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Research Paper

Floods and droughts: The Afghan water paradox

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The views and opinions expressed in this paper are those of the authors and do not necessarily reflect those of CPHD.

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1. Abstract

1.1. Rationale

Afghanistan is a landlocked mountainous country with a climate that can be classified as dry. The climate ranges from arid in the south-west to semi-arid in the central, north and east, with some specific high-mountain climates at the higher elevations. According to most references, the country as a whole is not under water stress, with annual per capita water availability far above 1,000 cubic metres per capita. This is due to a relatively low population density and relatively high precipitation in the highest parts of the mountain ranges. The water availability is unequally distributed spatially, as well as temporarily. This causes the country to suffer from two rather contrary threats: water shortages, often causing serious drought, and water excess, causing frequent destructive floods. While the country has a large variability in climate and landscape characteristics and can be hydrologically subdivided into five river basins with distinct characteristics, many of the issues discussed in this paper have a countrywide bearing. Water scarcity is discussed at the river basin scale, while practical examples are given for the Panj-Amu river basin.

This paper looks at the country's climate characteristics and its sensitivity to drought and floods from various viewpoints and proposes methods for the development of forecasting and coping strategies. It also analyses the legal and institutional framework for implementing such strategies.

1.2. The information known

Most of the precipitation in Afghanistan falls in the winter months, and snow accumulates in the high mountains, forming a school example of water towers. This water becomes available during the snow-melt occurring from April to August in different parts of the country and coincides with (part of) the period of highest water demand. The accumulation of much of the water in the form of snow offers the unique opportunity rather accurately to predict water availability and the probability of floods and drought at the beginning of the growing season. New technologies such as remote sensing and computer modelling enable point observations to be extrapolated or interpolated to area-wide values and so significantly improve the predictions

of water availability, floods and drought. Remote sensing provides continuous measurements of target variables over large areas; however, ground verification is often needed. To date, little has been done with this information, partially due to uncertainty about the reliability of remote sensing data. There is a lack of sources for ground verifications because of the absence of systematic data collection on weather, snow accumulation and river flows.

The new Water Law combines modern public management principles, such as the division of tasks and private sector involvement, with sound hydrological and environmental principles, such as integrated water resources management in river basins and mechanisms for public participation in decision-making. This is an ideal setting for the use of forecasts in defining preparedness strategies. The tradition of local institutions in water management improves the excellent potential for the proactive participatory management of water resources and the mitigation of forecasted shocks. Due to the remoteness of rural areas and the multitude of locations sensitive to drought and floods, public participation in flood and drought preparedness and mitigation is essential. This is simply impossible for a government alone, however well resourced to deal with all the frequently occurring crises.

The combination of information provision to the public and the development of plans and mitigating and coping strategies is still in the initial stages. Thus, Afghanistan is not yet fully benefiting from the unique opportunities that nature and state building offer for the development of an effective participatory flood and drought preparedness strategy.

1.3. Discussion summary, conclusions and recommendations

It is highly recommended that the Afghan Government and donors jointly develop a flood and drought early warning, preparedness and coping system. Such a system should be built on the use and calibration of satellite-based estimates. The system should be accompanied by an information sharing strategy using the opportunity of new participatory institutions. These institutions could also form the basis for preparedness and coping mechanisms. This system could have a tremendous impact by reducing the effects of repetitive floods and drought. The current situation offers unique opportunities to develop such a system.

2. Introduction

2.1. Background

Afghanistan is a mountainous landlocked country located between 29° and 36° north. The climate ranges from arid in the south-west to semi-arid in the central, north and east, with some specific high-mountain climates at the higher elevations. The country is characterized by the frequent occurrence of drought and floods. Often, the question is posed whether Afghanistan can be classified as water rich or water poor. One of the problems with this question and others that require an exact answer is poor data availability.

On water resources, the available data are weather data and river flow or hydrometric data. The hydrometric data available are from the period between 1940 and 1979, and there is a complete absence of new structured data. Climate and weather data are available for the same period. However, there are scarce additional data between 1979 and 2002; new data have been collected since 2002. The use of these new weather data is limited since they are incomplete and often difficult to access. Much of the analysis presented through the Agromet Project of the US Geological Survey (USGS) is based on average conditions. Although useful for climate descriptions and in indicating long-term trends, average conditions are a rather theoretical concept in describing weather, especially in semi-arid regions where inter-annual variability is high.

Floods occur regularly in Afghanistan and are documented in a large number of articles in newspapers and on web pages. Only recently (18 April 2010), flash-floods occurred in Baghlan Province and caused victims and considerable material damage (*Afghanistan Times*, 21 April 2010; UNOCHA 2010). There is no systematic monitoring system, however, and information on floods and their causes is extremely poor because no measurements are being conducted on rainfall intensities. Floods resulting from high water accumulation in the mountains may be predicted and followed; nonetheless, a national database is absent.

There is a need for preparedness for drought and floods. Specifically, drought and gradual snow-melt floods can be relatively well forecasted for seasonal planning due to the special precipitation characteristics in Afghanistan. Most of the precipitation in Afghanistan falls in the winter and in the form of snow, which accumulates in the high mountains, which are often called water towers (for example, see Viviroli et al. 2007).

