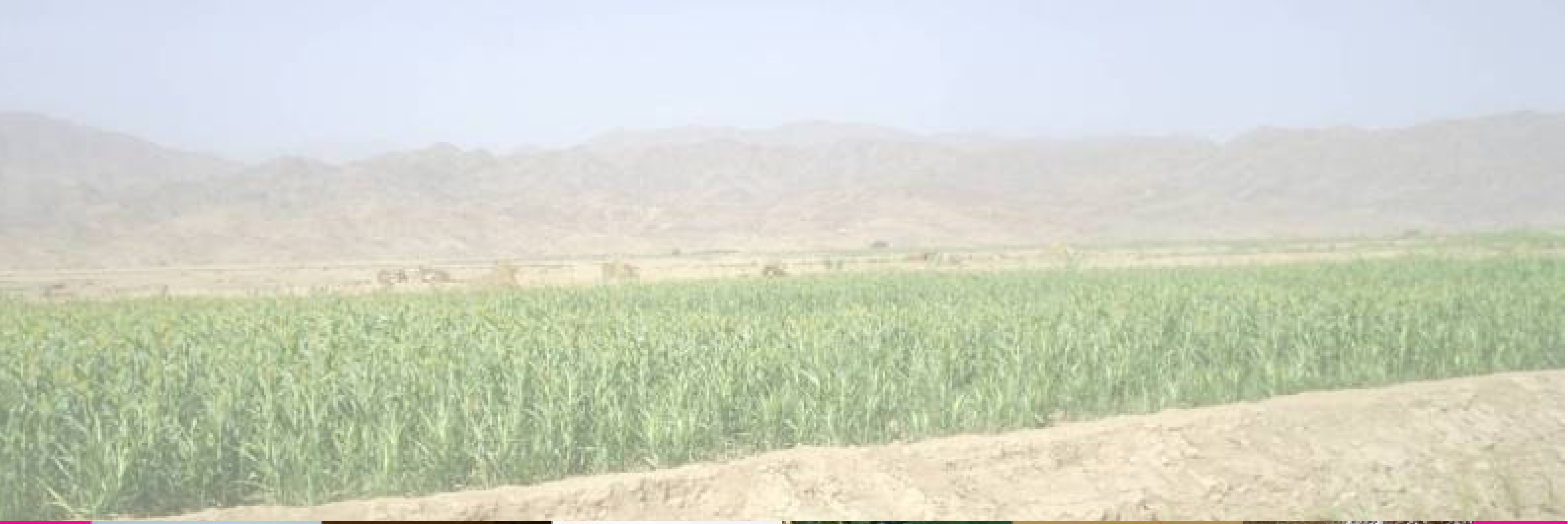


Spate Irrigation, Livelihood Improvement and Adaptation to Climate Variability and Change

IFAD

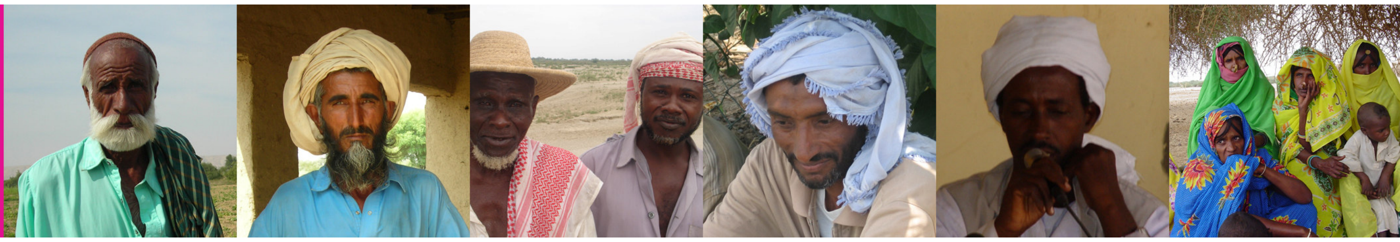
META

UNESCO-IHE
Institute for Water Education

This paper was commissioned by IFAD and prepared by Frank van Steenbergen, Olaf Verheijen, Sanne van Aarst and Abraham Mehari Haile.

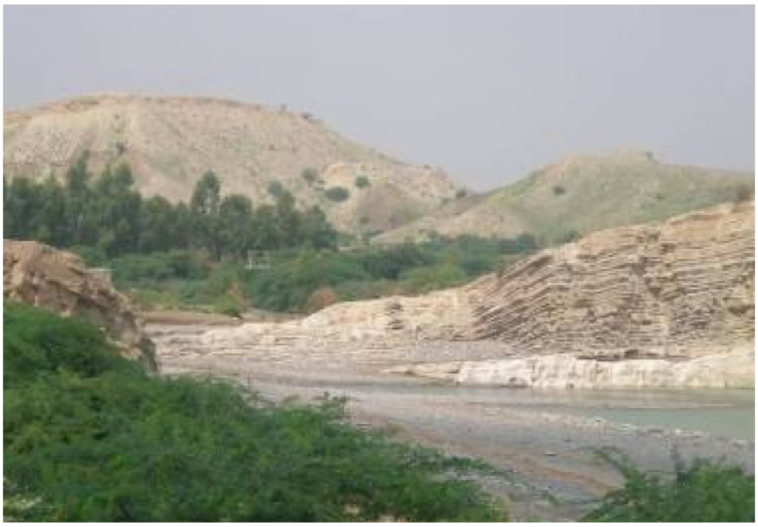
TABLE OF CONTENTS

LIST OF TABLES AND FIGURES



1. Introduction

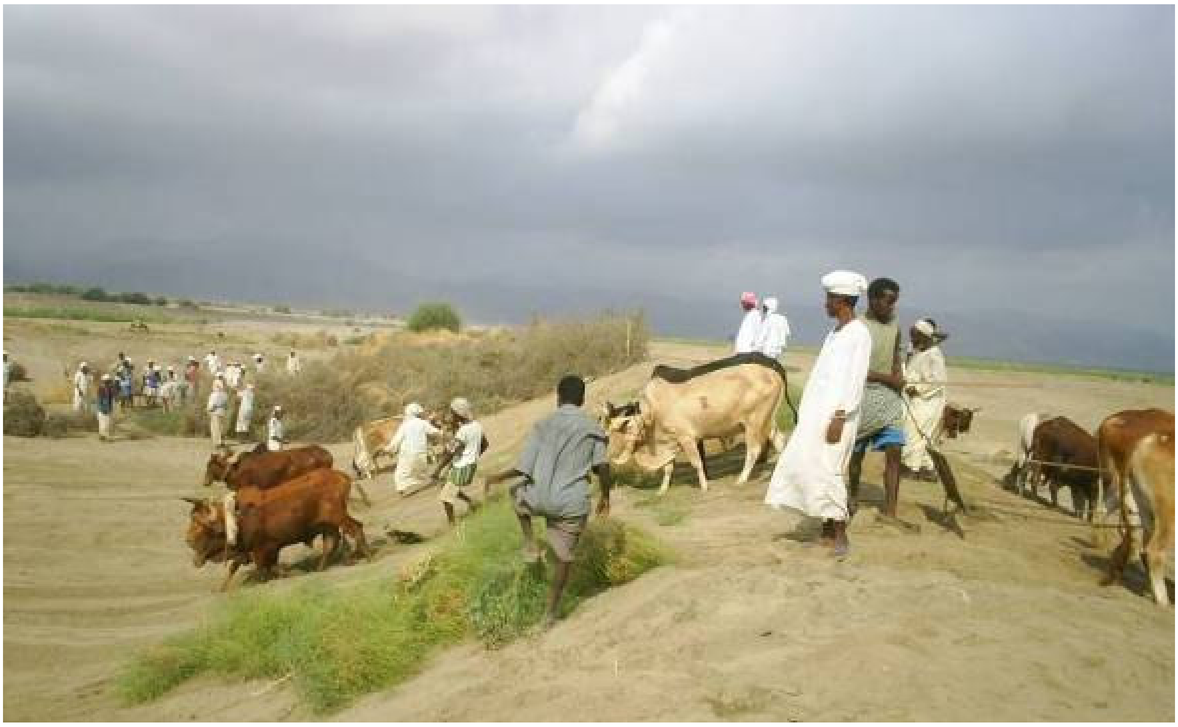
Spate irrigation is a type of water management, unique to arid regions bordering highlands. It is a largely neglected and forgotten form of resource management, in spite of its potential to contribute to poverty alleviation, adaptation to climate change and local food security. Spate irrigation can be found in West Asia (Pakistan, Iran, Afghanistan), the Middle East (Yemen, Saudi Arabia), North Africa (Morocco, Algeria, Tunesia) and the Horn of Africa (Ethiopia, Eritrea, Sudan, Somalia) and more sporadically in other parts of Africa, South America and Central Asia.



Pakistan, Daraban Zam, Spate Irrigation is A Type of Water Management Unique to Arid Regions Bordering Highlands

Floods originate from episodic rainfall in macro-catchments. They are diverted from ephemeral rivers and spread over agricultural land. After the land is inundated crops are sown, sometimes immediately, but often the moisture is stored in the soil profile and used later. The spate irrigation systems support low value farming systems, usually cereals (sorghum, millet, wheat, barley), oilseeds (mustard, castor, rapeseed), pulses (chickpea, clusterbean), but also cotton, cucurbits, tomatoes and other vegetables. Besides providing irrigation, spates recharge shallow aquifers (especially in river beds), they fill (cattle) ponds and in some areas are used to spread water for pasture or forest land.

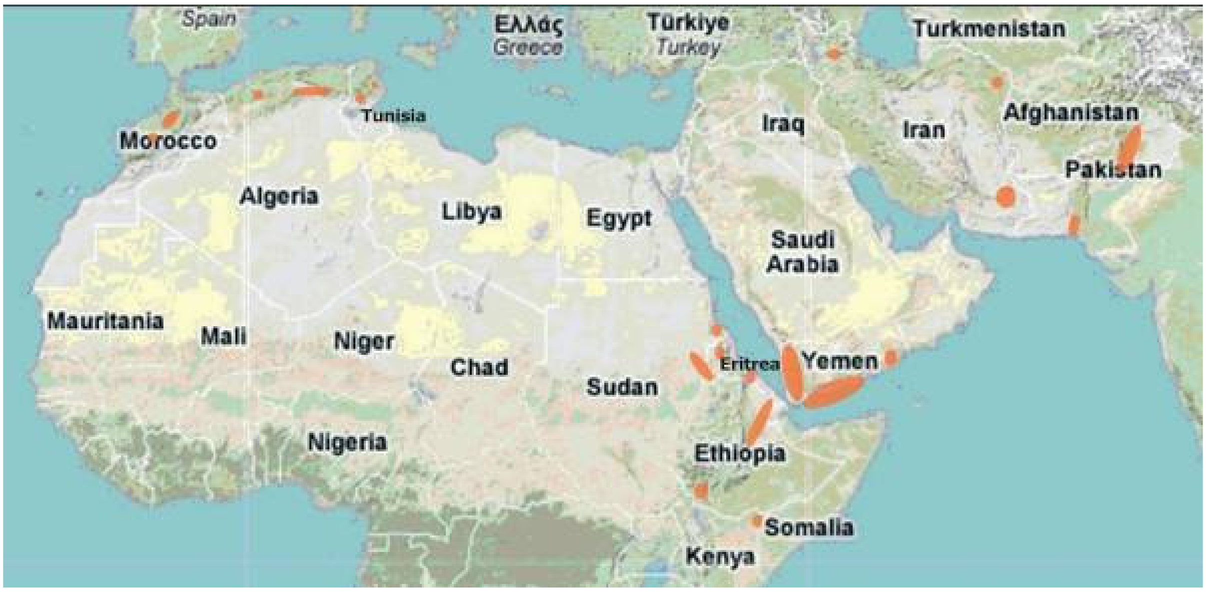
These water management systems are among the most spectacular and complicated social organizations around. They require the local construction of diversion structures that are able to withstand floods and guide flash water over large areas, dissipating its erosive power. This requires strong local cooperation and agreement on how to distribute a common good that is unpredictable and uneven.



Eritrea, Sheeb - Spate Management Arrangement Are Among the Most Spectacular Local Organization

The area under spate irrigation globally is substantial. It forms one of the largest, but also least known and most neglected water harvesting systems around. The most accurate estimate of the area under spate irrigation brings it close to at least 2,600,000 ha, but the nature of spate irrigation is such that the acreage varies from year to year depending on rainfall. A map and an overview of the main spate irrigation areas is given in figure 1 and table 1 respectively. There are also unquantified areas under spate irrigation not presented in figure 1, namely in Afghanistan, Saudi Arabia, Tanzania and Kenya. In addition to these there are largely undocumented water resource systems in Central Asia, China/ Mongolia and Latin America, whereby first floods are used to fertilize and soften-up the land, to be followed by semi-perennial irrigation supplies.

Figure 1 Main Spate Irrigation Areas (represented in orange)



Country	Year	Area under Spate Irrigation in Hectares	Source
Algeria	2008	53,000	Anonymous
Eritrea	2004	16,000	Haile (2005)
Ethiopia	2007	140,000	Alemehayu (2008)
Iran	2008	450,000 – 800,000	Kowsar (2008)
Morocco	2008	79,000	Oudra (2008)
Pakistan	1999	640,000 – 1,280,000	NESPAK (2001), Ahmed (2008)
Somalia	1984	150,000	FAO Aquastat (www.fao.org)
Sudan	2007	132,000	UNEP (2007)
Tunisia	1991	30,000	FAO Aquastat (www.fao.org)
Yemen, Rep. of	1999	117,000	World Bank (1999)
Mongolia	1993	27,000	FAO Aquastat (www.fao.org)
Kazakhstan	1993	1,105,000[1]	FAO Aquastat (www.fao.org)
Kyrgyzstan	1994	0	FAO Aquastat (www.fao.org)
Tajikistan	2002	0	FAO Aquastat (www.fao.org)
Turkmenistan	1994	0	FAO Aquastat (www.fao.org)
Uzbekistan	1996	0	FAO Aquastat (www.fao.org)

Table 1 Estimated Areas under Spate Irrigation

[1] FAO Aquastat shows a substantial area under spate irrigation in Kazachstan and Mongolia. In the cause of the preparation of this work we have tried to get this figure verified, but have not been able to find a second reference.

In North Africa the area under spate irrigation reduced in the last twenty years, as a result of reservoir construction on several of the ephemeral rivers. Conversely, in the Horn of Africa the area under spate irrigation is expanding rapidly, especially in Ethiopia and Eritrea. Population pressure encourages settlement in the lowlands, which have become more habitable as malaria and trypanosomiasis are slowly being brought under control. The largest areas under spate irrigation can be found in Pakistan and Iran. In both countries spate irrigation has been neglected, regardless of the significant areas under spate irrigation and its potential to reduce poverty and contribute to food security. In Pakistan and Iran the focus has been on perennial irrigation.

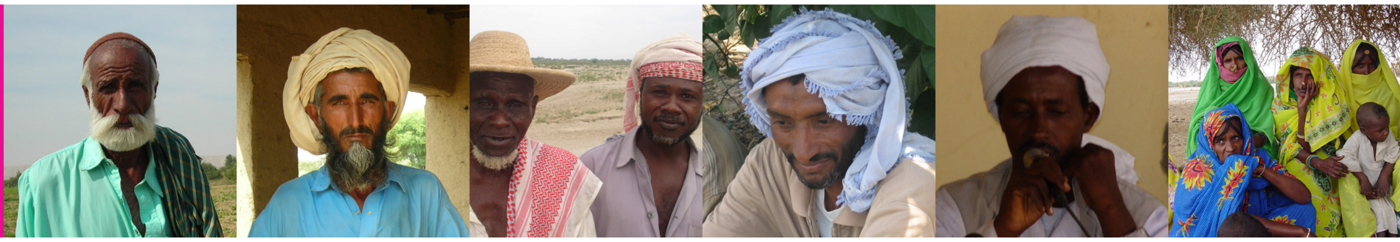

Eritrea - High Production Sorghum - Spate Irrigation Can Significantly Contribute to Local Food Security

The contention of this paper is that spate irrigation is unfortunately neglected, and that improved spate irrigation could significantly contribute to the reduction of rural poverty and enhance adaptability to climate change in some of the most fragile areas on earth. There has been a running argument that in several poor countries, especially in Africa, the reservoir capacity per capita is low. Yet in spate irrigation moisture is stored in the soil profile and in shallow aquifers. This can be done at a much lower cost than storing water in a surface reservoir. Even though spate irrigation is inherently risky, it can potentially contribute significantly to local and regional food security, which in a world of higher food prices and reduced food aid assumes large importance.

In several cases highly productive agricultural systems are sustained by spate irrigation. One example can be found in the Eastern Lowlands of Eritrea, where thanks to a sophisticated system of moisture management, sorghum yields of 3,750 kg/ha are achieved[2]. This is three to six times higher than sorghum yields elsewhere. A second example is the Tihama Plains in Yemen, where the conjunctive use of spate irrigation and groundwater (recharged from spate) sustains the grain basket (and livestock basket) of the country. Similarly, the coastal spate and groundwater systems in Saudi Arabia have the highest water productivity in the entire country. The point to make is that spate irrigation is a complex but not necessarily marginal resource management system.

This paper first describes spate irrigation in the light of climate change adaptation and climate change (section 2). It then discusses the effect of spate irrigation on livelihood improvement and poverty alleviation (section 3). Section 4 provides an overview of experiences with improving spate irrigation. The final section summarizes IFAD's experiences in supporting spate irrigation in Yemen, Tunisia, Eritrea and Sudan, also suggesting a road map for further engagement.

