can reduce the evaporation rate.

Due to climate change, precipitation during the monsoon is likely to show a slight increase in the short-term perspective. However, in the long term there will be less rainy days and more heavy rainfalls. Extreme precipitation events create more runoff, and sediments will go into the *talabs*. Sediments seem to be a minor problem, during the interviews it was not highlighted as a problem at all. The drought occurrence will increase and this may increase the in situ water need by as much as 13-47% percent during winter and 12-33% in summer. Adding population and livestock increase, the pressure on the available water will be massive. Increased population was not seen as a challenge, but rather a motivation for enhancement of the structures. I want to emphasize that adding climate scenarios gives a clearer and broader view of future challenges, as only regarding on population increase may be insufficient if emissions of GHG are not cut.

4.6 How reliable and generalizable are the results from this study

Regarding the methodology of the research, it is evident that my results would have a higher validity if more villages and experts were included. The influence I had on the interviews, in terms of asking leading questions and controlling the interviews, do have an impact on the results. Also, my understanding of the problem, the situation, affects my interpretations of the results and also the discussions. My understanding comes from the literature I read but also from my experience from the field. How I choose to categorize my data depends on my understanding. What did surprise me was that the villages and the experts were in agreement on a lot of issues. This is likely due to the close relationship between JBF and the villages. Regarding the future, the experts were more planning ahead, discussing physical parameters that could be improved. The people in the villages were not as much planning ahead, due to cultural reasons. Future perspectives were therefore harder to discuss in the villages. The themes for the interviews were slightly different between villages and experts, a lot due to the fact that I needed an interpreter in the villages, so their answers are all second hand information. The fact that an interpreter was needed complicated my work. To compensate, I could have done more interviews, as this would have increased the validity of the results. This was however not possible as I was advised to the occasions when there was a driver available.

My study would have been more reliable if I had included own measurements of physical or chemical character. Though this was seen as too vast of a project for a bachelor thesis.

I consider my methodology sufficient to elaborate on my research questions as I have managed to put climate change in correlation to adaptation measures. It could however have been enhanced by a bigger collection of empirical material. The aim of conducting interviews in a triangular model regarding the RWH systems and their resilience was to combine the “top-down” perspective with the “bottom-up” perspective to increase the reliability of my results. As JBF works in close collaboration with the villages there is a risk of my results not fulfilling that purpose.

4.7 From resilience into the future

For rainwater harvesting systems, the crucial task is to improve the ability to co-manage water supply and ecosystems so that overall resilience is achieved. To achieve resilience, there is a need to ensure that social, economic, technical and institutional factors are able to interact with environmental factors to support long-term resilient systems. It seems like, building a resilient trans-disciplinary system is the key to meet and adapt to future climate change. For the case of my study, the participatory aspect is there and it agrees with the IWRM concept saying that water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels. The interviews revealed that there is no single approach to adaptation planning because of the diverse, complex and context dependent nature of CCA. This is in line with adaptation paradigms saying that that simple 'cure-all" pathways therefore no longer should be promoted (GWSP, 2011 p.7; Mimura *et al.*, 2014, p.3). Provision of water and its management must also be applied in combination with other processes shaping societies, economies and the environment (Mimura *et al.*, 2014, p.3; GWSP, 2011, p.7).

The aim of my thesis was to examine whether the there will be any influence on the existing rainwater harvesting structures in the future due to climate change and examining the adaptation factors needed to increase the resilience of the systems. The villages and the experts pointed out that as the system was working well now, it was resilient to climate change due to social, institutional, economic, physical and technical factors. To interpret the results I have used the prevailing paradigm within adaptation and resilience research to understand what challenges and what factors that co-exist for climate change adaptation. In a global sense, Denton *et al.* (2014, p.23) recognize that further research is needed on issues of social values, climate justice, equity, participation and how they intersect with adaptation interventions and sustainable development policy in different regional and sociopolitical contexts.