Of Afghanistan's water resources, 80 percent originate in the Hindu Kush Mountains at altitudes above 2,000 metres. These resources include permanent snowfields and glaciers, as well as seasonal snowfall, which accumulates during the winter months and melts during spring and summer, thus supporting the perennial flow of all major rivers. Afghanistan is therefore heavily reliant on irrigation during the summer months when there is virtually no precipitation in the lowlands to support agricultural production. These cryospheric elements are highly susceptible to long-term climatic change, as well as inter-annual climatic variation.

Remote sensing can give a good indication of the changes in snow and ice cover over the last 40 years. It can also be of great value in the development of a forecast and preparedness system based on snow cover and snow-water equivalent (SWE) estimates. Information flow to the public and the development of self-help strategies and participatory planning for preparedness will be of great importance in effectively establishing and responding to the forecasts.

Apart from seasonal, short-term planning, there is a need for long-term planning of drought and flood preparedness. A long-term drought and flood control plan should include control of river flow through large and medium storage dams, as well as catchment protection and water harvesting techniques; all these control measures are widely recommended (for example, see Bhattacharya et al. 2004, Eriyagama et al. 2009).

The ability to monitor both the extent of snow cover and the timing of depletion is invaluable in predicting flood frequency and intensity and the expected summer drought before the winter rains. The use of satellite sensors and the interpretation of the data using remote sensing tools provide a suitable platform for monitoring environmental variability at high spatial and temporal resolutions. This is especially useful in countries such as Afghanistan where the widespread lack of security restrict the collection of field data.

The vulnerability of Afghanistan's water resources was demonstrated at the national level, with disastrous consequences, in 1999–2001, when below average precipitation, combined with mild winters, resulted in significant decreases in snowfall. Moreover, increases in the daily low temperature caused early and accelerated snow-melt in the Hindu Kush. This resulted in a substantial decrease in the water available for crucial irrigated crops over the summer months (FAO and WFP 2004). The trend is expected to continue. In the course of the 21st Century, water supplies stored in glaciers and snow cover are projected to decline, reducing water availability in many regions supplied by melt water from major mountain ranges (Christensen and Hewitson 2007).

Water crises occur in many countries. The crisis in water management is generally considered a crisis of governance (World Water Forum 2006). The new Water Law in Afghanistan forms an excellent enabling environment for good water governance (*Gazette* 980, April 2009). In its first article, the law recognizes the need for economic development, social equity and environmental integrity. The law is based on integrated water resources management. It uses river basins as the basic management unit and identifies institutions that are to participate in operations and maintenance, system development and decision-making. Water users can form water user associations and can be represented in river basin and sub-river basin councils, which are empowered in decision-making after an initial capacity-building period.

Combining the possibilities of remote sensing and other new techniques with a good information strategy and participation in decision-making, this represents a tremendous opportunity for good water governance. This good water governance has the potential to pave the way for preparedness for efficient flood and drought impact mitigation through the creation of water storage facilities at various scales and increased water use efficiency, demand management, the sharing of water and responsibilities, and responsible decision-making. This would include climate change preparedness.

2.2. Literature review

Water is a precondition for life and therefore one of the most precious resources, especially in the drier regions of the earth, which are generally found between 20° and 35° north and south of the equator. Due to rapid population growth, combined with economic development, the pressure on water resources has increased rapidly over the last century and is accelerating (Michel and Pandya 2009). The result is fierce competition over water across various sectors in society, administrative units and countries.

To classify Afghanistan as a water-scarce or water-rich country is not an easy task. There is considerable variation in the literature on how to classify water scarcity, and the data availability in Afghanistan is poor.

Considerable attention has been paid to classifying water availability and drought severity in regions, countries, or river basins and sub-river basins (for example, see Smakhtin et al. 2004, Thenkabail et al. 2004, Vörösmarty et al. 2000, 2005). However, it is not all that straightforward to determine if water is truly scarce (a supply problem), or should be used more efficiently (a demand problem) (Rijsberman 2006).

One of the most straightforward and common indicators is the water stress index of Falkenmark et al. (1989), often referred to as the Falkenmark indicator. This indicator is based on annual water availability per capita as an index and distinguishes four classes, as follows: (1) no stress for water availability per capita: greater than 1,700 cubic metres per capita; (2) moderate stress: between 1,700 and 1,000 cubic metres per capita; (3) water scarcity: less than 1,000 cubic metres per capita; and (4) absolute scarcity: less than 500 cubic metres per capita. Yang et al. (2003) conclude that there is a threshold of about 1,500 cubic metres per capita per year below which a country's cereal imports become strongly inversely correlated with renewable water resources. Smakhtin et al. (2004) use environmental flows as a basis. In this perspective, Afghanistan would be considered water scarce.