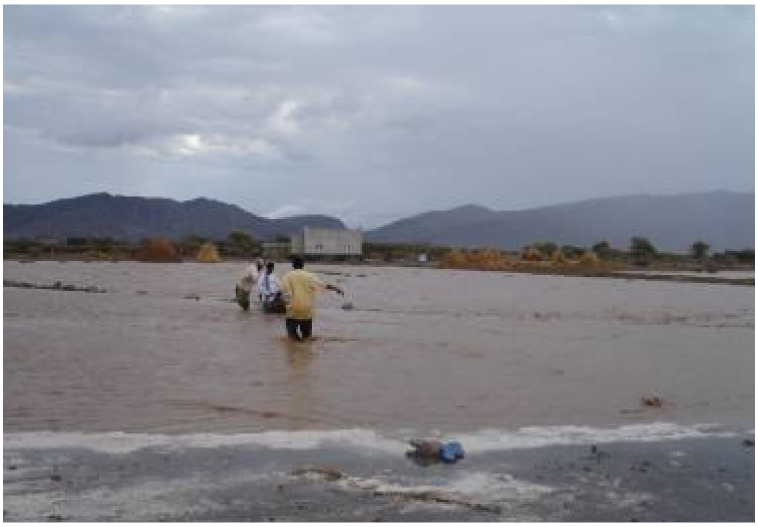
[2] Recent crop cutting put grain yield between 2200 to 8400 kg/ha in Sheeb.



2. Climate Variability and Climate Change

2.1. Adaptation to Climate Variability

Spate irrigation is the quintessential adaptation to climate variability. Spate irrigation depends on the availability of floods, but the number and sequence of floods vary from one year to another. Good years alternate with bad years. A bad year may be caused by a drought or by off-season floods. A bad year may also be triggered by the arrival of a very high flood that takes out diversion structures and makes it impossible to control water. If a large flood enters the command area, it leads to severe damage, destroying flood channels and creating deep gullies. These deep gullies may cause the depletion of soil moisture or simply make it impossible to command a sub-area. On the other hand in a good year, typified by a series of medium-sized floods, the availability of water may exceed the local capacity to prepare land and store moisture.

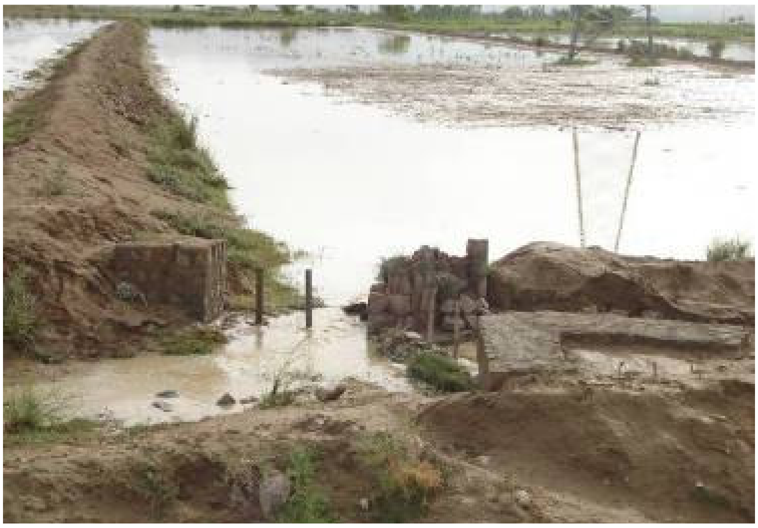


Yemen, Flood in Wadi Siham Spate Irrigation is the Quintessential Adaptation to Climate Variability

Another important characteristic of spate irrigation is that sedimentation is as important as water management. Rivers in spate lift and deposit huge quantities of sediment. As a result there is constant change in bed levels, both in the river system and in the distribution network. This results in frequent changes and adjustments. The severity of sedimentation depends on the sediment load of the ephemeral flows. These sediment loads are related to the rainfall pattern and the geology, morphology and vegetation cover of the catchment. Despite the frequent changes, the mere existence of a functioning spate irrigation system will consolidate an ephemeral river system and prevent it from constant braiding and degradation in extreme weather events. Farmers often actively use the force of the sedimentation and scour processes. They may deepen the head reach of a flood channel in order to attract a larger flood that will further scour out the channel. In other cases farmers may block a flood channel to force the bed level to come up.

In all spate irrigation systems there are mechanisms in place that help adapt to climate variability, both at household level and farming system level. These mechanisms give an indication of the response that may be required in adjusting to climate change as well.

Many households in spate-irrigating communities have developed a range of livelihood strategies in order to cope with the inherent uncertainties of spate-irrigated agriculture, and occasional crop failures. The most common strategy is the diversification of the household economy, whereby poor(er) households in spate-irrigated areas generally depend on multiple sources of income. Livestock keeping is an integral component of livelihood strategies of most households involved in the cultivation of spate-irrigated crops, providing draught power, transport, animal products for home consumption and sale, and dung used as fuel and/or construction material. In general, households in spate-irrigated areas keep oxen, cows, goats, sheep, donkeys and poultry. The number of cattle kept by farmers is often in proportion to the amount of fodder available. The ownership of at least one pair of oxen is often a good indicator of wealth. For many households it is difficult to support a pair of oxen because their farm size is too small to produce sufficient fodder to feed them in years with normal floods. In the Sheeb area in Eritrea, about 30% of the farmers do not own bullocks, whereas in the Yandafero scheme in Ethiopia only one-third of the landowners have one or two oxen. The number of animals owned by an average household varies considerable between and within countries and spate irrigation schemes, ranging from about 7 sheep in Wadi Rima in Yemen to 62 small ruminants in the Toiwar scheme in the Province of Balochistan (Pakistan).



Spate Irrigation is Unfortunately Neglected but Could Contribute to Poverty Alleviation and Climate Change Adaptation

Other strategies adopted by households in spate-irrigated areas to cope with the uncertainties inherent to spate irrigation include:

- Households having different plots of land with high and low probabilities of spate irrigation;
- Saving of surplus grains from one year with crop surplus to bridge the gap to the following year;
- Investment in easily disposable property, such as livestock, in good years with crop surplus to be sold in a lean year;
- Wage labour and off-farm income-generating activities (i.e. handicraft, petty trade, transport);
- Exploitation of locally available natural resources, in particular trees for the sale of timber, fuel wood and charcoal;
- Migration of male household members in search of labour; and
- Borrowing money from relatives, suppliers and/or money lenders.

Many of these mechanisms require integrating spate irrigated areas into the larger economy – to sell of surplus in good years and access alternative income opportunities in lean years.

Traditional mechanisms of solidarity and mutual assistance also exist in several spate-irrigated areas in order to support people in need or during important social events, such as a wedding or funeral. For instance, labour and oxen are mobilised to cultivate the land belonging to widows, sick and handicapped persons, and very poor households. In addition, farmers form mutual self-help groups assist each other during field activities or the construction of a house. In Islamic countries, the payment of *Zakat* either in cash or in kind is another important solidarity mechanism to help the needy in the rural communities.

At farming system level there are also several adaptations to climate variability. The most common mechanisms are:

- Using local varieties, adjusted to the peculiar local conditions of spate systems;
- Crop choice in accordance with the timing of first irrigation;
- Staggered sowing dates to control the outbreaks of pest and/or attacks by birds;
- Intercropping with two or three different crops with different water requirements and harvesting dates, so that at least one crop can be harvested in dry years;
- Low investment in agri-inputs – minimizing the risk of financial losses if the crop fails;
- Using crops as livestock fodder as fall-back in case of crop failure. This is for instance common in Pakistan, where good yields depend on mid-season rainfall, which may not come; and
- Keeping the command area relatively compact. This increases predictability of flood water supplies and with it willingness to adequately prepare land (in particular pre-irrigation ploughing) as well the likelihood of a second irrigation, that may substantially increase crop yields. Several sources suggest that the water productivity of the second irrigation maybe higher than the first one.

Some spate irrigation systems are more susceptible to crop failure than others. Table 2 provides an overview of factors that determine this vulnerability. The most vulnerable systems are those with low rainfall, small catchments, and overstretched command areas, with no opportunities for conjunctive use and deeply incised rivers requiring the construction of relatively large diversion structures. Also remote areas with less opportunity for alternative sources of income, and areas where there is no strong link between livestock keeping and farming, are more prone to severe setbacks in times of prolonged drought.

Highly vulnerable	**Moderately vulnerable**
Low rainfall in catchment (<200 mm), higher variability	Moderate rainfall (>200 mm) in catchment
Small catchment – chance of floods being missed higher	Relatively large catchment – higher probability of at least small number
High maintenance systems – diversion bunds in incised rivers	Low maintenance systems – run off the river systems
No conjunctive use – as groundwater is too deep or saline or not utilized	Conjunctive use of groundwater
Overstretched command area – most areas will have zero or one flood	Compact command areas – large chance of two to three floods
Low link with livestock keeping	Livestock as important complementary source of livelihood
Remote area – less opportunities for alternative incomes	Well-connected area – activities integrated in larger economy

Table 2 Factors Determining Vulnerability in Spate Irrigation Systems

2.2. Climate Change

In most areas there are mechanisms in place that accommodate climate variability and for several areas – with the exception of the most vulnerable spate irrigation systems – these mechanisms contribute to the robustness of spate areas.

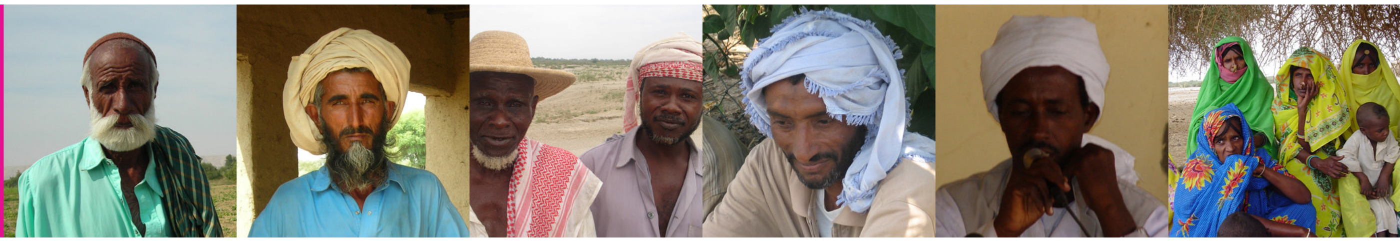
Whereas climate variability is already at present the defining feature, climate change is likely to alter the variability as well as other parameters that affect productivity of spate irrigation systems. In the last five years tremendous effort has gone into predictions of climate change and more progress is expected. Current predictions still have a level of generality or uncertainty, requiring considered interpretation. On the other hand, different predictions and trends observed point in the same direction, where it concerns the incidence and timing of floods, the extent of droughts or the rise in surface temperature.

Annex 1 summarizes the predicted climate changes for major spate irrigated areas, prepared on the basis of the IPCC Fourth Assessment Report and other documents. Climate change will have an impact on spate irrigated areas as well as their catchments. The impact of climate change may take on different forms, such as: more floods, larger floods, later floods, longer droughts and increased risks of pests and diseases. Current climate models are able to predict the changes on a number of these parameters – but at a 'coarse resolution' only, limited essentially to regions and countries, but not yet at the scale of specific areas. Table 3 provides a summarized overview of the likely change for different countries, as well as the impact on the spate systems and the required response.

Not all changes are negative for spate irrigation. A lot depends on the flood regimes. In most cases floods are expected to increase, an important feature of floods being their timing and size. Out of season floods generally make no contribution and in many areas are not diverted and at best, allowed to spread over outwash areas. Similarly large floods are of limited use, but can wreak havoc with local infrastructures unless carefully managed. On the other hand, more frequent moderate floods can increase returns from spate irrigation. An increase in temperature, predicted at 1.5% globally, will also have numerous effects. Temperature changes will have an impact on crop yields and on evapotranspiration. It will trigger the adaptation of new varieties or changes in cropping pattern. There will be also a greater need to optimize moisture conservation techniques.

Possible climate change	Countries	Likely impact	Likely adjustment or effect
More frequent floods	Pakistan Iran Yemen, Rep. of Ethiopia	This effect depends very much on the nature of the catchment and the precipitation pattern. More frequent medium-sized flood	Increased production
Longer drought periods	Sudan Eritrea Ethiopia Morocco Algeria Tunisia	Stress on livestock – undermining capacity to prepare land Stress on population – out migration results in loss of critical mass to do maintenance work	Need for alternative livelihood sources
Temperature rise	Pakistan Iran Yemen, Rep.of Sudan Ethiopia Eritrea Morocco Algeria Tunisia	Higher soil evaporation Crop sensitivity to temperature – change of crops or varieties	May need adjustment in crop varieties May need more emphasis on moisture conservation techniques such as mulching
More larger floods	Pakistan Iran Yemen, Rep. of	Damage to diversion structures and risk of gullying and extensive damage to command area	May need to intensify use of outwash areas for rangeland and agroforestry
Later or earlier floods	Unknown	Later floods will cause change in crops – for instance from sorghum to barley Earlier floods may make it more difficult to store moisture	May need adjustments in the cropping pattern
Higher risk of pest and diseases such as grasshoppers	Pakistan Iran Yemen, Rep. of Sudan Ethiopia Eritrea Morocco Algeria Tunisia	Likely, but uncertain in which direction this effect will go.	Require vigilance and back-up system in pest control

Table 3 Expected Impact of Weather Events Resulting from Climate Change



3. Alleviating Rural Poverty and Improving Livelihoods

"The greatest scope for poverty reduction and livelihood improvement in these (high potential) areas is represented by the untapped agricultural potential, both for farming and livestock. Intervention options should not encompass merely irrigation but, in the case of the agro-pastoral zones indeed, exploit the great potential for promoting interventions more related to soil moisture management and rainfall harvesting options as well as livestock watering. For all these reasons such areas offer the greatest opportunities for expanding food production and warrant a large portion of rural investment funds, especially through water interventions but also undertaking farm improvements, such as crop diversification and production intensification. Investments and other interventions in water control are needed to support farm improvements, and can make the difference for livelihoods."
Quote from FAO (Water and the Rural Poor: Interventions for Improving Livelihoods in Sub-Saharan Africa - *Draft*)

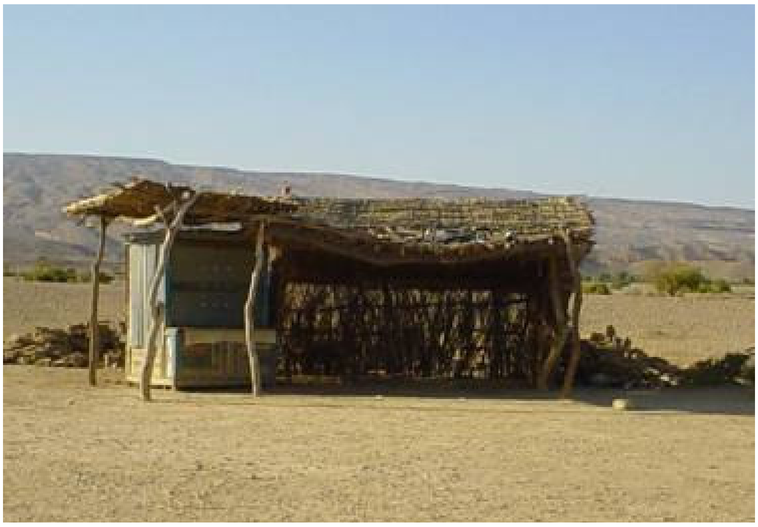
Spate irrigation is the defining characteristic of large areas in arid and semi-arid regions of the Middle East, Africa, South and Central Asia and Latin America, providing a livelihood base for many economically disadvantaged households in these areas. The people inhabiting spate-irrigated areas generally belong to sedentary households (Pakistan, Yemen) or are semi-nomadic (Eritrea). However, in the Gash irrigation scheme (Sudan) and the Gareh Bygone Plain (Iran) the present inhabitants were originally nomadic pastoralist who were forced to settle. The number of persons depending on spate irrigated areas – land owners, tenants and other dependents - probably ranges between 9 to 13 million. This range is in part due to the fact that the number of people active or dependant on spate irrigation varies annually depending on the amount of rainfall experienced in spate irrigated areas. Moreover, information on the number of people inhabiting spate areas or otherwise involved/dependent on spate irrigation is limited to a number of areas; these values have been used to determine a reasonable range that is believed to represent the number of people dependent on spate irrigated areas.

3.1. Income Levels

Income levels in spate-irrigated areas are usually low. Per capita income in many systems is less than US$ 1 per day. Moreover spate-irrigated areas are often situated in remote regions. Hence, spate areas are among the main poverty pockets in most countries.

The net annual income for households in the Sheeb area in Eritrea was US$ 355 against US$ 300 for the Toiwar spate irrigation scheme in Pakistan and US$ 412 in the Shabwah Governorate in Yemen. In 2000, 28% of the households in Wadi Tuban (Yemen) and 35% in Wadi Zabid (Yemen) lived below the poverty line of US$ 203 per year. However, these are average figures and they mask differences in income between households in the up- and downstream locations of spate-irrigated areas. Reportedly farm incomes differ by a factor three between up- and downstream areas in spate irrigation schemes in the Tihama region of Yemen.