The main concern lifted from the results regarded the survival of the crops, as all crops are rain fed, no irrigation is used. However, research shows that the viability of the RWH structures is in communication with the agricultural sector and crop failure due to dry spells can be reduced as RWH trap sediments and enhances nutrient availability in their near surrounding (Vohland & Barry, 2009, p.122). In dry land ecosystems water is the major limiting factor in agricultural production systems, and the performance of landscape relies heavily on the availability of water (Vohland & Barry, 2009, p.120). Research is therefore needed on how in situ rainwater harvesting systems can be used as an adaption tool for CCA adaptation regarding agriculture. Here, knowledge regarding rainwater-harvesting systems can serve as a starting point for unlocking the potential of agricultural development in arid areas.

One important implication is that greenhouse gas mitigation can reduce the magnitude and rate of future climate change (Mimura *et al.*, 2014, p.3). In the short term, societies will have to adapt to changes in the climate that are linked to past emissions, and both incremental and transformative adaptation may thus be of importance. Even though, adaptation is central, global policies have the responsibility to mitigate the extent of CCA and resilience integration (Denton *et al.*, 2014, p. 11). Even if severe mitigation measures are put in place on a global level, the effects may take several decades to manifest, while adaptation strategies have immediate effect. Proper and long-term management of water based in interdisciplinary adaptation dynamics will therefore influence sustainable development in all economic, social and environmental dimensions.

Relevance to environmental science

Global warming is one of the major threats to human forth living on this planet. Studies on global warming and its effect on climatic change are being pursued vigorously as a multi-disciplinary problem (Denton et al 2014, p.11). Climate change calls for new approaches that take into account complex interactions between climate social and ecological systems. Climate-resilient systems are development paths that combine adaptation and mitigation. They can be seen as continually evolving processes for managing change within complex systems, and thus generating resilience. Adaptation is closely linked to water. Climate change will bring constraints in ensuring sustainable water supply, especially in arid areas where the vulnerability is high and people already are living with constant water scarcity. Rainwater harvesting is globally recognized as a key to adapt to climate change and release the pressure on groundwater tables. My study has elaborated on the crucial factors included in adapting to climate change by creating resilient water systems. Enhancing consensus regarding resilience paths and understanding the effects of climate change is central because it creates strong incentives for global policy makers to reduce GHG emissions. It also provides a stable ground for further exploration of possible adaptation measures such as up scaling and implementation of the same practices elsewhere. It encourages actions to assure that effective institutions and strategies will be identified, implemented, and sustained as an integrated part of achieving sustainable development and adapting to climate change, which is predominant in many environmental discourses.

6. Conclusion

Global warming is one of the major threats to humans and ecosystems, especially in already fragile areas. If green house gas emissions continue at the present rate, the temperatures in the Thar Desert will likely to increase by 2.3 to 4.0 °C in the long term future; rainfall will get more erratic and the frequency of heavy showers will increase. There is also increasing risk of drought. The consequences of climate change will approximately increase the in situ water need by 12-23% in summer, and by 13-47% during winter in the Thar Desert. This threatens the survival of the rainwater harvesting systems that today provides some villages with all year around drinking water. Where earlier management focused on the aspiration to control change there is now a move towards a perspective that strives for sustaining and improving the capacity of both human and natural systems to cope with and adapt to the change. Objectives for water security involve protecting and living with the water cycle by relying on adaptive factors to create resilient water structures. Resilience of the RWH structures lies upon several intertwined factors and having sustainable water supply is equivalent to having a resilient rainwater harvesting structure. Hence, building a resilient trans-disciplinary system is the key to meet and adapt to climate change. To broader the understanding it is vital to add climate scenarios in adaptation. There is no single approach to adaptation planning because of the diverse, complex and context dependent nature of climate change adaptation. This study found that the key factors for bridging resilience into the future in this case are of social, institutional, economic, technical and physical character. Understanding the factors essential for a resilient RWH structures and the links between them is vital to precede global work and consensus regarding climate change adaptation. Climate change is already affecting the Thar Desert, future research is especially needed on how to unlock the potential for rain-fed agriculture in a changing climate.

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