Human Development Report 2006 (UNDP 2006), which focuses on the global water crisis, uses the Falkenmark indicator of 1,700 cubic metres per capita as the threshold value for water stress. It admits, however, that this is an arbitrary value. The report also uses a social minimum of fresh water consumption, which it defines as 20 litres per person per day for all uses. An average consumption of 50 litres per person per day for all uses is taken as the threshold value below which a country is considered to be experiencing water poverty. How much water will be needed per person per day in coming decades is not a fixed number, but depends on a myriad of policy and personal choices. This is the reason quantifying water scarcity is such a complicated matter (Rijsberman 2006). In this paper, for the sake of simplicity, we use the Falkenmark classification because it includes the water requirements for households, agriculture, energy and the environment.

There is also the phenomenon of drought in Afghanistan. Drought is not restricted to arid, semi-arid, or water-scarce areas only, but occurs in all climates periodically. It starts with a lack of precipitation, but can have effects on stream-flow, soil moisture and groundwater. It is generally a slow process and difficult to detect (Eriyagama et al. 2009). Drought events evolve slowly, and their impacts generally span a long period (Cancelliere et al. 2007). Therefore, it is important to develop a robust drought monitoring and forecasting system, conduct evaluations of the impacts and the duration of drought and relate this to characteristics of drought events such as duration and magnitude. The magnitude seems to be more important than the duration of the drought period (Eriyagama et al. 2009).

Various types of drought—meteorological, hydrological and agricultural—have been distinguished. However, all sources generally agree that countries with weak economic structure, reliant mainly on agriculture, are more impacted by drought than economically more diversified countries. According to the National Drought Mitigation Center (NDMC 2006), meteorological drought refers to degree of dryness under conditions of less than normal precipitation, agricultural drought relates to the impact of reduced precipitation or stream-flow on agriculture and hydrological drought refers to reduced stream-flow or groundwater availability as a result of reduced precipitation.

Thenkabail et al. (2004) present a drought forecasting method for southern Asia, including Afghanistan. Their drought assessment study is based on remote sensing and aims at drought preparedness. Ground verification for their data was mainly based on data from western India and Pakistan. They demonstrate that drought in India could have been forecasted several months earlier using remote sensing rather than conventional methods alone.

Eriyagama et al. (2009) have conducted a worldwide study on drought impact that is also largely based on remote sensing and publicly available data. They conclude that agricultural economies, such as Afghanistan, are much more vulnerable to drought than other economies. They also point to the danger of drought mitigation strategies that rely on surface water only.

Many drought indicators are based on the statistical analysis of rainfall data; low rainfall is often followed by low flows in rivers, with a time lag of several weeks. This time lag makes drought monitoring important and offers opportunities to forecast drought impact. The indicators most widely used for the analysis of rainfall data are the standard precipitation indices, which express the severity of drought. Through the use of statistical techniques, forecasts can then be made on drought impacts (Cancelliere et al. 2007). Another frequently used method for drought classification is the Palmer indices, which also provide valuable forecasts of drought impacts (Vasiliades and Loukas 2009).

However, in Afghanistan, the availability of rainfall data and the density of rainfall stations are too low for the performance of such analyses. Therefore, data could possibly be supplemented by satellite-based rainfall estimates (RFEs). There will need to be calibration of the rainfall data to the RFEs, which can be cumbersome. For example, Artan et al. (2007) mention that there is only good correspondence between the two data sources if the data are accumulated on a monthly basis. Daily data do not show a good correlation.

Afghanistan is not only subject to regular drought, it also experiences intense floods. There are two types of floods occurring in Afghanistan, flash-floods and gradual floods due to rising rivers. A flash-flood is described as "a flood that rises and falls quite rapidly with little or no advance warning, usually as a result of intense rainfall over a relatively small area" (Colombo et al. 2002: 1). Information on the impact of floods worldwide is available through the Disaster Risk Index of the United Nations Development Programme and the Natural Disaster Hotspots Project of the World Bank (UNDP 2004, Dilley et al. 2005). The latter project uses mortality and economic loss as indicators of the severity of earthquakes, volcano eruptions, landslides, floods and drought.

As with drought, flood predictions are also increasingly being made on the basis of remote sensing data. Verdin et al. (2005) describe a method using imagery of the US National Oceanic and Atmospheric Administration and the resulting RFEs to develop river basin excess rainfall maps, which are applied to forecast floods and river flows. Asante et al. (2007) and Artan et al. (2007) show the potential of remote sensing and the geospatial stream-flow model for flood forecasting in southern Africa, Egypt and South-East Asia. Artan et al. (2007) warn that appropriate calibration is needed.

The most complete set of flood and flood-related data are maintained through the Dartmouth Flood Observatory, an interactive database and map (see http://floodobservatory.colorado.edu/index.html). Associated with the database are algorithms to convert spectral data from remote sensing to flow data on rivers.

Snow and Ice account for 80 percent of Afghanistan's water resources. Remote sensing can be used effectively to monitor trends in snow and ice. Current glacier surveys make use of high-resolution satellite imagery such as Landsat and the Advanced Spaceborne Thermal Emission and Reflection Radiometer, together with topographical parameters, to delimit glaciers. Global programmes such as the Global Land Ice Measurements from Space Project and the World Glacier Monitoring Service are documenting the extent of global land ice and monitoring changes due to recent warming trends (Bishop et al. 2004, Haeberli et al. 2002).