The income derived from spate-irrigated agriculture is also determined by the size of the land owned or cultivated by a household. The average landholding in spate irrigation systems tends to be small, ranging 0.5 to 2.1 ha in the Sheeb area in Eritrea, Nouael II project in Tunisia, Wadi Tuban and Wadi Zabid in Yemen. The average landholding in the Gash irrigation scheme in Sudan is less than 0.5 ha. In the Province of Balochistan in Pakistan, on the other hand, the average landholding ranged from 5.4 to 7.8 ha and extensive use is made of tenants. The distribution of land within spate irrigation schemes varies from relatively egalitarian (i.e. Eritrea and Ethiopia) to highly skewed (i.e. Pakistan, Sudan and Yemen). In the latter countries a limited number of very large landholders own large tracts of land, sometimes in the upstream parts of spate irrigation systems that have first access to spate water. In addition, there are also landless households, who usually earn an income as daily labourers. In Wadi Zabid and Wadi Tuban (Yemen), 55% and 25% respectively of all households living within the command areas of these spate irrigation schemes did not own or lease any arable land. In the Gash irrigation scheme in Sudan, at least 20,000 of the total 72,000 households are landless. In this area there were no fixed land titles and land was allocated annually, foreclosing investment in land development or field bunds. Under the Gash Rural Livelihoods Project secure land tenure is being introduced.


DG Khan, Pakistan Local Housing - Spate Areas Are Among the Main Poverty Pockets

It is common in many spate irrigation systems that a large proportion of land is cultivated by tenants and sharecroppers. In Yemen roughly 82% and 51% of the total command area in Wadi Zabid and Wadi Tuban respectively, were cultivated by sharecroppers and tenants. In large parts of the command areas of the spate irrigated areas in Pakistan a system of 'hereditary tenancy' is in place. The tenant is de-facto co-owner, with his entitlement dating back to the time that the lands were prepared for the first time. To retain his title the hereditary tenant has to continue cultivating the land.

3.2. Benefit Streams

Spate irrigation systems generate important benefits. First and foremost spate irrigation makes it possible to grow crops in hot arid and semi-arid regions where evapotranspiration greatly exceeds annual rainfall. In addition, households living in and around the command areas of spate irrigation schemes may enjoy one or more of the following benefits:

- (Improved) access to animal feed;
- Groundwater aquifer recharge;
- (Improved) access to water for humans and livestock; and/or
- (Improved) access to forest products.

Examples from spate-irrigated areas in Ethiopia, Eritrea, Pakistan, Yemen and Sudan are presented briefly in the following sections, in order to illustrate the different benefits of spate irrigation for populations whose livelihoods are based mainly on the use of diverted spate flows.

3.2.1 Crop Production

The cropping patterns in spate-irrigated areas is dominated by the cultivation of low-value, drought-resistant subsistence crops, such as sorghum, wheat, millet, pulses and oilseeds, whereas cotton, pumpkin and melons are also grown as cash crops. In addition, the production of fodder crops to support livestock is also important in most spate irrigation systems. The selection of the crop and varieties used is mainly determined by the location within the spate irrigation system; resistance to drought, pests and diseases; fodder production; storage; and market prices.

The yields of spate-irrigated crops vary widely between and within countries, and are influenced by the spate-irrigation scheme adopted, years with good rains and floods, and years with less than normal rainfall. In Yemen, reported yields varied from 600 to 3,500 kg/ha for sorghum, 600 to 1,200 kg/ha for millet, 1,000 to 1,500 kg/ha for maize, 350 to 700 kg/ha for sesame, 5,000 to 14,100 kg/ha for melon, and 650 to 1,600 kg/ha for cotton. The reported yields in the Province of Balochistan (Pakistan) are significantly lower with only 360 to 550 kg/ha for sorghum, 150 to 350 kg/ha for oilseeds, 200 to 500 kg/ha for pulses and 360 to 620 kg/ha for cotton. This relates to the lower rainfall and infrequent floods in Pakistan.

In the Gash Barka region in Eritrea, the average sorghum yield was 1,200 to 2,100 kg/ha in spate-irrigated areas, whereas only 450 kg/ha sorghum yield was derived from rain fed land. In Sheeb (Eritrea) sorghum yield fluctuates but in good years reached 3,750 kg/ha and in some cases even 6,000 kg/ha. In the northern part of Amhara State in Ethiopia, the sorghum yield doubled and the pepper yields were 400% higher with the availability of flood water. In the spate-irrigated areas of the D.G. Khan District in the NWFP (Pakistan), the average yield for spate-irrigated cereals is significantly higher (2,113 kg/ha) than for rain fed grain crops (1,243 kg/ha).

The wide ranges in yields observed in different spate irrigation systems in various countries are attributed to the unreliability of irrigation, degree of control of spate flows, planting date, sensitivity to inadequate watering, crop husbandry skills, soil moisture conservation practices, crop type as well as by insect plagues and diseases. Yields also vary depending on the location within spate irrigation systems, as areas have different probabilities of irrigation. It is estimated that yields could be increased by 30 to 50% with the ownership of a pair of oxen, as ploughing and mulching could be undertaken more frequently. In the Western Lowlands of Eritrea and the Gash irrigation scheme, planting of the crops were delayed in many cases due to a high demand for a limited number of available tractors and implements.

Eritrea - Mulching is Key to Adequate Moisture Management

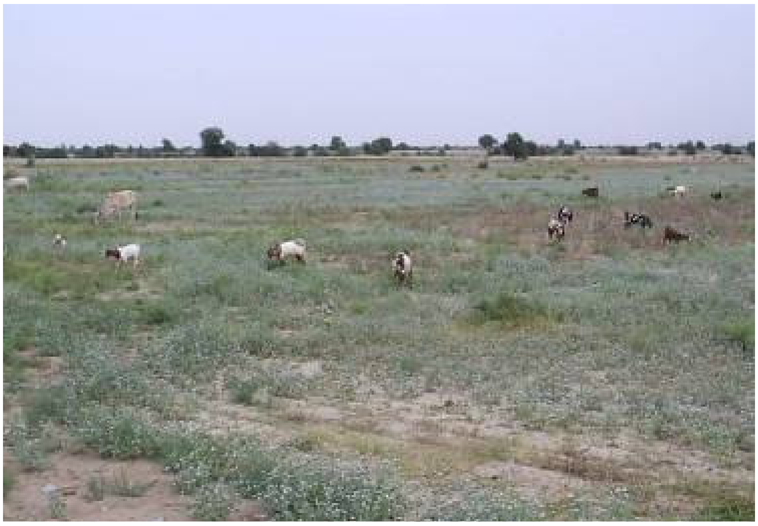
In most spate irrigation schemes, farmers prefer the use of local cultivars as they are well adapted to the local agro-climatic conditions. In the D.G Khan District in Pakistan, yields of wheat, chickpea, millet and sorghum increased by 10 to 24% when the farmers' seeds were cleaned and graded. Improved varieties had 25 to 37% higher yields. There is minimal use of chemical and organic fertilisers as most spate-irrigated farmers believe that their soils are naturally fertilised by the fine sediments that are deposited during the floods. The use of pesticides and insecticides is also rare. High costs, limited availability and risk aversion are other factors that have limited the use of agro-chemicals. Most spate-irrigating farmers can not take the risk of losing their entire crop in a dry year by changing to higher yielding varieties that are less tolerant to drought and require application of fertilisers and other agro-chemicals. In general, the provision of agricultural extension services to farmers in spate-irrigated areas is poor, and available services often do not meet local needs and demands.

The relatively limited agricultural research that has been undertaken in spate irrigated areas suggests that large productivity increases are possible. Research by the Arid Zone Research Institute in D.I. Khan in Pakistan came up with a number of significant production increases varying from 21 to 50% for spate irrigated wheat - in response to single improved practices, such as mulching, deep ploughing, early planting, weed control. Chickpea yields increased between 24-60% for each improved practice in trials with early planting, seed treatment, grazing, higher seeding rates and easy use of pesticides. Intensified agricultural extension under the Irrigation Improvement Project in the Tihama in Yemen managed to increase sorghum yield with 35-140% by introducing seed treatment, fertilizer application and new varieties. In cotton, yield increases with 30-70% with row planting, the use of high quality seeds and fertilizer as well as timely weeding.

Another source of improvement is grain storage. In Eritrea traditional grain storage causes 4-14% crop loss (Haile et al., 2003). In DI Khan (Pakistan) was 7% was lost. This post-harvest loss in Pakistan was reduced to almost negligible amounts (close to zero) with the use of improved storage methods, consisting of a seed cleaning before storage and the use of adobe storage containers, placed away from living places and detached from the floors and walls of the houses.

3.2.2 Livestock

Because livestock is an integral and important component of the livelihoods of resident households in most spate-irrigated areas, access to sufficient fodder is crucial. The main source for animal feed is usually crop residue and rain fed grazing lands. A second source is the cultivation of spate-irrigated fodder crops, such as (green) sorghum. In Eritrea and Sudan, ratoon sorghum is an important feed for livestock as well. The cutting of weed in the fields and along the canals is another source of forage, whereas leaves from trees in and around the spate-irrigated fields are also used to feed animals. For instance, households in the Sheeb area in Eritrea practice 'zero-grazing' from October to May, whereby the animals are fed with cut grass from the fields, to prevent livestock from causing damage to standing crops and to economise the scarce animal feed. Farmers in the northern part of Amhara State (Ethiopia) also indicated that spate irrigation boosted the availability of animal feed due to a significant increase in biomass production. The improved availability of animal feed has improved household income generated from livestock products.

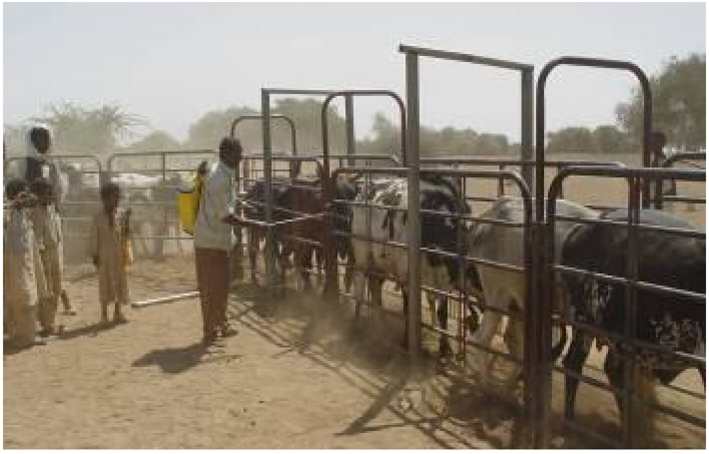


Pakistan, Rangelands Surrounding Spate Areas

A less common but potentially important source of fodder is spate-irrigated grazing land. In the Gash flood plains, a substantial area is covered with a large variety of annual and perennial grasses due to seasonal flooding with excess flood water from the Gash River. According to traditional water governance practices, the first flood in the river would be diverted to the extremes of the scheme in order to stock drinking water for livestock and to irrigate the grazing lands, so that animals would be kept away from the planted crops. However, increased mechanised farming activities in traditional grazing lands as well as the migration of additional livestock herds from other areas have increased the pressure on the remaining rangelands, which are gradually deteriorating.

Under the Artificial Groundwater Recharge Project on the Gareh Bygone Plain in Iran, the average yield of indigenous vegetation on spate-irrigated rangeland was 11 times higher (445 kg/ha) than for rain fed land (42 kg/ha), whereas the average crown cover was 31% for spate-irrigated rangeland against 16% for rain fed grazing land. If the yield of the planted quail bush is also added, the overall yield for spate-irrigated rangeland is 23 times higher, which is enough to graze 4 sheep on one hectare for an entire year.

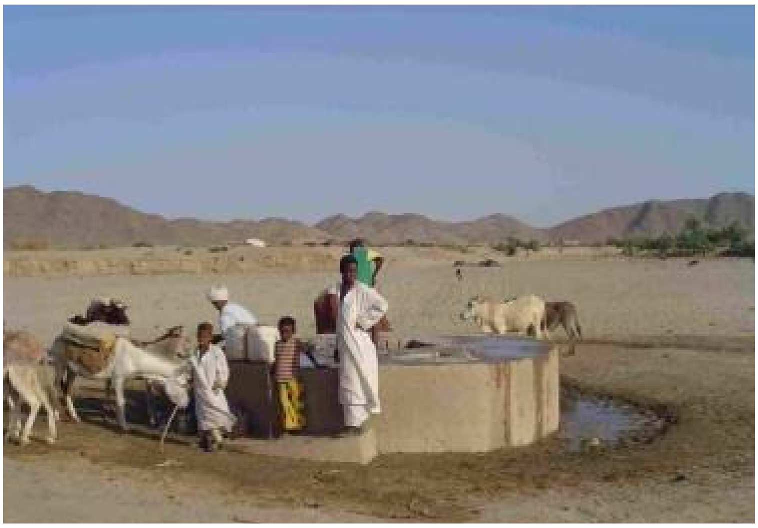
Spate irrigation was tried in Turkana district (Kenya) in the late 1980s, and aimed at producing pastures for pastoral communities. This was done with large temporary brushwood diversion weirs with graded canals to facilitate the overtopping and uniform spread of the water. The systems, although productive, were not sustainable since they had been constructed through food for work programs with little community ownership.



Sudan, Gash - Livestock in an Important Source of Income

3.2.3. Groundwater Recharge

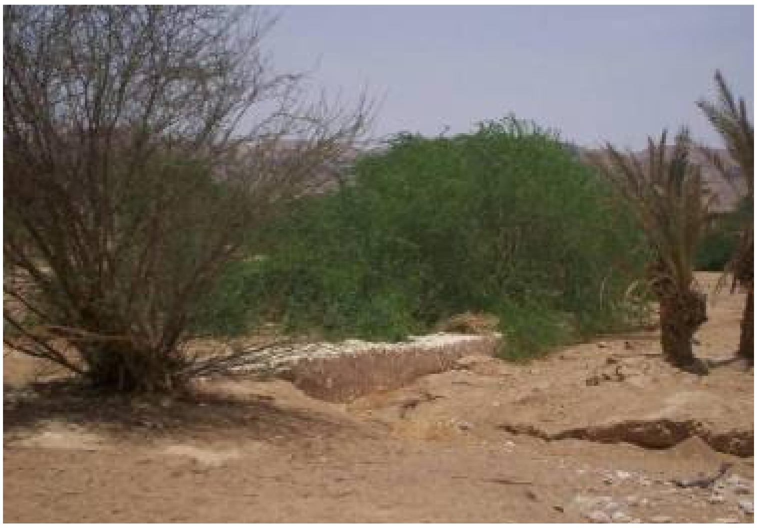
Groundwater is saline in spate-irrigated areas in Pakistan, Tunisia and Eritrea, and hence the conjunctive use of groundwater and spate water for irrigation is not an option. In the coastal areas of Yemen, however, the quality of the groundwater is good enough for irrigation. Since the 1970s, there has been a rapid increase in the number of installed (shallow) wells and the cropping pattern has changed dramatically towards the cultivation of high value crops, including bananas, mangoes and vegetables. This was a result of the conjunctive use of spate flows and groundwater. Consequently, the area under banana cultivation in Wadi Zabid has increased from only 20 ha in 1980 to more than 3,500 ha in 2000, while about 2,300 ha are cultivated with vegetables in Wadi Tuban. Groundwater is also used for the cultivation of green sorghum that is sold as a high value fodder crop in Wadi Zabid. In the Gash flood plain in Sudan, groundwater from shallow wells is used for the cultivation of horticultural crops (i.e. bananas and onions), which has become the foundation of the regional economy and hThen as generated a significant demand for wage labour. Groundwater is also the major source of water for livestock in the tail reach of the Gash irrigation scheme. Reportedly, three groundwater basins are recharged with flood water from the Gash River, whereby one branch canal is devoted to the recharge of one groundwater basin. In the command area of the Nouael II Project in central Tunisia, about half and two-thirds of the households in the middle and tail portions of the main canal had developed their



Eritrea, Wadi Laba - Drinking Water Well in River Bed own dug-wells for the cultivation of vegetables. As a result, the well-owners had stopped their contributions to the maintenance of the spate irrigation system. As spate water only reached the

tail of Wadi Al'Ain/Harib (Yemen) during large floods following the construction of two weirs in 1980, many farmers have developed wells in the downstream reaches in order to become less dependent upon spate water. In the central region of Shabwah Governorate in Yemen, about 20% of the households have installed wells in order to reduce the risk of crop failure. Households with access to pump irrigation obtained net annual revenues that are at least twice as much as for households depending exclusively on spate irrigation.

The higher productivity of groundwater-based irrigation raises the question if the best strategy for the spate water management should be focused on groundwater recharge rather than agricultural productivity of spate-irrigated agriculture. At present, the relationship between spate diversion and groundwater recharge is not well quantified. According to a study in the Gareh Bygone plain in Southern Iran, an estimated 9.25 million m^3 of the total diverted volume of 13.23 million m^3 (about 70%) had reached the groundwater table in 2002-2003 as a result of the artificial groundwater recharge (AGR) system. In addition, the spreading of flood water over an area of 2,445 ha also resulted in an expansion of irrigated agriculture from 148 ha in 1984 to 1,193 ha in 1998 with relatively high yields for wheat (up to 5 ton/ha).



Yemen, Hadramawt - Artificial Groundwater Recharge from Traditional Low Weir

3.2.4. Access to Water for Domestic Use and Livestock

The access to reliable sources of (ground)water for potable and domestic purposes throughout the entire year is a precondition for the permanent settlement of people in an area. In a number of spate-irrigated areas, however, (ground)water is not available permanently and the local population does not have another choice than to leave their villages in search of water for themselves and their animals. For instance, the majority of the local population in the Sheeb area (Eritrea) the Kachhi Plain in Balochistan (Pakistan) migrates each year for a number of months, because there is not sufficient water to satisfy the water requirements of the local population and their livestock for the entire year.

In spate-irrigated areas of D.G. Khan District (Pakistan), earthen ponds were renovated and new ones were constructed. Improvements consisting of lining the reservoirs, ensuring adequate depth (1.5-2.5 meter) to reduce evaporation and constructing hand pumps and sand filters. In addition fencing ponds and protecting the inflow through sand traps and vegetative measures can make a large difference in water availability and water quality.

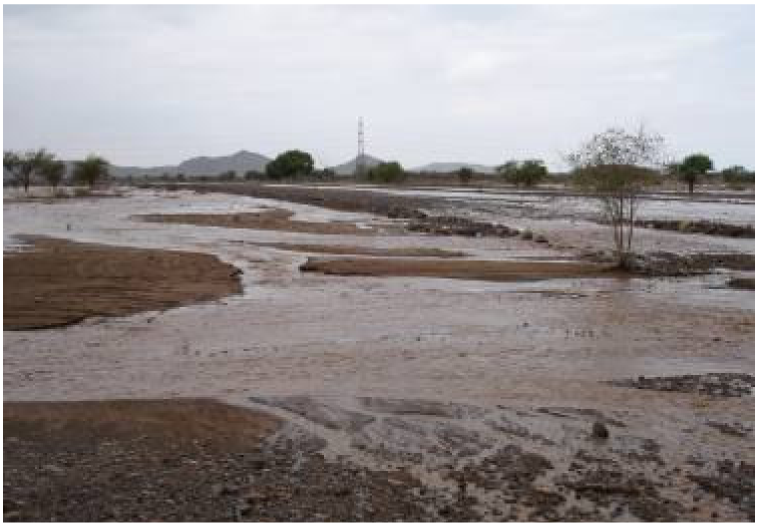
In the Gash irrigation scheme 13 reservoirs (locally known as *hafir*) were excavated having a total design capacity of 375,000 m^3. These were located outside the cultivated area in vast rangeland constituting the grazing ground for nomadic tribes. These reservoirs are filled with the early flood water, so that silt would not be deposited in the canal systems. The Gash irrigation scheme used to excavate the *hafirs* annually to ensure their water-holding capacity, but the annual maintenance was abandoned at one stage due to the collapse of scheme management. In addition, there are also underground cisterns, locally known as *hod*, and they are filled with either outflow from irrigation canals or rainfall runoff.

In the northern part of Amhara State in Ethiopia, farmers divert flood water from the Gobu River to excavated ponds (called *haroyee*) for supplying water to livestock. These ponds are usually

constructed along the lower reaches of the main flood diversion canal and on the edge of the crop fields in order to keep animals off the cropped fields and to utilise only the excess runoff after irrigating the fields. If there is a scarcity of water for livestock, a traditional water management committee (locally known as *Aba-hagga*) may order farmers not to irrigate their fields with flood water until the animal drinking pond has been filled. In the Aba'ala Wereda in Afar Regional State (Ethiopia), the shallow ponds are used for watering animals and fetching water for domestic use.

3.2.5. Access to Forest Products

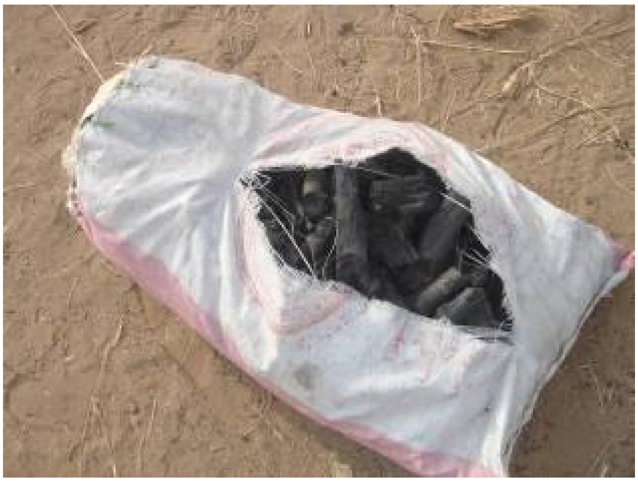
In the Shabwah Governorate in Yemen, each household has between 25 to 50 *Ziziphus spp* trees in and around their spate-irrigated fields for bee-keeping, fodder, fruits, timber, fuel wood and medicinal uses, whereas spate-irrigating farmers in the Tihama region earn an additional income from the sale of fuel wood and/or charcoal. In the Konso spate irrigation system in Ethiopia, many trees can be found, and many beehives have been installed. In the spate-irrigated areas of Pakistan, trees are also common and are used for many purposes. For instance, trees with large spines, such as the *Acacia spp*, are used for constructing fences around fields to protect standing crops from roaming animals, and to build corrals for safeguarding livestock at night. Women use dwarf palms for the production of mats, ropes and sandals. Trees also provide vital shade for livestock during the hot season. In D.G. Khan District and Balochistan (Pakistan), forest and horticultural trees (i.e. almond, apricot, pistachio, pomegranate, guava and citrus) were planted around earthen reservoirs and in the catchments. Furthermore, trees are also intensively used in the maintenance and repair of irrigation structures in traditional spate irrigation systems. Branches and even entire trees are used to strengthen diversion spurs as well as flood protection works. For example, 28,000 acacia trees were required annually for the construction of diversion spurs in the 3,000 ha spate irrigation system in the Sheeb area in Eritrea. In Somalia, low dams of wooden poles are used to divert spate flows into the fields or to open ponds and pools for temporary storage.



Yemen, Tihama - Worldwide There is An Estimated 2,500,000 ha Under Spate Irrigation

In the Tihama in Yemen tree coverage has increased with many important multifunctional indigeneous trees. The most important ones are *Zizyphus SpinaChrista*, for high quality honey forage, timberwood, fruit, detergent (from the dry leaves) and camel fodder; *Salvadora Persica*, used to produce toothbrushes (from the roots), food condiments (fruits) and also used to stablize sand dunes; *Balanites Aegyptica* for shelter, camel feed and fruits; and *Acacia Eherenbergiana*, providing premier quality honey forage, goat fodder and charcoal wood. The moisture captured from the acacia charcoal (*keteran*) is used for skin treatment of livestock (Haile and Al-Jeffri 2007).

In the Gash flood plain in Sudan, there are still flood forests that depend on the uncontrolled flooding of vast areas of the plains outside the Gash irrigation scheme. In the flood water spreading areas of the Gareh Bygone Plan in Iran, Eucalyptus and Acacia species were planted in a sedimentation basin of about 3.6 ha and the average yield after 8 years was 60 m^3/ha of stem wood and 18 m^3/ha of fuel wood. In a less flooded area of 6 ha, the average yields for stem wood and fuel wood were 39 m3/ha and 11.7 m^3/ha respectively. The annual carbon sequestration potential of spate-irrigated Eucalyptus is 3,699 tons/ha, and 3.392 tons/ha for Acacia. It is estimated that the annual income from stem wood, fuel wood and fresh leafs could be US$ 290, which is considerable taking into account the low risk and very low capital investment. Income could also be derived from forest by-products, such as forage, food products, pharmaceuticals, honey and beeswax.



Yemen, Tihama - Using Local Trees for Charcoal

Under the Project for Supporting Implementation of IWRM Policy in Balochistan (Pakistan), the development of tree plantations in spate-irrigated areas is promoted as it would enhance the sustainability of spate-irrigated farming systems by producing bio-diesel, timber, fuel wood, fruit and nuts. The proposed trees could survive drought years as they can extract groundwater from greater depths and they are tolerant to ponding of excess flood water. In DI Khan agroforestry plantations were laid out in the outwash areas. Fields were prepared in order to concentrate run-off and spate releases to the tree plantations.

3.2.6. Improving Livelihoods

The livelihoods of households in spate-irrigated areas, which are based on the cultivation of spate-irrigated crops in combination with additional incomes from livestock, off-farm activities, wage labour and/or migration, are under threat by the following developments:

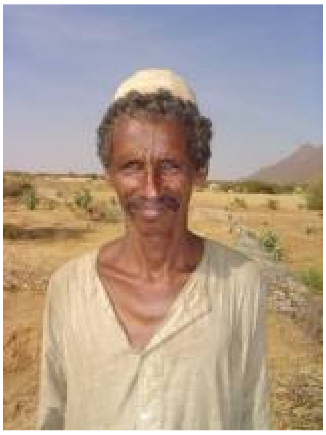
- Average size of landholdings decreases due to further sub-division through inheritance and/or settlement/migration of households from elsewhere (i.e. Gash irrigation scheme: number of tenants increased from 22,000 in 1988 to 45,000 in 2002);
- Capacity to maintain spate irrigation infrastructure diminishes due to (permanent) migration and installation of wells, so that remaining farmers are unable to mobilise sufficient labour and draught animals;
- Modernisation of spate irrigation systems as well as (subsidised) bulldozer programmes could have a detrimental impact for farmers in the middle and tail sections as it has become easier for upstream water users to divert more if not all spate water to their fields despite existing rules regarding the allocation and distribution of spate water;
- Degradation of the riverbed, which could be accelerated by deforestation and overgrazing in the upper catchments as well as in and along the riverbed, may prevent farmers from diverting spate water to their fields as they are unable to build diversion structures that are high and/or long enough;
- Invasion of alien tree species, mesquite in particular can ‘suffocate’ flood channels and make land unusable; and
- Degradation of surrounding rangeland undermines incomes from livestock keeping and also triggers sand dune movement, as reported from Morocco for instance.

An understanding of the socio-economic circumstances and existing livelihoods of spate irrigation communities, including the adopted risk-coping strategies, is essential for the development of effective, sustainable and pro-poor interventions aimed at improving (traditional) spate irrigation systems. Although the cultivation of spate-irrigated crops is an important economic activity for most households in spate-irrigated areas, spate water is or could be used for other purposes as well, which may be more beneficial for the local population in financial and social terms. Therefore, it is crucial that any approach aimed at poverty reduction and economic development in spate-irrigated areas is based on “integrated land use” (crop-livestock-plantation farming systems), whereby diverted spate water is optimally used for crop production, horticulture, groundwater recharge, fodder/pastures, forestry and/or small-scale water storage.

An area of special concern is improving the position of women. The death of a working husband or a divorce is a major cause of impoverishment for female-headed households. In the Gash irrigation

scheme in Sudan, some 4,500 of the 20,000 poorest households are female-headed, who do not own (spate-irrigated) land and livestock, and they fully dependent on earnings from daily labour and sale of fuel wood and charcoal.

All domestic tasks are usually the exclusive responsibilities of the female household members, including the fetching of potable water and fuel wood. Even though the role of women in spate-irrigated agriculture and other economic activities varies between regions and cultures, the role of women in the livelihood strategies of households in spate-irrigated areas should not be under-estimated and under-valued as they are important actors in agricultural activities (i.e. sowing, weeding, harvesting, threshing and processing) and rearing livestock, including the processing of livestock products. In general, men are responsible for irrigation and cleaning of canals, but women may assist with infield irrigation. In poorer households, women are often engaged as wage labourers as well or involved in handicraft, petty trade and sale of fuel wood.

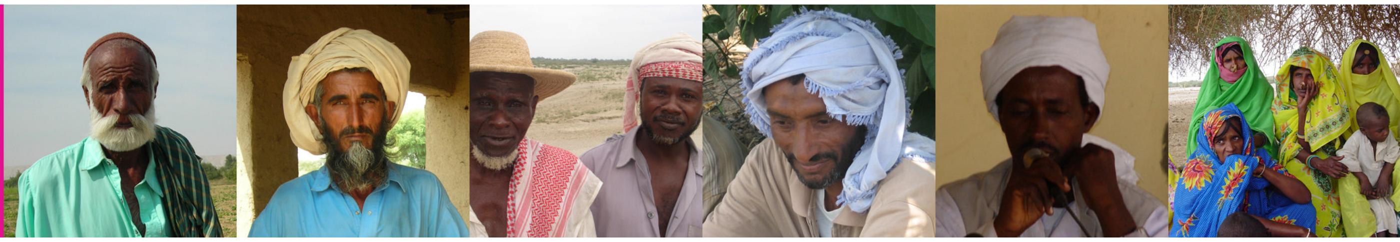


Eritrea, Gash Barka - There Are Several Ways of Improving Spate Irrigation Beyond Focussing on Diversion Works

Although women are usually entitled to inherit land, socio-cultural practices in (mostly Islamic) countries prevent women from cultivating their lands themselves. As a result, these lands are either cultivated by male relatives of the female landowners or by tenants/sharecroppers. Lack of oxen and insufficient household labour are additional constraints that make it difficult for female-headed households to crop their own fields.

In order to improve the position of women in general, particularly (poor) female-headed households, in spate-irrigated areas, a spate irrigation improvement project should assess the need to develop and implement interventions aimed at improving access to:

- Credit facilities (i.e. micro-finance, saving and credit groups);
- Draught power;
- Extension and training services;
- (Drinking) water supply (i.e. wells, ponds, cisterns);
- Fodder and water for animals (i.e. ponds and reservoirs);
- Special training in vaccination and health care for small ruminants;
- Energy sources (i.e. (re)forestation, tree plantations, fuel-saving stoves);
- Appropriate, low-cost technologies to reduce women’s workload (i.e. milk churners); and
- Income-generating activities (i.e. handicraft, petty business, horticulture).



4. Improving Spate Irrigation Systems

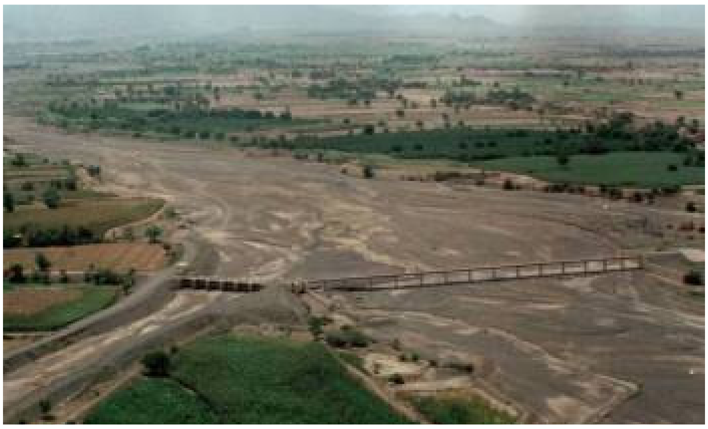
Large spate irrigation areas have been neglected and external support has been minimal. Over the past three decades spate irrigation development has been supported under a range of national and international programs in some areas. Even so, the vast majority of spate irrigation programs are 'untouched'. This section summarizes the experience with different types of external support given to spate irrigation system world-wide.

4.1. Improving Water Diversion

The most 'high profile' external investments in the last 25 years in spate irrigation have consisted of improving the diversion of spate flows. In improving diversion three very different approaches have been followed:

- 'Modernization';
- Improving traditional systems; and
- Making earth moving equipment available.

4.1.1. 'Modernization'



Yemen, Wadi Zabid -Modernization Has Interfered with Water Rights

Under the guise of 'modernization' extensive civil engineering investments have been made in the headworks of spate irrigation systems in Yemen and to a lesser degree in Morocco, Pakistan, Eritrea and Ethiopia. Characteristically, traditional intakes were replaced by civil headworks, typically a weir, an off-take gate and a sluice gate. In some cases a breaching bund was provided, to save on construction costs and to provide the means to handle very large floods. Also in some systems a sedimentation pond was part of the headworks, designed to avoid coarse sediments going into the command area. Because such modernized headworks are costly, in many cases, a traditional system with multiple off-takes from the river was replaced by a single diversion structures supplying a newly-built long flood channel.

In the Tihama plains in Yemen several large spate irrigation systems (5,000 ha or more) were ‘modernized’ along these lines in the 1980s (i.e. Wadi Zabid, Wadi Rima and Wadi Mawr) using World Bank funding. Major investment in the Tihama continued until 2003, when Wadi Siham was modernized with EU financing[3]. Similarly, large civil works have been undertaken in the large spate systems in South Yemen (or People’s Democratic Republic of Yemen as it was called at the time) in the eighties with Soviet support. Since then, the focus on new developments in Yemen has shifted to smaller systems (i.e. in Hadramawt), usually as part of larger rural infrastructure projects funded by World Bank or Arab Funds. Recently under the Irrigation Improvement Project (World Bank) two of the systems modernized earlier are being rehabilitated and brought under farmer management.

Ethiopia - Trash Accumulation In Front of Small Modernized System - Modernization Concepts Have Not Always Been Appropriate

Yemen, Tail End Wadi Mawr - Constant Risk of Changes in Bed and Changes in The River Course Level

In some cases (in Pakistan) investments have been made on flow division and regulation structures in ephemeral rivers, but the main focus has been on diversion structures. Under a number of programs in Balochistan Province new spate headworks have been constructed. In the early days these investments were strongly inspired by perennial systems and were not able to cope with the heavy sedimentation process or violent peak floods. An evaluation of 47 relatively minor spate systems built from 1960 up to 1990, established that as little as 16 were still operational.