Glaciers have been studied in Afghanistan since at least the mid-1970s, when Jack Shroder at the University of Nebraska began systematically inventorying and monitoring changes in the glaciers of Afghanistan using Landsat imagery and Russian topographic maps. This work has been continued in the past decade by USGS.

Among the glaciers and areas that have been the subject of detailed investigations are the large debris-covered, retreating North and South Issik and Zemestan Glaciers of the central Wakhan area in the Pamir Mountains; the small retreating cirque and valley glaciers of the Koh-i-Baba Range located west of Kabul; the retreating, debris-covered Keshnikhan Glacier; adjacent small debris-covered glaciers at the western end of the Wakhan panhandle; and the retreating, debris-covered valley glaciers in the region of Panjshir Valley (Molnia 2009).

Results from the USGS survey in the Wakhan area report that nearly all glaciers examined (approximately 500) show signs of recent thinning and retreat. Many cirques and small glacier fragments are present, and many glaciers have significant debris-covered lower reaches hosting numerous supraglacial lakes and thermokarst pits, which are often found on stagnant or slowly moving ice (for example, see figure 1).

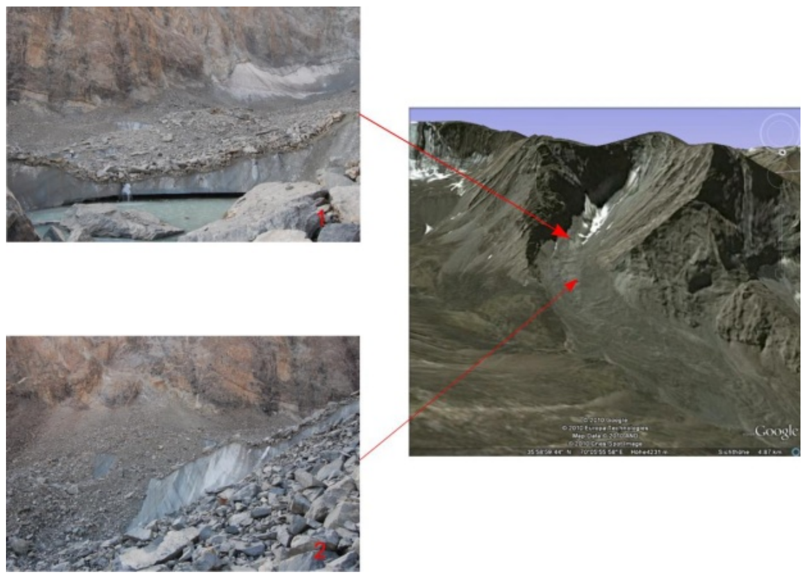


Figure 1: A typical debris-covered glacier in the Mian Shar Valley, Warsaj. Automated glacier-mapping algorithms rely on the reflectance properties of snow and ice. The glacier pictured is almost entirely debris covered. Field investigations in 2008 confirmed this to be a debris-covered glacier, but with evidence of down-wasting, as shown by thermokarstic supraglacial ponds. Reliance on reflectance properties alone underestimates water resources in regions where debris-covered glaciers are common.

The reduction in ice mass poses a significant threat to the security of water resources at a time when Afghanistan seeks economic development. Together with a growing population, this will most likely place greater demands on water supplies. In addition, glacial lakes often form as glaciers melt and recede. These are often held back by moraine dams, which may fail due to increased volumes of water or become overtopped due to increased glacier-melt rates. These events are known as glacial lake outburst floods and have been observed in parts of the Himalayas and the Andes in recent years. While none have been recorded in Afghanistan to date, a careful monitoring programme is certainly needed as new water bodies form in high-mountain areas.

A major difficulty in assessing water resources locked up in glacial ice is the large proportion of debris-covered glaciers in Afghanistan. This makes it difficult to discern the extent of glaciers from surrounding moraine debris using traditional satellite-based reflectance algorithms. Paul et al. (2010) find that mapping the debris-free portion of glaciers alone in the Himalayas underestimates the glaciated area by up to 50 percent. They propose a new technique involving the level of coherence across radar images acquired on separate dates. Low coherence signifies movement and can therefore be used to differentiate between a debris-covered glacier and moraine debris.

Regardless of the severity of floods and drought and the impact of climate change on water resources and regardless of the success of long-term efforts taken to manage water shortages and periods of high water more effectively, such as through storage dams and catchment protection, a major and consistent challenge is achieving the involvement of civil society in information sharing and flood and drought preparedness (for example, see Revenga 2006, Bhattacharya et al. 2004).

In Afghanistan, seasonal snowfall is an extremely important input to the annual water budget. The vast majority of the precipitation falls at high elevations and in winter, mainly as snow. As it melts in spring, this frozen reservoir recharges groundwater and feeds rivers through surface runoff. Agriculture and human settlements are dependent on the state of the winter snowpack in many areas of Afghanistan. According to an old Kabuli saying, "May Kabul be without gold rather than without snow."