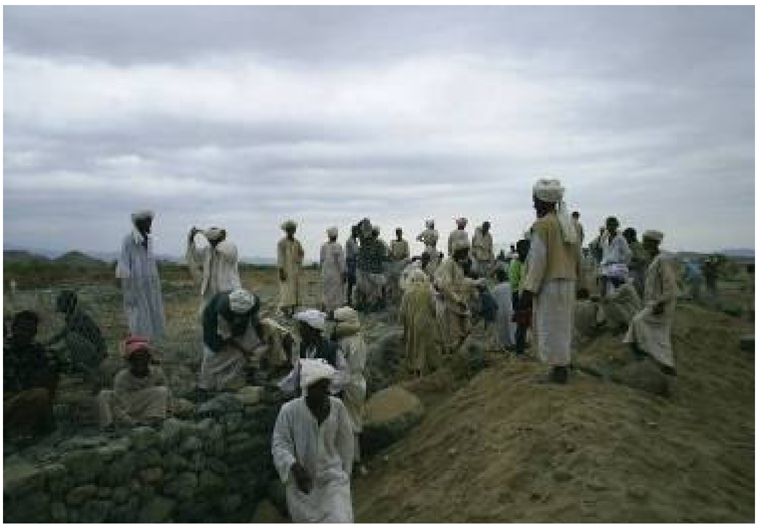
[3] The Wadi Siham works suffered seriously from poor design: the traditional flood channels were dissected by a new canal from the civil headworks, which had a far lower capacity. There was substantial damage to the culvert and flood protection, because the effects of scour and sheer were underestimated.

The track record of such civil engineering investments then is mixed: a large number of disappointments with a few real success stories:

- Investments in flow division and regulation rather than diversion have performed reasonably well. Examples are the Gaj Nai in Sindh in Pakistan or the Mitaj in Balochistan (both in Pakistan);
- Modern flow diversion structures on relatively large systems (1,000 ha and more). All spate projects developed under the Balochistan Community Irrigation Project, implemented from 1995-2002 suffered from operational or social problems. Similarly the Mithawan system developed with JICA funding in Punjab has failed because of inadequate sediment management arrangements. In the Tihama plains of Yemen the designs of the modernized systems became more sophisticated over time, but in many cases suffered from inadequate sediment handling. Moreover, serious social problems persist in Yemen. These are related to the increased capacity of upstream landowners to control spate flows after the civil works investments. In the past the inherently weak nature of traditional diversion structures made such full control difficult. For instance, in violation of written rules the local elite in Wadi Mawr diverted water to another catchment. Similarly in Wadi Siham and Wadi Zabid powerful upstream farmers created new diversions and deprived downstream water users;
- In contrast small civil engineering works on smaller flood systems (less than 500 ha) have generally performed better. The investments have in these cases usually been straight forward (serving one bank at a time; no complication with distribution of water; no long flood channels; selection of sites with attenuated flows);
- Leaving aside effectiveness of modernization programmes, there are many areas where the modernization approach, even if desired, is not feasible, because of the elevation of the land, the width of the rivers or other reasons.

4.1.2 Support to Traditional Systems

Most spate-irrigated systems remain ‘traditional’. The traditional structures can be spectacular, with high earthen bunds spanning a river, guide bunds measuring several kilometers or extensive spurs made of brushwood and stones. Often the traditionally designed systems are the most appropriate interventions: they have fewer problems with handling peak floods and excessive sedimentation. Spurs and bunds are generally built in such a way that the main diversion structures in the river break when floods are too big. The breaking of diversion structures also serves to maintain the floodwater entitlements of downstream land users. The capacity to divert water in traditional off-takes is less reliable and the work of reconstructing them can be a considerable burden, and can exceed the capacity of the local community, resulting in the systems being abandoned.

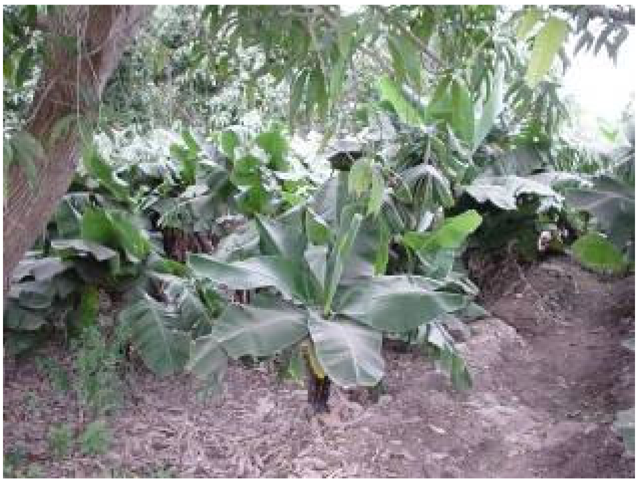


Eritrea, Wadi Labka - Improving Traditional Structures

Supporting traditional systems is done to improve their reliability and reduce the maintenance burden. In some cases they make it possible to guide floods where this was not possible earlier. Recently the Government of Eritrea launched an impressive campaign whereby the head reaches of the traditional diversion bunds are replaced by gabions and bulldozered bunds, with farmers providing the labour for filling the gabion crates. One area where this approach was implemented was Wadi Labka, where 1,200 meters of guide bunds were reinforced, and positioned at different places in the wide river bed. The different diversion bunds serve to split the floods in the Labka river to manageable portions in harmony with traditional water rights, and guide the flows to the command area.

Another example of improved traditional systems approach is the Rehanzai Bund (Balochistan, Pakistan), where farmers used external financial support to construct a very large new soil bund on the offshoots of two ephemeral rivers, in order to spread floodwater to more than 15,000 ha of land. In the same area the construction of gabion bed stabilizers was contemplated on the Korasan River. As the Korasan River was degrading, the inexpensive bed stabilizers were to reverse this development and raise the bed level of the river. This would allow farmers to build earthen bunds in the deeply incised river, causing the bed level to rise further. By raising the bed level, natural depressions would start functioning as natural spillways again, in case of very large floods.

Yemen- Wadi Sibam Weir with Traditional Abutments - The Traditional Structures Can Be Spectacular



Yemen, Zabid – High Value Horticulture Sustained by Conjunctive Use of Spate and Groundwater Irrigation

Pakistan, Sindh - River Bed Protection by Tamarisk

A fundamental difference with the 'modernization' approach is that in improving traditional systems the emphasis has been on river engineering rather than on controlling the flood at a single point. Strategies used have been to split the flood in manageable proportions (Wadi Labka), to spread the flood over a large area and reduce its force (Rehanzai) or to reverse the degradation of the bed level (Korasan). The advantages of such programs have been that at reasonable cost they have improved reliability of the systems, reduced maintenance burden and kept local management intact.

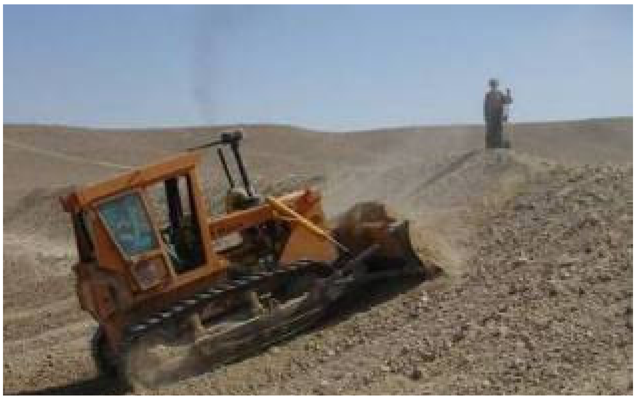
In many cases intense use has been made of gabion structures. The experience with gabions has not always been positive. In some countries the use of substandard wire crating has been problematic. In the Wadi Beihan Project in Yemen it was found that gabions were only marginally cheaper than the local reinforced structures, but the capacity to repair the gabions did not exist in the area and supply of new gabion crates or even meshwire was difficult. In the end in the Wadi Beihan project traditional stone abutmens were preferred over the gabion diversions.

4.1.3. Provision of Earthmoving Equipment

A closely related support strategy to the improvement of traditional structures has been the provision of earth moving equipment. In such programs bulldozers and front loaders are made available at rates that typically cover part of the running costs but none of the capital expenses. Such earthmoving equipment was often made available by aid-in-kind programs. In Eritrea, Iran, Pakistan and Morocco the Ministry of Agriculture has been supplying bulldozer services.

With 'bulldozer' programs farmers are given new means to build or restore diversion work (especially earth bunds), or improve command areas, ranging from gully plugging and repairing canal bunds to making new flood channels. In countries where bulldozer programs are in place they tend to be uniformly popular and have developed into the lifeline for spate irrigation. The downside of the bulldozer programs is that traditional water distribution systems were sometimes upset, because upstream farmers were now able to build bigger bunds. This happened in the Kacchi Plains in Balochistan (Pakistan).

Eritrea - Gully Plugging Can Restore Soil Moisture Over Larger Areas



Pakistan, Mastung - The Provision of Earthmoving has Supported the Improvement of Traditional Structures

Another issue has been the sustainability. The prime example is Pakistan, where a vacuum was created after bulldozers had outlived their economic life: the traditional means and organization of the repairing bunds with bullocks had withered away and the number of bulldozers in operation was insufficient. The challenge of the bulldozer programs is to create a situation whereby the rental price covers all running costs of the bulldozers, and to stimulate local entrepreneurs renting out earthmoving equipment.

4.2. Improving Productivity and Economic Opportunities

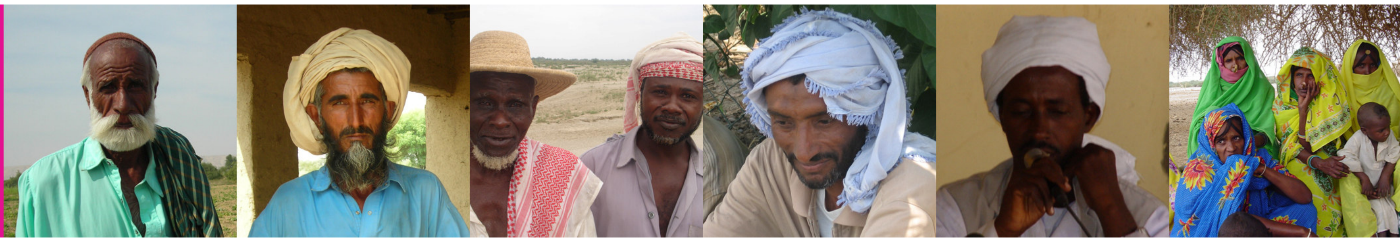
Improving diversion has been the natural starting point for the spate improvement program, yet some questions can be asked about the usefulness, especially when the focus is exclusively on improving diversion. First of all in several spate irrigated areas the rivers no longer reach the sea. Water is exploited intensively and at basin level no water is lost. More efficient diversion in one place means less water in another place. The way forward in improving water productivity lies in making better use of water within the command area. Major advantages can still be experienced here with improved field moisture management, conjunctive use and in improved agronomic practices. The second argument is that there is more to spate irrigation than agriculture. The systems may or may not effectively recharge groundwater, fill drinking water ponds, serve range and local forest areas. The exclusive focus on diversion is often at the cost of supporting different multifunctional uses. Lastly, it is not sufficient to focus only on the spate irrigation per se, but look at the entire local economy. As the livelihoods of many poor households in spate-irrigated areas only rely in part on incomes generated by spate-irrigated agriculture, any spate irrigation improvement project aimed at poverty alleviation in an effective and sustainable manner should also develop and implement activities that create the basis for local sustainable development in general.

Yemen, Hadramawt - Land Preparation Can Ensure Moisture Management - Key to High Productivity

There are several ways of improving spate irrigation beyond focusing on diversion works only. If a broad approach is chosen in several countries spate irrigation presents good potential for improved livelihoods and local food security, almost always for the poorer segments of the population. The most promising interventions are:

- Improving water productivity and soil moisture management. There are several ways to achieve this. First is the use of improved field-to-field structures (inlets and overflow structures), allowing more regulated inflows and outflows during the hectic of spate irrigation. Another strategy is to ensure that animal traction power is adequate to plough and mulch so as to conserve soil moisture after irrigation. A final strategy is to concentrate flows on a relatively compact command area, thus increasing the probability of land being irrigated, making it less risky for farmers to prepare their land prior to irrigation, and increasing the capacity to absorb water. More compact command areas also increase the chances of a second and third irrigation, taking crops out of the 'stress zone'
- Agronomic improvements in field preparations, seed treatment, use of improved seeds, early planting, targeted usage of agro-chemicals
- Introducing of new crops – vegetables, cucurbits, pulses, oilseeds. Also invest in post-harvest technology, such as seed cleaning and improved storage, which have reduced grain losses from 7% to 0% in the DI Khan in Pakistan
- Enhance the productivity of livestock, including improved access to animal feed (i.e. fodder crops and spate-irrigated pastures), watering points and veterinary services, as well as the processing and marketing of livestock products
- Promote local agroforestry, particularly of indigenous trees that serve to stabilize surrounding areas and provide fuel wood, timber, medicine and/or bee forage. Often this has to be accompanied by improvement in the governance of local forestry

- Improve drinking water facilities in the spate areas. These are often meagre and unreliable, i.e. unprotected open ponds – but can be improved by a range of technical and institutional improvements
- Where possible, the development of conjunctive use of groundwater and spate water, including the construction of infrastructure for artificial groundwater recharge and improved access to credit facilities for installation of wells and pumps
- Improved land and water tenure, issuing individual titles, where they do not exist and codifying or reviewing water rights, in order to minimize conflicts and also to accommodate new realities, such as the intense use of groundwater and need for recharge
- Working on the bigger picture – improving access roads to spate irrigated areas, general amenities and market facilities
- In general, the development of opportunities for wage labour and off-farm income, in particular for landless (female-headed) households



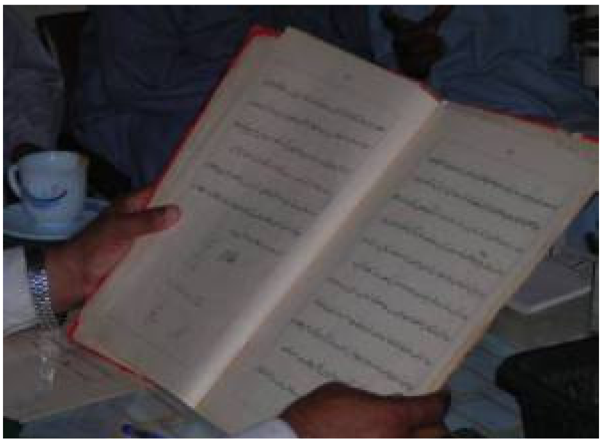
5. A Road Map for IFAD

5.1. Experiences of IFAD in Spate Irrigation

IFAD has been a leading international player in spate irrigation. It has supported spate irrigation systems improvement in Tunisia, Yemen, Eritrea and Sudan. In all these projects an integrated approach has been followed in varying degrees, and has not been limited to water resource development and river diversion.

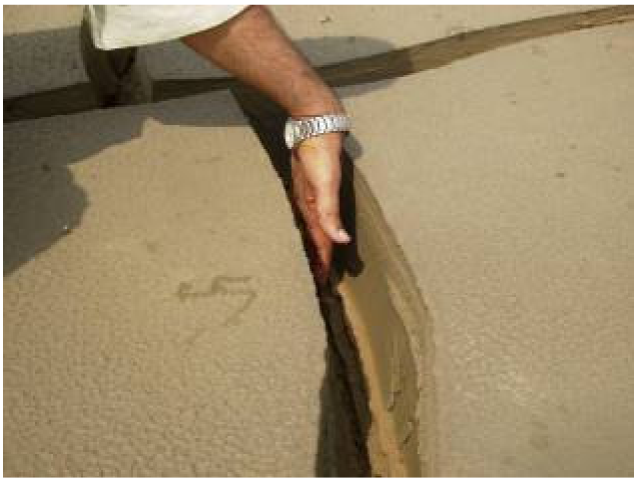
IFAD Has Been A Leading Player in Spate Irrigation

Experiences with these systems, as documented in evaluations and other source documents of IFAD, does not differ from global experiences, described elsewhere in this paper. Experiences are briefly captured hereunder.



DG Khan, Pakistan - Records of Water Rights and Rules Have Been in Use for More than a Century

The first substantial involvement of IFAD in spate irrigation was the co-financing of three projects under the larger Tihama Development Programme in (former) North Yemen, led by the World Bank. The emphasis in this larger programme was very much on ‘modernizing’ water diversion on five of the main ephemeral rivers in the Tihama, essentially by the development of large civil works. Interestingly a parallel approach carried out in the main Wadis in South Yemen with Soviet support. Lessons learned from the Tihama Programme were that the projects were too far removed from the deeply engrained local tradition of resource mobilisation and spate management. The results were modernized irrigation systems that were 'costly to construct, operate and excessively dependent on government support'. Moreover, in one of the three projects (Wadi Mawr), changes to the original design concept created an opportunity for the well-entrenched upstream group of farmers to commandeer an excessively large share of both perennial base flows and spate flows. As a consequence the downstream farmers suffered rather than benefited from the project, and observed how their irrigated area declined. A review of the Tihama projects formulated a number of lessons. These are still valid for the Tihama today: build more local capacity to support the development of spate irrigation, use a strong orientation on local livelihoods and local practices, and ensure a deep understanding of local water rights and allocation rules.



Sedimentation is An Important Feature of Spate Irrigation

A second early experience with spate irrigation concerned the Irrigation Development Project in the Governorate of Sidi Bouzi in Tunisia. This consisted of a range of irrigation improvement activities in the area. In the original project design the rehabilitation of one modernized spate irrigation scheme with a command area of 3,000 ha (damaged four years after commissioning) was foreseen. After the rehabilitation works were finalized for this Wadi El Hachim system, it turned out that the small catchment of the wadi was insufficient to reliably spate-irrigate the entire 3,000 ha system. An alternative supply was developed for the lower part of the system area. This was a runaway success and in the end managed to serve 4,000 ha. Maintenance of the systems remained an issue, with farmers compensating no more than 15% of costs. The spate system was also supposed to recharge the underlying aquifer but was ineffective to this end, the hydrogeology was not well-understood. Lessons learnt from the spate component in the Sidi Bouzid project were: the need to design the dimensions of infrastructure based on understanding of the catchment; not interfere but leave the water distribution to farmers themselves; work towards improved maintenance of the infrastructure by users (i.e. establish a maintenance fund that is replenished in 'good' years); and develop a better understanding of the spate potential in the area.

In Eritrea two spate irrigation projects were implemented. The first project was the Eastern Lowland Wadi Development Project, which was hoped to become a 'role model', already just after Eritrea's independence. The project consisted of modernizing two spate irrigation systems (Wadi Laba and Mai Ule); a livestock restocking component (war and drought had reduced the livestock population); training of local paravets; strengthened agricultural extension; international research into sorghum varieties and the provision of safe drinking water supply. In the course of the project much emphasis was given in building up a Farmers Association on the foundation of the traditional organization of blocks and subsection leaders.

The main lesson from the ELWDP was to revisit the modernization approach to spate irrigation development. The overall functionality and cost efficiency of some of the civil engineering set-pieces in ELWDP (sedimentation, pond, breaching bund, by-pass channels) would need to be rethought. It was recommended that, in spate irrigation development, a broad range of options be considered and that improving or supporting spate irrigation was not to be automatically equated with the development of civil works, particularly not the top range solutions that were adopted in the project.

In many locations such headworks would be technically difficult, economically not viable, and difficult to manage. In these areas, the provision of bulldozers on paid or even commercial rates;

the improvement in command areas networks and water distribution; the development of spate systems on smaller tributaries; the use of low-cost technology to strengthen traditional diversions; the introduction of improved draught animals, and the development of high value cropping patterns, may all be better value-for-money.

The evaluation of ELWDP also demonstrated the value of the livestock restocking component. Livestock restocking provided the means to plough, mulch and restore field bunds, and as such was crucial was managing field moisture. Unfortunately in ELWDP the provision of livestock was discontinued as the budget for this component was requisitioned to pay for cost overruns on the diversion weirs.

A final lesson of ELWDP was to engage the farmer organization right from the start, particularly where strong local structures exist as in Wadi Laba and Mai Ule. In ELWDP there was at one stage considerable confusion and discontent with the new system. Presentations of the proposed works had been given, but to ad hoc assemblies of farmers, by-passing the local leaders in the process.

The other project in Eritrea was implemented in the Western Lowlands, which at the time was coping with an influx of returning refugees. The Gash Barka Livestock and Agricultural Development support investment in agriculture and livestock. This consists of improvement in rangeland management, the construction of water supply systems and the improvement of local health care services. Included in the project package is a component of small spate diversion works.

The most recent spate irrigation project supported by IFAD is the Gash Sustainable Livelihood Regeneration Project (GSLRP) in Sudan. This programme is situated in the Gash Delta in the eastern part of Sudan. In this area water resources are under pressure due to the large number of displaced people and the relentless population growth. The GASH spate irrigation scheme area is overburdened by large expansion of the number of sharecroppers. This leads to a decrease in the average area cultivated by households and a decrease in the herd size per household, insecure access to water for livelihoods and fragmented management of the scheme.

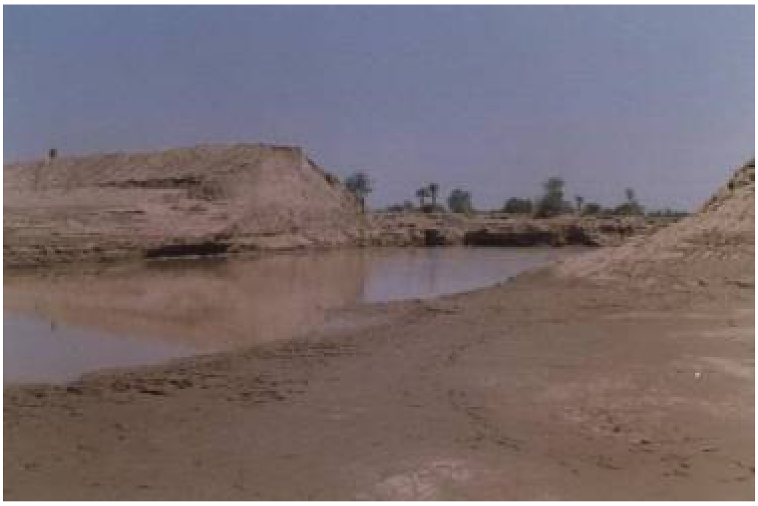
The overall aim of the project is to regenerate the livelihoods of poor people in the area and to secure their access to irrigated land and water supplies. The project uses a livelihoods approach. Investments are made in reform of land (change the land leasehold system by imposing a minimum and maximum holding, changing the system of land rotation) and water governance (ensuring first flood releases to downstream pastoralist areas, fee collection from land users, local maintenance linked to water delivery), in rehabilitation of upstream river protection, scheme irrigation and rehabilitating drinking water infrastructure, the eradication of the invasive mesquite, support improved crop husbandry by renewed extension services, and rangeland management. Tradition-based farmer organizations take over responsibility for canal operation and maintenance costs. In addition, river training and regulation works will protect Kassala city and existing irrigation infrastructure. There are a number of early lessons from the GSLRP: reform is possible when local action and national policies are linked and aligned with each other; constant participation and transparency is essential to build trust between stakeholders; strong political and government commitment ensures momentum in field activities; the local Farmers' Union plays a useful role in facilitating the adaptation to governance changes. A final lesson is that progress is demonstrated by increased production in the scheme, especially on plots where land and water rights and access are secured (Cleveringa et al., 2006).

5.2. Road Map

It is strongly recommended that IFAD continues to play an important role in supporting spate irrigation improvement. In many ways IFAD is well-positioned in this regard, as it has been engaged in various spate projects in different countries and contexts. IFAD also has a strong focus on the alleviation of rural poverty and agricultural development, and a broad livelihood-based approach in most of its activities. Supporting spate irrigation relates to three of IFAD's key themes, namely rural poverty alleviation, local food security and local climate changed adaptation.

In terms of development projects IFAD should seriously consider becoming actively involved in spate irrigation in Pakistan and in Ethiopia, in addition to continuing with work in which it has already engaged in other countries.

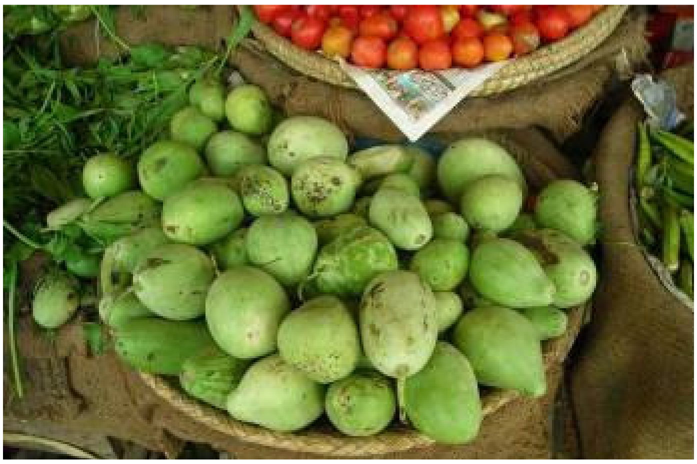
In Pakistan spate irrigation concerns a huge area – covering the dry Western side of the Indus. The most reliable estimate for the area under spate irrigation (called *rodh kohi* in NWFP and Punjab, *sailaba* in Balochistan and *nai* in Sindh) in Pakistan is 1.2 M ha –equivalent to 9% of the entire irrigated area in Pakistan. It covers entire or major portions of the cultivable land in the districts of DI Khan, Tank, Kohat, Laki Marwat, Bannu (NWFP), DG Khan, Rajanpur, Mianwali (Punjab), Kacchi, Sibi, Jal Magsi, Qila Saifullah, Lorelai, Musakhel, Barkhan, Las Bela (Balochistan), Dadu, Larkana, Jamshoro, Karachi and Thatta (Sindh).



Pakistan, Las Bela Broken Bund - Uncertainty is Inherent to Spate Irrigation

The area under spate irrigation in Pakistan also represents the area where there is widespread poverty, probably more than any other single area in Pakistan. Poverty is related to the uncertainty that is inherent to spate irrigation, the absence of a reliable drinking water supply and the marginal location and political clout of spate areas in all four provinces, NWFP, Punjab, Balochistan and Sindh. Periods of drought are inherent to spate irrigation, resulting in hardship and temporary depopulation of areas. The spate areas have high infant mortality, low literacy and school attendance and tensions between landlords and (hereditary) tenants.

In spite of the size of the area under spate irrigation and its importance in poverty alleviation in Pakistan, the area is very much neglected and almost invisible in programs and policies of government and civil society. In several parts there has been a steady deterioration in water management, resulting in a downward spiral for these areas. This deterioration is manifest in the construction of unauthorized water diversions, the silting up of the flood channels and the development of gullies distorting the hydraulics. In addition there has been an impoverishment in forestry resources, rangelands and livestock material.



Pakistan - Wild Teetak Vegetables

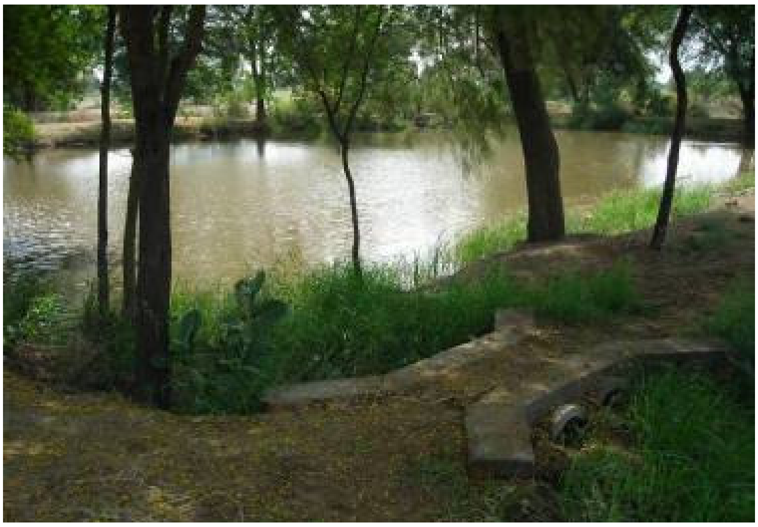
Nonetheless, there are considerable opportunities to revive and improve the productivity of the spate irrigated areas. Crop yields of the main spate irrigated crops in Pakistan (sorghum, millet, wheat, pulses) are low compared to international figures – and there is considerable scope to do better. Also, improved grain storage can reduce losses that are now at 6-20%. Spate areas are potentially the most suitable areas in the country for the cultivation of oilseeds. In addition there are a number of very promising crops to be promoted by agricultural extension and improved marketing and processing, such as guar and sesame. There are also promising minor crops, from area-specific vegetables and medicinal plants to truffle mushrooms. There is scope to improve forest production, either along river banks or in special fenced plots in the

outwash areas. Livestock is an important and stable source of income and spate areas have produced important species, such as Bagh Nari, Sindhi Red Bull and Loghari Goat and Sheep. There is substantial scope for reviving livestock production by improving indigenous stock, improved fodder and feed (such as molasse blocks and urea treatment) as well as rangeland management. Much more can be done to ameliorate drinking water supply by improved clay or plastic lined drinking water ponds for humans and livestock.

Water management has been problematic in recent years. The introduction and subsequent withdrawal of free and/or subsidized earth moving equipment has resulted in a decline of local institutions and has eroded the capacity to maintain and restore. At the same time the effective co-management system of local government (under Revenue Department) and farmers that ensured the regulation and timely construction of the earthen structures has declined for a number of reasons, for instance a change of power in local government under devolution. Even though water management decreased, there is still room for many low cost high impact improvements, such as reinforced earthen diversion bunds, fixed canal intakes, bed sills, gully plugs, field intakes and overflow structures. A number of these interventions have been undertaken recently in some areas and have been very beneficial.

Pakistan - DI Khan - Investments in Small Field Intakes and Overflow Structures Can Greatly Improve Field Water Management

In Ethiopia spate irrigation is increasing substantially in Tigray, Amhara, Oromia, Afar and SNNPR. This is driven both by farmer's investment and by development programmes of government and a limited number of civil society organizations. According to various recent estimates traditional spate irrigation farms in north, south and south-eastern parts of the country collectively exceed 100,000 ha. The recent Annual Report by the Ministry of Federal Affairs of Ethiopia claims that the total area covered by spate irrigation in the lowland parts of the country is 140,000 ha. There is growing government investment in spate systems. Spate projects under design and construction are close to 50,000 hectares, mainly in the south-eastern parts of Ethiopia.



Spates Fill Ponds for Use by Humans and Livestock

There is a search for appropriate engineering approaches and techniques in Ethiopia. In Ethiopia, as in other parts of the world, spate irrigation is not a topic taught at universities or polytechnics and there is little exchange of intra- and international experiences – either among farmers or among professionals. Techniques well-known in other parts of the world, such as soil guide bunds or flood water spreading, still have no history in Ethiopia. There is also much to gain from innovative practices in the field of agronomy, spate agro-forestry, and moisture management techniques, livestock keeping as well as improving local drinking water supply, either from groundwater or improved drinking water ponds. Conjunctive use of spate systems as means of soil and water conservation add more value to spate irrigation practices. Water stored in the sub-surface will be utilized in absence of the floods and the alluvial deposit helps minimize expenditures on fertilizer.

The agronomy of spate irrigation systems shall be given great attention. High value crop production, such as sesame and groundnut, have much potential, if supported by improved marketing conditions, as almost all of the spate areas are situated in remote areas.

The potential for spate irrigation in the Ethiopian lowlands is much greater. Many of lowland areas receive food relief aid every year, the continuation of which is becoming increasingly insecure in this changing world. It has become very necessary to systematically assess the potential of spate irrigation in the lowlands of Ethiopia and implement livelihood improvement based on integrated spate irrigation support programmes.

Apart from direct investment there is also a need to boost knowledge management on spate irrigation. It is still not known what the total land area under spate irrigation is worldwide, particularly data is lacking on spate irrigation in Central Asia, China and Latin America. Data from FAO’s Aquastat show either no spate irrigation (China, Latin America) or very substantial areas (Kazakhstan) – but the true nature and scale of these largely informal systems are unknown.

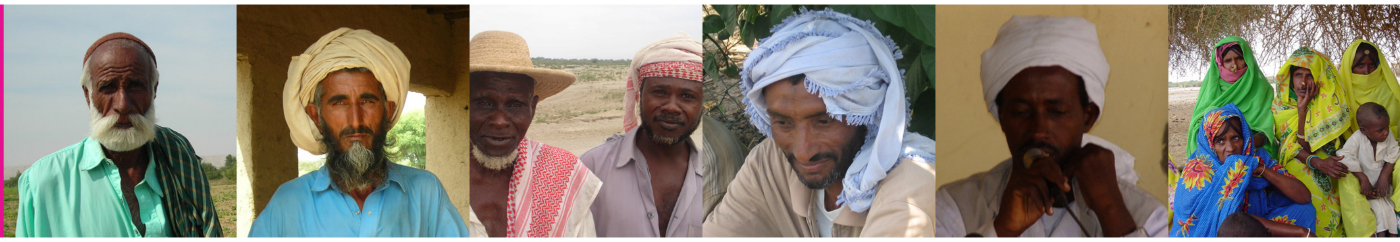
Eritrea - Farmer Leader - Social Organization Is Different from Conventional Water System

Currently no university or polytechnic provide a course dealing with spate irrigation, even though the hydraulics, the field water management, the agronomy and the social organization are different from conventional water resource systems. Presently there are also very few research programmes on spate irrigation. Where they exist, they work with limited national funds and often operate in relative isolation. The record of international research on spate irrigation is not commendable. Some CGIAR institutes mention spate irrigation superficially in some of their publications, but contribute very little to the topic. Only the FAO distinguishes itself in this regard, and in collaboration with the Spate Irrigation Network, is working on updated guidelines and organizing the first international meeting on the topic in twenty years. The Spate Irrigation Network (with a list of 250 spate practitioners and professionals and two country networks) has used its own resources to work on developing training packages in spate irrigation, on promoting the earlier version of the guidelines, providing support to spate irrigation projects and maintaining a library with grey material on its website. The Spate Irrigation Network has been documenting local practices with the help of ILEIA (Institute of Low External Input Agriculture) and will organize short international summer courses on spate irrigation with IHE-UNESCO starting from 2008.

There is a need for more exchange and experience sharing on general approaches and on specific topics, such as agronomic practices or improving traditional engineering. It is important to connect the different organizations working in spate irrigation within countries and across borders and promote and lobby for adequate and appropriate attention to spate irrigated livelihoods and developing appropriate courses in national educational institutes.

The Spate Irrigation Network, FAO and others could play an active role in:

- Advocacy and promotion of adequate support activities and policies;
- Initiating activities and initiatives to support the development of spate irrigation areas and build a wider knowledge base – primarily from documentation of on-going practices in writing but more in visual material;
- Exchange of information on the improvement of livelihoods in spate irrigated areas on a wide range of topics: improved water management, local engineering, livestock and domestic water supply, crop management, livestock and forestry and others;
- Dissemination of material and publications of small write ups in popular local media describing status and potential of spate irrigated areas, linking with local journalists;
- Supporting the development of trainings in local education facilities and engage NGOs, local governments and others in this; and
- Actively initiate activities in support of spate irrigation – trials, demonstration and pilots.