The ability to monitor both the extent of snow cover and the timing of depletion is invaluable in predicting flood frequency and intensity and the expected summer drought before the winter rains. The use of satellite sensors and the interpretation of the data using remote sensing tools provide a suitable platform for monitoring such environmental variability at high spatial and temporal resolutions. This is especially useful in countries such as Afghanistan where widespread lack of security restricts the collection of field data.

The winter snowpack can be described according to three main parameters: snow-covered area, snow depth and SWE. SWE is an extremely useful measure for water resource planning as it takes into account the density of the snowpack and therefore indicates how much water would be available if the snowpack were suddenly to melt.

Snow-covered area is the most robust snow parameter as it is measured at relatively high spatial resolution (500 metres) and is directly observed via the moderate-resolution imaging spectrometer (MODIS) satellite using a snow detection algorithm (Hall 2002).

Rosegrant et al. (2002) offer a comprehensive review of the expected developments in the water sector until 2025. They use river basins as the basic unit of analysis and extend the analysis beyond water-for-food scenarios by introducing environmental water constraints. They also introduce water as an economic good and use pricing mechanisms to analyse the effect of price on water use efficiency relative to corresponding results based on the business-as-usual scenario. Revenga (2006) gives a positive assessment of this publication in a book review. She argues, however, that the inclusion of an analysis of required governance and institutional reforms would have made the publication of Rosegrant et al. even more comprehensive and groundbreaking.

3. Materials and Methods

3.1. Historical hydrological and climate records

The best information source on renewable water supplies in Afghanistan is the *Watershed Atlas* of Favre and Kamal (2004). The atlas uses river basins as management units and grounds an hydrologic analysis on hydrometric data at 31 selected stations. These stations span a period from the 1940s or 1950s to 1979. The hydrometric data consist of daily discharge data in cubic metres per second and are generally referred to as historical data.

The complete historical hydrometric data of some 100 stations have been analysed through various projects, and time series analysis indicates that the series is consistent and reliable, although the data from some stations cover only short time intervals. The raw data have been lost, however, and, presently, only the daily average recharges are available. This precludes the analysis of river levels and instantaneous high floods.

The climate of Afghanistan falls within a dry climate zone typical for regions between 20° and 35° latitude. The data on climate are mostly from the period before the Russian invasion in 1979, and many of the data have been lost. Therefore, basic data for drought analysis are not available. Data indicating rainfall intensities and the corresponding trigger values for overland flows and resulting flash-floods are absent as well. Most of the precipitation falls in the winter months, and the largest quantities occur in the form of snow in the mountains. (Savage et al. (2009) have carried out an analysis of climate change and its impact on Afghanistan.)

Traditional methods of drought assessment and monitoring rely on precipitation data. These are quite limited in this part of Asia, and satellite imagery may be used as an alternative (for example, see Thenkabail et al. 2004). This is more specifically the case in Afghanistan. Fiddes (2007) uses satellite imagery data to compare snow coverage with river flows and to detect climate change. Savage et al. (2009) use the model data from climate modelling work recently undertaken in the United Kingdom for the Department for International Development by the University of Oxford and the Tyndall Centre for Climate Change Research.

Valuable satellite imagery data for drought and flood monitoring are available through the US National Oceanic and Atmospheric Administration and MODIS. These data are freely available and can be used to calculate vegetation indices—the normalized difference vegetation index (NDVI) and the vegetation condition index—and drought indices (see https://lpdaac.usgs.gov/). MODIS data are also used for the calculation of SWE by USGS based on a method developed at Utah State University. The resulting maps for Afghanistan are available on the Famine Early Warning Systems Network website (http://earlywarning.usgs.gov/index.php). They form an important source of information that can be used to forecast drought, as well as high water and floods related to snow-melt.

Much of the information currently used in Afghanistan is based on interviews with key informants. This information is valuable and gives a good indication of trends and memorable events. It could also be helpful in determining drought and flood preparedness, mitigation and coping strategies. However, the data do not facilitate quantitative analysis or forecasting.

New data are mainly collected through projects. Exceptions are basic monthly agrometeorological data published through the USGS Agromet Project funded by the United States Agency for International Development. The data are in summary form, however, and the raw data are not readily available.

The Emergency Irrigation Rehabilitation Project funded by the World Bank has installed about 100 of a planned 174 hydrometric stations. These stations conduct automated measurements of water pressure as an indication of water level. However, the calibration and verification of the data consistency are still needed. This study uses some flow data collected through the Panj-Amu River Basin Programme funded by the European Commission.

3.2. Satellite imagery

The freely available data of the US National Oceanic and Atmospheric Administration and Famine Early Warning Systems Network on various indices are used to monitor vegetation conditions and snow accumulation. RFEs could be used to fill the gaps in the low-density measurement network. Ground verification and calibration, however, are also needed. There is also the possibility of developing river flow monitoring using remote sensing (see Dartmouth Flood Observatory, at http://floodobservatory.colorado.edu/index.html).