References

AIACC, 2007. A Stitch in Time: Lessons for Climate Change Adaptation from the AIACC Project, AIACC Working Paper No. 48. The AIACC Project Office International START Secretariat 2000 Florida Avenue, NW Washington, DC 20009 USA www.aiaccproject.org.

Ahmad, S. Spate Irrigation Profile of Pakistan (ftp://ext-ftp.fao.org/AG/Data/agl/aglw/Spate/Profiles/Pakistan/Profile-MS-CG%20Pakistan.pdf).

Alamerew, E., B. Fentaw and Seid Ali.Traditional Rainwater Harvesting Systems for Food Production: the Case of Kobo Wereda, Northern Ethiopia. Addis Abeba: ERHA.

Cleveringa, R. Audrey Nepveu de Villemarceau, Ali M. Adeeb, 2006. Local governance to secure access to land and water in the lower Gash watershed. Rome: IFAD.

Egemi, O. Assessment of the Land Tenancy Reform Process – Gash Sustainable Livelihoods Regeneration Project. Rome IFAD.

Fars research Centre for Agriculture and Natural Resources, 2003. Assessment Methodology, prepared for Second Project Workshop "Sustainable Management of Marginal Drylands (SUMAMAD)".

FAO, Draft. Water and the Rural Poor: Interventions for Improving Livelihoods in Sub-Saharan Africa.

Floodwater Spreading of Spate Irrigation, the Artificial Recharge of Groundwater, and Flood-Damage Mitigation in Iran (ftp://ext-ftp.fao.org/AG/Data/agl/aglw/Spate/Profiles/Iran/Spate-Iran.doc).

Ghebremariam, B.H., 1998. Community Spate Irrigation in Bada (Eritrea). MSc Thesis Wageningen University.

Government of Balochistan, Asian Development Bank and Royal Government of Netherlands, 2007. TA-4560 (PAK) project for "Supporting Implementation of IWRM Policy in Balochistan", Water for Balochistan Policy Briefings, Volume 3, No.10.

Haile Ghebremariam, B. and F. van Steenbergen, 2006. Agricultural Water Management in Ephemeral Rivers: Community Management in Spate Irrigation in Eritrea. African Water Journal, 1, 1, pg 54-71.

Haile, A. M, B. Schultz and H. Depeweg, 2003. Water Sharing and Conflicts in the Wadi Laba Spate Irrigation System, Eritrea. Sponsored by the Netherlands Government within the NUFFIC-MHO programme; co-operation between the University of Asmara, Eritrea and the Wageningen University: ref. MHO/UoA/WU Agricultural Science II project nr. ERI/624A and ERI/625B).

Hussain, S. S. and M. Mudasser, 2007. Prospects for wheat production under changing climate in mountain areas of Pakistan – An econometric analysis. Agricultural Systems 94 494–501.

IFAD, 2003. Gash Sustainable Livelihoods Regeneration Project; Target Group and Project Description, Volume 1 of Appraisal Report 1462-SD.

IFAD, 2004. Local Governance to Secure Access to Land and Water in the Lower Gash Watershed, the Sudan; Land and Water Governance Case Study – Gash Sustainable Livelihoods Regeneration Project.

Iqbal, F. History of Daraban Zam. DI Khan: Veer.

IPCC, 1998. IPCC Special Reports to the Regional Impacts of Climate Change – An Assessment of Vulnerability. Edited by Watson, R. T., M. C. Zinyowera, R. H. Moss and D. J. Dokken. Cambridge University Press.

IPCC, 2007a. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, *Published for the Intergovernmental Panel on Climate Change*. Cambridge University Press.

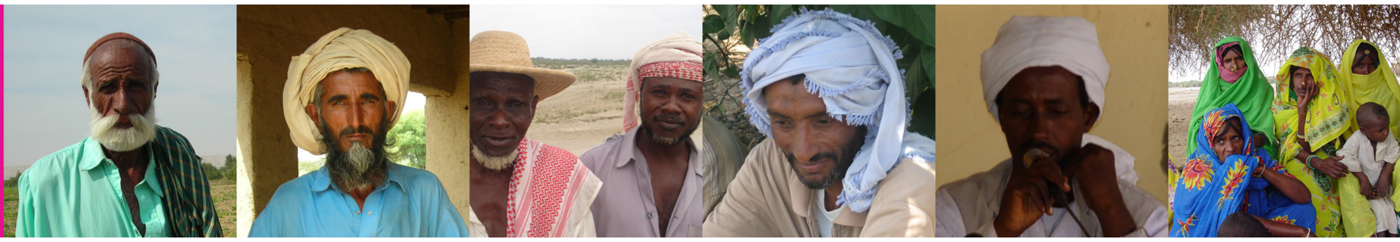
IPCC, 2007b. Climate change 2007 - The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, *Published for the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Lawrence, P. and F. van Steenbergen, 2005. Improving Community Spate Irrigation, Report OD 154, DFID.

Lawrence P. and F. van Steenbergen, 2004. Community Spate Irrigation Guidelines. Wallingford: HR Wallingford. To be reissued by FAO.

McKee, J., 2007. Ethiopia Country Environmental Profile. EC Delegation, Addis Abeba.

Mehari A. H., 2007. A tradition in transition: water management reforms and indigenous spate irrigation systems in Eritrea. Leiden: Taylor and Francis/Balkema.
Mehari Haile, A., F. van Steenbergen and B. Schultz, 2005. Water rules and rights and management in spate irrigation systems. In: B. van Koppen, J. Buttersworth and I.J. Juma (eds), African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa: Proceedings of Workshop, Johannesburg 26028 January. Pretoria: IWMI, page 23-1-15.
Ministry of Agriculture, 2007. Spate Irrigation Agriculture Baseline Study for Villagers in Gash Barka Region, Eritrea.
Mitiku, H. and Diress Tsegaye. Water Harvesting for Crop Production in Semi-Arid Areas of North-Eastern Ethiopia: Case Study of Floodwater Diversion in Aba'ala Agro-Pastoral Area.
Nawaz, K. and M. U. Qazi. Community Spate Irrigation – Spate Irrigation in Pakistan: Problems and Prospects (www.spate-irrigation.org/librar/spate-pakistan.htm).
Nepvue de Villemarceau, A., 2006. Back-to-Office Report – Mission to Gash, Sudan. Rome, IFAD.
Ogba-Michael, B. The State of Eritrea: Agronomy in Spate Irrigated Areas of Eritrea. Ministry of Agriculture, Department of Regulatory Services, Plant Health Division (http://www.spate-irrigation.org/librar/documents/AgronomyinSpateIrrigatedAreasofEritrea_000.pdf).
Oudra, Ismail, 2008. Spate Irrigation in Morocco: Country Profile. Paper prepared for FAO Expert Meeting on Spate Irrigation, Cairo 7-10 April 2008.
Ragab, R. and C. Prudhomme, 2002. Climate Change and Water Resources Management in Arid and Semi-arid Regions: Prospective and Challenges for the 21st Century. *Biosystems Engineering* 81 (1), 3-34.
Saleh, S. A. A., 2008. Spate Irrigation in Yemen. College of Engineering – Sana'a University, Yemen.
Shahid Ahmad and Abdul Ghaffar Khan, 2007. Sailaba and Khushkaba Farming Systems of Balochistan – Policy Support for Changing Land Use and to Avoid Infrastructure Damages Caused by Flash Floods. Water for Balochistan Policy Briefing (3, 10). Quetta: ADB.
Simms, A. and H. Reid, 2005. Africa – Up in smoke? The second report from the Working Group on Climate Change and Development, nef Publishers.
SOS Faim, 2006. Improving Spate Irrigation – the Experience of Farmers' Communities in Western Lowlands of Eritrea, Farming Dynamics Number 11/12.
Thomas, R. J., *in press*. Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change, Agric Ecosyst Environ (2008).
Thornton, P. K., P. G. Jones, T. Owiyo, R. L. Kruska, M. Herrero, P. Kristjanson, A. Notenbaert, N. Bekele and A. Omolo, with contributions from V. Orindi, B. Otiende, A. Ochieng, S. Bhadwal, K. Anantram, S. Nair, V. Kumar and U. Kulkar, 2006. Mapping climate vulnerability and poverty in Africa. Report to the Department for International Development, ILRI, PO Box 30709, Nairobi 00100, Kenya. Pp 171.
UNEP, 2007. Sudan: Post-Conflict Environmental Assessment. United Nations Environmental Programme, P.O. Box 30552, Nairobi, Kenya.
UNFCCC, 2007. Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries. United Nations Framework Convention on Climate Change. Climate Change Secretariat (UNFCCC) Martin-Luther-King-Strasse 8 53175 Bonn, Germany.
UNHCR, 2002. Assessing the Potential of Spate Irrigation Schemes for the Gash Barka Zoba, Proposal for Pilot Spate Irrigation Scheme.
UNOPS, 2004. Gash Sustainable Livelihoods Regeneration Project IFAD Loan 630-SD/UNOPS project SUD/03/F01, UNOPS Supervision Mission – Aide Memoir.
Water Resources Research Institute & National Agricultural Research Centre, 2001. *Rod-Kohi* System Development and Management in Pakistan - a National Project.
World Bank, 2002. BCIAP Completion Report.
Zaki, El Sayed A.A. and A. Nepveu de Villemarceau, 2006. Gash Sustainable Livelihood Regeneration Project – Follow-Up Mission November 2006.



Annex 1

Experienced and Projected Climate Variability and Change in African and Asian Regions that Practice Spate Irrigation

The climate worldwide is changing at a rate that has not been experienced before in recent human history (Thornton *et al*., 2006). This annex summarizes the projected climate change and variability, and the impact thereof on the different countries where spate irrigation is practiced. This has been done by reviewing a number of recent key publications on the topic. The consequences of climate change are expected to be most significant in tropical countries, and are particularly likely to affect developing countries, which tend to be more vulnerable to the influences of climate change due to their lower capacity to adapt to this change (Thornton *et al*., 2006). There is a clear link between development level and vulnerability to climate and other natural hazards. Disaster risk is significantly lower in high income countries than in medium and low income countries (AIACC, 2007). The low adaptive capacity and susceptibility to climate change in developing countries relate to factors such as a strong dependence on natural resources, restricted capacity to adapt financially and institutionally, low per capita GDP and poverty, as well as a lack of safety nets (Thornton *et al*., 2006). Predominantly countries in Africa are considered most susceptible to climate variability and change (Thornton *et al*., 2006).

Thornton *et al*., (2006) have indicated that in Africa a changing climate is not a future trend, but a phenomenon of the recent past. Throughout the twentieth century the African continent has been warming at a rate of roughly 0.5 ˚C per century (Thornton *et al*., 2006). This is slightly less than the global average surface temperature increase of roughly 0.6 ˚C during the twentieth century, as indicated in the Third Assessment Report of the Intergovernmental Panel on Climate Change (Thornton *et al*., 2006). However, for the past 50 years most of the global warming observed is a result of human activities (Thornton *et al*., 2006). Changing climate trends have not been consistent throughout the African continent. Hulme *et al.* (2001) (Thornton *et al*., 2006) have shown that there are large regional differences in rainfall variability, the Sahel having shown the most substantial multi-decadal variability with recent drying. In East-Africa and South-east Africa the rainfall regime has remained relatively stable, with some evidence of long-term wetting and marked inter-decadal variability in East and South-east Africa respectively (Thornton *et al*., 2006). By 2100 global average surface temperatures have been predicted to increase between 1.4 to 5.8 ˚C, depending to a great extent on the amount of fossil fuel combustion from now onwards, and on the different models used (Thornton *et al*., 2006). Model work carried out more recently suggests even greater temperature increases by 2100 (Thornton *et al*., 2006). Thornton *et al.* (2006) claim that many regions in Sub-Saharan Africa are expected to be negatively affected by climate change, including…"the mixed arid-semiarid systems in the Sahel, arid-semiarid rangeland systems in parts of eastern Africa, the systems in the Great Lakes 4 region of eastern Africa, the coastal regions of eastern Africa, and many of the drier zones of southern Africa."

When it comes to the potential consequences of climate change, generally reference is given to the associated increase in temperature, as denoted by 'global warming' or the 'greenhouse effect'. This tends to undermine other very severe impacts that a changing climate can bring about, namely a change in precipitation; evapotranspiration; runoff and soil moisture, all of which are essential factors to take into account when it comes to water planning and management (Ragab and Prudhomme, 2002). The climatic condition influences and is influenced by the hydrological system, which forms an integrated part of this planet's geophysical system. Hence, with a change in temperature evapotranspiration rates, cloud characteristics, soil moisture, storm intensity, as well as snowfall and snowmelt regimes, will be affected. In turn, with a change in precipitation the magnitude and timing of floods and droughts, shift runoff regimes and ground water recharge rates, will all be affected (Ragab and Prudhomme, 2002).

There is a lot of information to be found regarding climate change and variability and the expected affects thereof on our environment, society and future. However, generally climate data is discussed in a regional context, for instance, the expected climate change and variability in North Africa or South-East Asia. It has been more difficult to find more localized future climate prognosis. Nonetheless, by cross referencing various articles and books, and reference to a number of local case studies, it has been possible to derive rough estimates and descriptions of future climate patterns for countries that are dealt with specifically in this paper. For some countries information retrieved has been more exhaustive than for others. In Tables 1.1 to 1.3 and Tables 2.1 to 2.4, information is provided on present and future climate change and variability for three Asian and four African countries respectively.

Asia	Climate Description	Climate Change	
		Impacts	Sectoral Vulnerabilities
Pakistan	Climate → In the summer, the South Asian region is dominated by the southwest Monsoon which lasts from June to September and dominates the seasonal cycles of the climatic parameters (IPCC, 2007b) *Temperature* → Since the early 1900s the mean temperature in coastal areas has risen between 0.6 to 1.0˚C (IPCC, 2007a) *Precipitation* → In the coastal belt and the hyper arid plains, there has been a 10 to 15% decrease in precipitation, whereas in northern Pakistan there has been an increase in summer and winter precipitation (IPCC, 2007a) *Droughts* → El Niño responsible for 50% of the droughts, the 1999 and 2000 droughts caused a sharp decline in the water tables (IPCC, 2007a)	*Temperature* → For South Asia warming expected to exceed global mean, projected at 3.3°C higher by the end of the 21st century. This warming is large compared to the inter-annual variability of temperature, hence most years and seasons will probably be excessively warm by current standards (IPCC, 2007b) → The number of very cold days in South Asia are expected (*very likely*) to decrease (IPCC, 2007b) *Precipitation* → Predicted rainfall increases, particularly during the summer monsoon (IPCC, 2007a; UNFCCC, 2007), *very likely* increase in the frequency of intense precipitation events in parts of South Asia (IPCC, 2007b) → South Asia is expected to be exposed to more frequent tropical cyclones, coupled with extreme rainfall and winds. The monsoonal flows and the tropical large scale circulation are likely to be weakened (IPCC, 2007b) *Floods and Droughts* → Increased monsoon rains may increase flood prone areas (IPCC, 2007a) → Coastal areas and heavily populated mega delta regions, will be at greatest risk due to increased flooding from the sea and, in some mega deltas, flooding from the rivers (IPCC, 2007a) *Other* → Freshwater availability expected to decrease by the 2050s, especially in large river basins (IPCC, 2007a) → Global warming has caused melting of glaciers in the Himalayas (UNFCCC, 2007) *Note* → The manner in which monsoon processes have been represented has varied a great deal with different models. This, as well as uncertainties with regards to the changes in ENSO, has rendered the future of regional monsoon and cyclone behaviour vague. This has been a bottleneck for obtaining quantative estimates of projected precipitation change. Since the region has a very complex topography and marine influences, it is expected that some local climate changes will vary substantially from regional trends (IPCC, 2007b)	*Agriculture* → Potential locust plague hazard, especially on food crops (Simms and Reid, 2005) → Crop yields predicted to fall by 30%, creating very high risk of hunger (IPCC, 2007) → Hussain and Mudasser (2007) claim that if by the mid-21st century the mean temperature will have risen 3 to 4˚C above the pre industrial period, there is a chance that the average change in wheat yields in South Asia may range between +4% and -34% *Health* → Projected alterations in the hydrological cycle are expected to increase the incidence of floods and droughts, which are consequently expected to increase endemic morbidity and mortality due to diarrhoeal disease (IPCC, 2007a) *Land and Natural Resources* → Pressures on the environment and natural resources are expected to be compounded by rapid urbanisation, industrialisation and economic development (AIACC, 2007)