SWE maps are available through the Famine Early Warning Systems Network (http://earlywarning.usgs.gov/index.php) of USGS and the US Agency for International Development and are computed from a distributed, physically based energy balance model (the Utah Energy Balance Model; see Tarboton and Luce 1996) (figure 2). Inputs for the model are downscaled climatology from a regional climate model (solar radiation, air temperature, wind, humidity and atmospheric pressure) and daily gridded precipitation data (RFEs; see Xie and Arkin 1997). The resolution of the SWE output is 10 by 10 kilometres. This means that each grid cell of 10 by 10 kilometres has an average SWE value.

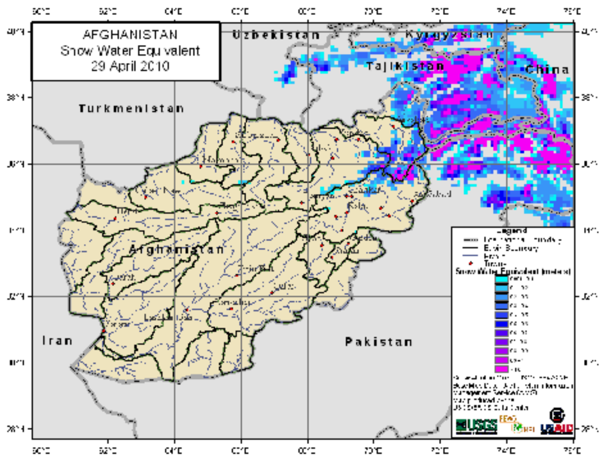


Figure 2: SWE map for Afghanistan, April 2010. Modeled SWE computed using the Utah Energy Balance Model, downscaled climatology (http://www.mmm.ucar.edu/mm5/) and RFE rainfall grids.

This method suffers from two main problems, as follows:

1. There is no calibration of RFE grids from rain gauges on the ground in Afghanistan (unlike the sister project in Africa; see Herman et al. 1997).
2. The complex topography of the Hindu Kush that dominates the domain where snow is important makes downscaling climate data a difficult task. Topography dictates the climatology at or near land surface. This means that key inputs to the model (air temperature and so on) vary to a great extent at resolutions far below the model resolution. For example, if one were to travel north from the Salang tunnel within a 10 kilometre horizontal distance, there is an elevation gradient of over 1,000 metres, which roughly equates to a temperature gradient of 6°–7°C (assuming a standard lapse rate). Another key parameter for calculating the energy balance of snowpack is solar radiation, which shows even greater variability over much shorter horizontal distances, for example if one simply crosses a mountain ridge from the north side to the south side.

While models are able to provide data that are useful for inter-annual comparisons, they frequently offer a representation of conditions on the ground that is far from accurate without calibration using ground data. An important next step in the development of a national snow monitoring strategy is the establishment of a snow survey routine to measure snow depth and SWE on the ground. This will enable the calibration of current model estimates, as well as the establishment of an Afghan snow hydrology dataset for further analysis and a better understanding of surface processes in the Hindu Kush. Alongside this programme, the establishment of a network of simple meteorological stations hosting instruments that record air temperature, humidity, global radiation, wind speed and precipitation at various locations in the Hindu Kush domain would significantly improve the ability of current computer models to make accurate seasonal forecasts of hydrological processes in this complex topography.

3.3. The Water Law

We have analysed the new Water Law (*Gazette* 980, April 2009) and studied the related basic management unit (the river basin) and the principles of integrated water resources management, including various stakeholder and coordination platforms. We offer the proposal that the relevant institutions should be developed to act as major tools in flood and drought preparedness.

4. Discussion

4.1. Water scarce or water rich?

The best information source on renewable water supplies is the *Watershed Atlas* of Favre and Kamal (2004). This atlas uses hydrometric data that were collected at 31 stations from the 1940s or 1950s to 1979.

Assuming a population of 28 million (CIA 2010) and using the data from Favre and Kamal (2004), who estimate that there are 84 billion cubic metres of renewable surface water, we calculate that the quantity of renewable water per capita would amount to approximately 3,000 cubic metres. This would place Afghanistan in the category of countries without water stress. To compare spatial variability, we must rely on the only consistent data available, from Favre and Kamal (2004). The results on the variation in renewable water resources per capita are shown in table 1.

Basin	*Flow, cubic metres, millions*	*Population*	*cubic metres per capita*
Panj-Amu	48,120	2,968,122	16,212
Harirod Murghab	3,060	1,722,275	1,777
Hilmand	9,300	5,881,571	1,581
Kabul	21,650	7,184,974	3,013
Northern	1,880	2,783,033	676
Total	84,010	20,539,975	4,090

Table 1: Annual flow per basin, settled population per basin and annual renewable water per capita (Source: Favre and Kamal 2004)

Table 1 clearly shows the variability of annually renewable water in cubic metres per capita for different basins, ranging from 676 in the Northern basin to 16,212 in the Panj-Amu basin. According to the classification of Yang et al. (2003), this would mean that the Northern basin has a water shortage, while the Hilmand and Harirod-Murghab basins are close to the threshold value of 1,500 cubic metres per capita. Following the Falkenmark indicators, both the Northern and Hilmand basins fall below the threshold of 1,700 cubic metres per capita, and the Harirod-Murghab basin is close to this value. With the increase in population since 2004, both basins would probably also be marked as suffering some degree of water shortage.

The spatial differences are even more pronounced if we analyse data on a sub-basin scale. The Panj-Amu basin, at 16,212 cubic metres per capita, has a water availability of 10 times the threshold. However, the annually renewable water in the lower Kunduz, one of the sub-basins of the Panj-Amu basin, is around or slightly below the threshold value of 1,700 cubic metres per capita. The Kabul basin seems equally water rich; however, the majority of the water enters the basin in its lower reaches, close to the border with Pakistan. This indicates that the upper Kabul and Logar sub-basins would most likely be classified as water stressed.

The population data of Favre and Kamal (2004) are based on Central Statistics Organization data of 2003–04 (CSO 2004). However, there are difficulties in using these. In the general section about water resources, a total population of 22.2 million is given, whereas the table with settled population only totals 20.5 million. The remaining 1.7 million people most likely consist of repatriated refugees, internally displaced persons and people practising transhumance or nomadic pastoralism. Data on Afghanistan are often difficult to interpret because of such inconsistencies and large gaps in data collection as a result of years of conflict and deteriorated data collection systems. Rarely are data scientifically robust; as a result, they must be interpreted carefully.

4.2. Drought

In Afghanistan, drought occurs frequently, which is in line with the expectations for the dry areas in the world (for example, see Eriyagama et al. 2009). The most recent reported events were a long event in 1997–2004 and in 2008. The drought in 1997–2004 has been analysed on the basis of a running anomaly of average rainfall records and was reportedly one of the most severe in Afghanistan's climatic history (MRRD 2004). The 2008 drought has been called the most severe drought in living memory (Savage et al. 2009). The years 2005 and 2009, however, were characterized by large snow accumulations in the mountains, as well as floods.

Many regions in the world, including Afghanistan, are characterized by the unreliable and vulnerable nature of river discharges. Eriyagama et al. (2009) warn that, in these regions, there is a danger in adopting drought mitigation strategies that focus on river flows alone. They argue for the application of an integrated package, including water harvesting and river flows. Bhattacharya et al. (2004) propose the use of water harvesting techniques and indicate the large potential this might have for water supplies in the villages in the five main river basins of Afghanistan.

Drought sensitivity can be classified in various ways after Eriyagama et al. (2009). Including socio-economic data and accounting for the dependence of the population on agriculture for income and job generation, one may classify Afghanistan as one of the most drought-sensitive countries in the world. Only Ethiopia is classified as more sensitive, and few other countries are classified at the same high level as Afghanistan. Afghanistan is the most vulnerable country if we classify it according to an infrastructure index that considers the share of people having access to an improved water source and the general accessibility of rural areas. Although Afghanistan has a low ratio of storage to water availability relative to the rest of the region, the ratio of storage to water deficit is better in Afghanistan than in India and Pakistan and comparable with the corresponding ratio in Iran.

Drought monitoring and timely drought warnings could have an important impact on the successful mitigation of the impacts of drought. The Government of Afghanistan undertook this practice in 2004 (Bhattacharya et al. 2004); however, the limited availability of data hampers the timely detection of drought trends, and additional development has not taken place. The drought monitoring systems under development and described by Thenkabail et al. (2004) could significantly increase the ability to announce impending drought in a timely manner. There is also a chance of being able to predict crop yields using remote sensing, as shown by Unganai and Kogan (1998), who accurately predicted corn yields in southern Africa more than six weeks in advance using a vegetation condition index.

The NDVI is one of the most widely used indices for vegetation monitoring due to the simplicity of the algorithm. The results produced are found to correlate well with ground-truthed biomass measurements. The NDVI is based on the spectral response of the chlorophyll pigment present in biomass. Red light (0.6–0.7µ) has a high level of absorption, whereas near infrared light (0.8–0.9µ) has a high rate of reflectance. Therefore, a ratio of the image bands that represent these wavelengths of light gives a good measure of biomass.

In Landsat satellite imagery, band 4 represents near infrared wavelengths and band 3 represents red light wavelengths. The result of the calculation is a raster dataset in which all values lie between +1 and −1. Positive values indicate the presence of vegetation, with increasing biomass as the number increases. Negative values indicate the absence of vegetation.

The Famine Early Warning Systems Network supplies NDVI products on Afghanistan derived from the MODIS satellite on a 16-day cycle. However, the 500-metre resolution of these products prevents application to local impact studies. Within the framework of the Panj-Amu River Basin Programme, work has been carried out using the Landsat product to derive 30-metre resolution NDVI products that allow for the interpretation of local impacts (figure 3). Another task that is planned is the construction of a 20-year NDVI time series that would enable a long-term mean NDVI value to be calculated for each region. The analysis of current biomass can then be compared with the long-term mean to produce anomaly results. These results would represent a useful interpretation of the NDVI compared with the results of a simple comparison of values from the previous year. Figure 3 shows the results of an NDVI comparison of August 2007 and 2008. The severe drought of 2008 is evident in the much reduced NDVI values throughout the main irrigated zones of the Kunduz river basin. The construction of a long-term mean NDVI dataset would allow current seasonal values to be plotted against mean values to provide early warning of a developing drought situation. This work needs to be accompanied by ground truthing (which has begun) to calibrate values to existing crop patterns and thereby aid the interpretation of the NDVI results.