Table 1.1. Pakistan

Asia	Climate Description	Climate Change	
		Impacts	Sectoral Vulnerabilities
Iran	*Temperature* → There have been several stations between 1951 to 2003, located in different climatological zones of Iran, that have reported a significant decrease in frost days due to rise in surface temperature (IPCC, 2007a) *Precipitation* → Some stations show a decreasing trend in precipitation (Anzali, Tabriz, Zahedan) while others (Mashad, Shiraz) have reported increasing trends (IPCC, 2007a)	*Temperature* → Warming expected to be above global mean, for Central Asia projected at 3.7°C. This warming is large compared to the inter-annual variability of temperature, hence most years and seasons will probably be excessively warm by current standards (IPCC, 2007b) → The number of very cold days in South Asia are expected (*very likely*) to decrease (IPCC, 2007b) *Precipitation* → Predicted rainfall increases, particularly during the summer monsoon (IPCC, 2007a; UNFCCC, 2007), and the frequency of intense precipitation events in parts of South Asia will very likely increase (IPCC, 2007b) → South Asia is expected to be exposed to more frequent tropical cyclones, coupled with extreme rainfall and winds. The monsoonal flows and the tropical large scale circulation are likely to be weakened (IPCC, 2007b) *Floods and Droughts* → Coastal areas will be at greatest risk due to increased flooding from the sea and, in some mega deltas, flooding from the rivers (IPCC, 2007a) *Other* → Freshwater availability expected to decrease (IPCC, 2007a) *Note* → The manner in which monsoon processes have been represented has varied a great deal with different models. This, as well as uncertainties with regards to the changes in ENSO, has rendered the future of regional monsoon and cyclone behaviour vague. This has been a bottleneck for obtaining quantative estimates of projected precipitation change. Since the region has a very complex topography and marine influences, it is expected that some local climate changes will vary substantially from regional trends (IPCC, 2007b)	*Agriculture* → Potential locust plague hazard, especially on food crops (Simms and Reid, 2005) *Land and Natural Resources* → Pressures on the environment and natural resources are expected to be compounded by rapid urbanisation, industrialisation and economic development (AIACC, 2007)

Table 1.2. Iran

Asia	Climate Description	Climate Change	
		Impacts	Sectoral Vulnerabilities
Yemen, Rep. of	*Climate* → The majority of the region (Middle-East) can be classified as hot or cold desert (IPCC, 1998) *Temperature* → Temperature range from -10°C to 25°C (January) to 20°C to more than 35°C (July). From 1955-74 to 1975-1994 the observed change in annual temperature in the region was 0.5°C. In most of the Middle-East there was almost no annual temperatures change during the period 1901-96 (IPCC, 1998) *Precipitation* → In most of the region rainfall is low, but very variable seasonally and interannually (IPCC, 1998) → In the period from 1901 to 1995 there was a 200% precipitation increase in the South-Western part of the Arabian peninsula (IPCC, 1998)	*Temperature* → Warming expected to be above global mean (IPCC, 2007b), and greatest in continental Asia (including West Asia) (IPCC, 2007a). Warming is significant compared to the inter-annual variability of temperature, hence most years and seasons will probably be excessively warm by current standards (IPCC, 2007b) → With models that include the effects of sulphate aerosols the temperature in the region is projected to increase 1-2°C by 2030-2050. Increases are expected to be greatest during winters in the northeast and during summer in part of the region's south-West (IPCC, 1998) *Precipitation* → Predicted rainfall increases, particularly during the summer monsoon (IPCC, 2007a; UNFCCC, 2007) *Floods and Droughts* → Coastal areas will be at greatest risk due to increased flooding from the sea and, in some mega deltas, flooding from the rivers (IPCC, 2007a) → Climate change can affect the physical condition of soils. With an increase in precipitation and a constant or rising temperature, the permeability of soils in the semi-humid region will be altered. As a consequence, more land will become vulnerable to flood hazard and poor drainage (NCCSAP, 2006) *Other* → Freshwater availability expected to decrease (IPCC, 2007a) *Note* → The manner in which monsoon processes have been represented has varied a great deal with different models. This, as well as uncertainties with regards to the changes in ENSO, has rendered the future of regional monsoon and cyclone behaviour vague. This has been a bottleneck for obtaining quantative estimates of projected precipitation change. Since the region has a very complex topography and marine influences, it is expected that some local climate changes will vary substantially from regional trends (IPCC, 2007b)	*Agriculture* → Potential locust plague hazard, especially on food crops (Simms and Reid, 2005) → 20% of the GDP is derived from the agricultural sector, which also accounts for 58% of employment in Yemen. This sector is vulnerable to climate change. The livelihood of the majority of the population will be compromised with the depletion and degradation of natural resources, particularly water and soil (NCCSAP, 2006) *Land and Natural Resources* → Pressures on the environment and natural resources are expected to be compounded by rapid urbanisation, industrialisation and economic development (AIACC, 2007) → With a temperature increase and a drop in rainfall, groundwater resources are insufficient. In most water basins the aquifer levels have dropped by 1 to 8 metres. The countries annual renewable water quantity has been estimated at 2.1 billion m^3, with an estimated 2.8 million m^3 water being pumped up annually, 138% of the annual renewable water budget is used up. In the mountain areas water exploitation exceeds precipitation roughly five times. It is expected that in 50 years time water reservoirs in the region will have dried up at current rates of extraction (NCCSAP, 2006)

Table 1.3. Yemen

Africa	Climate Description	Climate Change	
		Impacts	Sectoral Vulnerabilities
Sudan	*Climate* → Wide geographical variation in rainfall. Large regions can be covered by dust and sand storms for days (UNEP, 2007) → Three seasons can be identified for central Sudan, namely the winter or dry season (Dec. to Feb.); the advancing monsoon season (Mar. to May); and the retreating monsoon season (Oct. to Nov.) (UNEP, 2007) *Temperature* → Monthly temperatures vary between 26 and 36˚C. In the north temperatures can exceed 40˚C (UNEP, 2007) *Precipitation* → Close to 0 north, to roughly 200mm annual precipitation around Khartoum. Annual precipitation can reach up to 700mm just south of Khartoum, but rarely does. Generally precipitation is erratic, with short and long-term droughts and periods with heavy rainfall (UNEP, 2007) → In the extreme south-west annual precipitation can exceed 1,600mm (UNEP, 2007) *Droughts* → Has suffered from a number of long and devastating droughts in the past 30 years (UNEP, 2007)	*Temperature* → 1.6˚C temperature increase in land areas over the Sahara by 2050 (Simms and Reid, 2005) → Detailed analyses based on data from Northern and Southern Kordofan (from 1961 to 1990) resulted in a climate model which indicated an average annual temperature increase of 0.5 to 1.5˚C, with variations across the study area (UNEP, 2007) → It is expected (*very likely*) that the whole African continent will warm more in all seasons than the global annual mean warming. The African continent is expected to warm roughly 1.5 times the global mean response, with the median temperature increase lying between 3°C and 4°C in all seasons by 2099 (IPCC, 2007b) *Precipitation* → By 2050 rainfall may decline by 10% (Simms and Reid, 2005) → Irregular but a distinct decline in rainfall, most vividly illustrated by rainfall data from Khartoum (see Table 2.1), indicate a long term regional climate change in several parts of the country (UNEP, 2007) → Detailed analyses based on data from Northern and Southern Kordofan (from 1961 to 1990) resulted in a climate model which indicated an approximate 5% drop in rainfall, with variations across the study area (UNEP, 2007) → It is unclear how rainfall in the Sahel and the southern Sahara will evolve (IPCC, 2007b) *Floods and Droughts* → Research has shown that historically droughts may have been a result of medium-term (years) change in ocean temperature, hence the potential for severe droughts to occur again remains (UNEP, 2007) *Other* → By 2050 the sea level may rise 25 cm (Simms and Reid, 2005) → An estimated 75% decrease in river flow in the Nile region by 2100 (Simms and Reid, 2005) → Climate variability is also affected by complex feedback mechanisms, mainly deforestation and land cover change and changes in atmospheric dust loading, which has especially resulted in prolonged drought in the Sahel and its surrounding areas (IPCC, 2007a) → In Africa, where soil moisture deficit is already experienced, soil moisture may further decrease. It is predicted that a 2-3°C rise in air temperature along with a 10% reduction in rainfall,	*Agriculture* → Decline in subsistence crops, i.e. sorghum and millet (UNFCCC, 2007) → Potential locust plague hazard, especially on food crops (Simms and Reid, 2005) → Crop models (based on a climate model derived from rainfall and temperature data from Northern and Southern Kordofan from 1961 to 1990) have shown a major and possibly disastrous decline in crop production for Northern Kordofan, as well as significant drops further south. In the El Obeid region, modelled sorghum production is predicted to drop by 70%, from 495 kg/hectare to 150 kg/hectare (UNEP, 2007) → One climate model which has focused on the changes in growing season, predicts that in the Sahel region growing seasons would reduce and the percentage of failed crops would increase (UNEP, 2007) *Health* → Droughts (in the Sahel) over the past 30 years have decreased incidence of malaria, with more floods there is an increased chance of malaria epidemic (Simms and Reid, 2005) → There is an alteration of spatial and temporal transmission of disease vectors, such as malaria, dengue fever, meningitis, cholera, etc. (UNFCCC, 2007) *Land and Natural Resources* → Due to rainfall reduction millions of hectares of land of marginal semi-desert grazing land turned into desert (UNEP, 2007) → Large parts of Sudan, which lie on the fringes of the Sahara desert and represent the northern most limits for rain-fed irrigation, possibly a slight increase in temperature and a small decrease in precipitation could tip the balance towards desert like conditions (UNEP, 2007) *Conflict* → The effects of climate change are believed to have contributed (or are directly related) to conflict in the region, as desertification as a result of climate change have added significant stress on livelihoods of pastoralist societies (UNEP, 2007)

		could result in a 40-70% drop in mean annual river runoff. This would have a dramatic affect on agriculture, water supplies and hydroelectricity (Ragab and Prudhomme, 2002) *Note* → There is a strong need for more country specific and improved climate analysis (UNEP, 2007)	

Table 2.1. Sudan

Rain Gauge Location	Average Annual Rainfall (mm) 1946 - 1975	Average Annual Rainfall (mm) 1976 - 2005	Reduction (-)	Percentage
El Fasher, Northern Darfur	272.36	178.90	- 93.47	- 34%
Nyala, Southern Darfur	448.71	376.50	- 72.21	- 16%
El Geneina, Western Darfur	564.20	427.70	- 136.50	- 24%

Table 2.1.1. Long-term Rainfall Reduction in Darfur (Derived from UNEP, 2007)

Africa	Climate Description	Climate Change	
		Impacts	Sectoral Vulnerabilities
Ethiopia	*Climate* → Ranges from equatorial desert to hot and cool steppe. Climate controlled by seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) and related atmospheric circulations, including the country's topography (McKee, 2007) → Three different seasons have been identified, namely the Bega (Oct. to Jan. Dry Season); the Belg (Feb. to May Small Rainy Season); and the Meher (Jun. to Sep. Long Rainy Season (Ibid, 2006 in McKee, 2007) *Temperature* → This ranges from and annual mean of 10˚C in the north-western and south-eastern highlands to 35˚C in the north-eastern lowlands (McKee, 2007) *Precipitation* → South-western Ethiopia receives up to 2,200mm average annual rainfall, this gradually decreases in all other directions, and averaging less than 200mm per year in the south-east and 100mm in the north-east (McKee, 2007)	*Temperature* → 1.6˚C temperature increase in land areas over the Sahara by 2050 (Simms and Reid, 2005) → Minimum temperatures have increase slightly faster than maximum or mean temperatures (IPCC, 2007a) → It is expected (*very likely*) that the whole African continent will warm more in all seasons than the global annual mean warming. The African continent is expected to warm roughly 1.5 times the global mean response, with the median temperature increase lying between 3°C and 4°C in all seasons by 2099 (IPCC, 2007b) *Precipitation* → By 2050 rainfall may decline by 10% (Simms and Reid, 2005) *Floods and Droughts* → More floods (McKee, 2007). → More frequent and intense droughts (McKee, 2007). *Other* → An estimated 75% decrease in river flow in the Nile region by 2100 (Simms and Reid, 2005) *Note* → The debate that is currently held with regards to climate change focuses too strongly on the presumed impact of global climate change and is inadequately related to the local interrelationships that prevail in Ethiopia (McKee, 2007). Droughts, other extreme weather events and high degrees of climate variability have been inherent to Ethiopia for centuries. Some areas classified as drought prone (i.e. Wag Hamra) have been receiving high and well distributed levels of rainfall for two consecutive years (McKee, 2007) → In Africa, where soil moisture deficit is already experienced, soil moisture may further decrease. It is predicted that a 2-3°C rise in air temperature along with a 10% reduction in rainfall, could result in a 40-70% drop in mean annual river runoff. This would have a dramatic affect on agriculture, water supplies and hydroelectricity (Ragab and Prudhomme, 2002) → In south-central Ethiopia changes in runoff and hydrology have been linked to climate through complex interactions (IPCC, 2007)	*Agriculture* → Decline in subsistence crops, i.e. sorghum (UNFCCC, 2007) → Potential locust plague hazard, especially on food crops (Simms and Reid, 2005) *Health* → There is an alteration of spatial and temporal transmission of disease vectors, such as malaria, dengue fever, meningitis, cholera, etc. (UNFCCC, 2007)

Table 2.2. Ethiopia

Africa	Climate Description	Climate Change	
		Impacts	**Sectoral Vulnerabilities**
Eritrea	*Temperature* → 70% of the land hot to very hot with mean annual temperatures exceeding 27˚C (Haile, 2003) → 20% of the land area is described as warm to mild with annual mean temperature of roughly 22˚C (Haile, 2003) → 5% of the land is cool with mean annual temperatures below 19˚C (Haile, 2003) *Precipitation* → 10% of the country receives more than 600mm of rain, 40% receives between 300 and 600mm, and 50% receives less than 200mm rain per year (Haile, 2003)	*Temperature* → 1.6˚C temperature increase in land areas over the Sahara by 2050 (Simms and Reid, 2005) → It is expected (*very likely*) that the whole African continent will warm more in all seasons than the global annual mean warming. The African continent is expected to warm roughly 1.5 times the global mean response, with the median temperature increase lying between 3°C and 4°C in all seasons by 2099 (IPCC, 2007b) *Precipitation* → By 2050 rainfall may decline by 10% (Simms and Reid, 2005) *Floods and Droughts* → Susceptible to droughts *Other* → By 2050 the sea level may rise 25 cm (Simms and Reid, 2005) → Climate variability is also affected by complex feedback mechanisms, mainly deforestation and land cover change and changes in atmospheric dust loading, which has especially resulted in prolonged drought in the Sahel and its surrounding areas (IPCC, 2007a) → Climate variability is also affected by complex feedback mechanisms, mainly deforestation and land cover change and changes in atmospheric dust loading, which has especially resulted in prolonged drought in the Sahel and its surrounding areas (IPCC, 2007a) → In Africa, where soil moisture deficit is already experienced, soil moisture may further decrease. It is predicted that a 2-3°C rise in air temperature along with a 10% reduction in rainfall, could result in a 40-70% drop in mean annual river runoff. This would have a dramatic affect on agriculture, water supplies and hydroelectricity (Ragab and Prudhomme, 2002)	*Agriculture* → Decline in subsistence crops, i.e. sorghum (UNFCCC, 2007) → One climate model which has focused on the changes in growing season, predicts that in the Sahel region growing seasons would reduce and the percentage of failed crops would increase (UNEP, 2007) *Health* → Droughts (in the Sahel) over the past 30 years have decreased incidence of malaria, with more floods there is an increased chance of malaria epidemic (Simms and Reid, 2005) → There is an alteration of spatial and temporal transmission of disease vectors, such as malaria, dengue fever, meningitis, cholera, etc. (UNFCCC, 2007)

Table 2.3. Eritrea

Africa	Climate Description	Climate Change	
		Impacts	Sectoral Vulnerabilities
Morocco, Algeria and Tunisia	*Climate* → The Sahara and Sahel region experience dust and sand storms which compromise agriculture, infrastructure and health (UNFCC, 2007) *Precipitation* → Currently the Mediterranean region receives 20% less rain in the summer than at the end of the 19th century. In the Moyen-Atlas mountains in Morocco, there has been a 400mm decrease in 30 years (Ragab and Prudhomme, 2002) → In the arid and desert-like zones, mean annual rainfall is less than 100 mm, falling mainly from October to April (winter rain) (Oudra, 2008) → The amount of water exploited in these countries, which is described as the water exploitation index (the percentage of renewable annual water resources) is 40% for Morocco, 20% for Algeria and 83% for Tunisia (Ragab and Prudhomme, 2002) *Temperature* In the arid and desert-like areas of Morocco mean monthly temperatures range from roughly 15°C (Jan. to Feb.) to approximately 35°C (Jul. to Aug.), where maximum temperatures often exceed 40°C during this period (Oudra, 2008)	*Temperature* → 1.6 °C temperature increase in land areas over the Sahara by 2050 (Simms and Reid, 2005) → It is expected (*very likely*) that the whole African continent will warm more in all seasons than the global annual mean warming. The African continent is expected to warm roughly 1.5 times the global mean response, with the median temperature increase lying between 3°C and 4°C in all seasons by 2099 (IPCC, 2007b) *Precipitation* → It is *likely* that annual rainfall will decrease in much of Mediterranean Africa and the northern Sahara (IPCC, 2007b) *Floods and Droughts* → Towards the end of the 21st century Mediterranean Africa is likely to experienced 20% drying, paired with hotter summer temperatures and decreased precipitation and increased likelihood of summer droughts (Thomas, *in press*) *Other* → By 2050 the sea level may rise 25 cm (Simms and Reid, 2005) → In Africa, where soil moisture deficit is already experienced, soil moisture may further decrease. It is predicted that a 2-3°C rise in air temperature along with a 10% reduction in rainfall, could result in a 40-70% drop in mean annual river runoff. This would have a dramatic affect on agriculture, water supplies and hydroelectricity (Ragab and Prudhomme, 2002)	*Agriculture* → Potential locust plague hazard, especially on food crops (Simms and Reid, 2005) → By 2080 Crop yields in the arid and semi-arid regions of Northern Africa, are expected to decrease by as much as 10-30% (Thomas, *in press*) *Health* → There is an alteration of spatial and temporal transmission of disease vectors, such as malaria, dengue fever, meningitis, cholera, etc. (UNFCCC, 2007)

Table 2.4. Morocco, Algeria and Tunisia