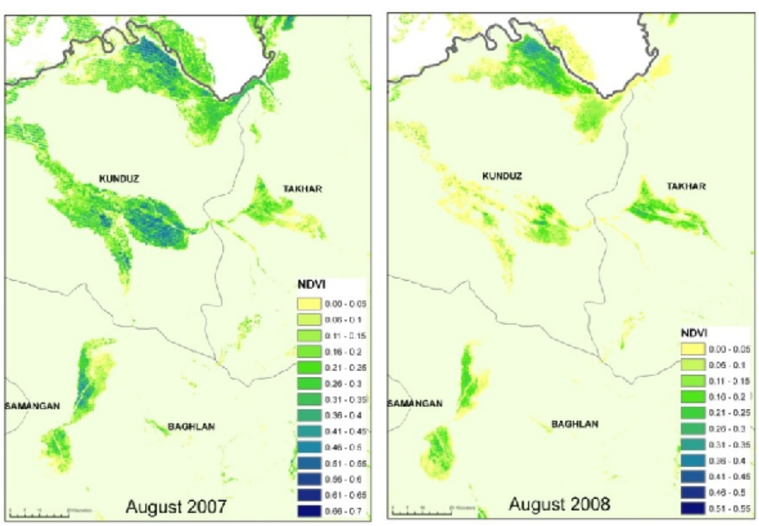


Figure 3: NDVI images of Baghlan, Kunduz and Taloqan irrigation zones in August 2007 and 2008. The impact of the 2008 drought is clearly shown.

4.3. Floods

Floods occur annually in Afghanistan mainly as (1) flash-floods or (2) gradual excess precipitation floods. Floods are often due to snow-melt. The first floods are difficult to predict; the later ones are more easily predicted, though no systematic approach is being used in Afghanistan yet.

The seriousness of the floods in Afghanistan is probably most effectively indicated in the maps of the Natural Disasters Hotspot Project (Dilley et al. 2005). In this project, the seriousness of drought in Afghanistan is indicated by the scores of 1 to 4 on a scale of 1 (slight) to 10 (extremely serious). Meanwhile, floods show indicators between 1 and 10, with the majority between 4 and 7. This clearly indicates that the deaths and economic damage might be higher for floods than for drought. However, Eriyagama et al. (2009) argue that these types of indices might be biased since it is difficult to confirm the mortality count associated with drought.

The United Nations Development Programme also rates the flood exposure and deaths in Afghanistan among the highest in the world. (Relative to population, Afghanistan is ranked second highest in the world only after Bhutan; see UNDP 2004.) Afghanistan also shows one of the highest shares of people exposed to drought (fourth in the world after Jordan, Iraq and Ecuador). The high exposure to floods, as in Bhutan, suggest that this is partially due to the mountainous character of the country; this argument is strengthened by the fact that other mountainous countries are among the top 10, such as Bolivia, Ecuador and Nepal.

There is some indication that significant rainfall in early spring represents a basis for risk assessment for flash-floods. In Afghanistan, flash-floods generally occur within the same months of the year, from February to June, except for the eastern part of the Kabul basin, which is influenced by the monsoon and often suffers from flash-floods in August and September. In the other areas, 30 of the 39 floods recorded between 2002 and 2010 occurred from February to June (Dartmouth Flood Observatory, at http://floodobservatory.colorado.edu/index.html). During the same period, 9 of the 12 floods that occurred from July to September occurred in the eastern Kabul basin.

In the area not influenced by monsoon, there seems to be a strong correlation between rainfall and snow in the early spring and the intensity of flash-floods (Dartmouth Flood Observatory, at http://floodobservatory.colorado.edu/index.html). The majority of floods that were recorded in 2003 and 2005 occurred following relatively wet, snow-rich winters. The absence of data on the 2009 floods in the Dartmouth series is quite remarkable and adds some doubt about the accuracy of the monitoring system.

The floods caused by snow-melt occur annually from the end of April until the end of August, depending on the basin. In general, the floods last from four to six weeks, and they can be predicted relatively well on the basis of the SWE estimates available through the Famine Early Warning Systems Network website (http://earlywarning.usgs.gov/index.php). The total sum of the SWE estimates per basin can be compared with average values and previous years and used for forecasts related to the average and previous year. This system, much like the basin excess rainfall maps presented by Verdin et al. (2005), is under testing through the Panj-Amu River Basin Programme and seems to be rather accurate. In 2008, a severe drought was predicted; this drought was confirmed in the analysis of Savage et al. (2009). The Panj-Amu River Basin Programme also carried out discharge measurements; they are compared with the historic data for the same location in figure 4, which shows clearly that the measured data fall consistently under the lowest historical discharges. In 2009, high flows were expected, and discharge measurements were again conducted. The results are shown in figure 5.

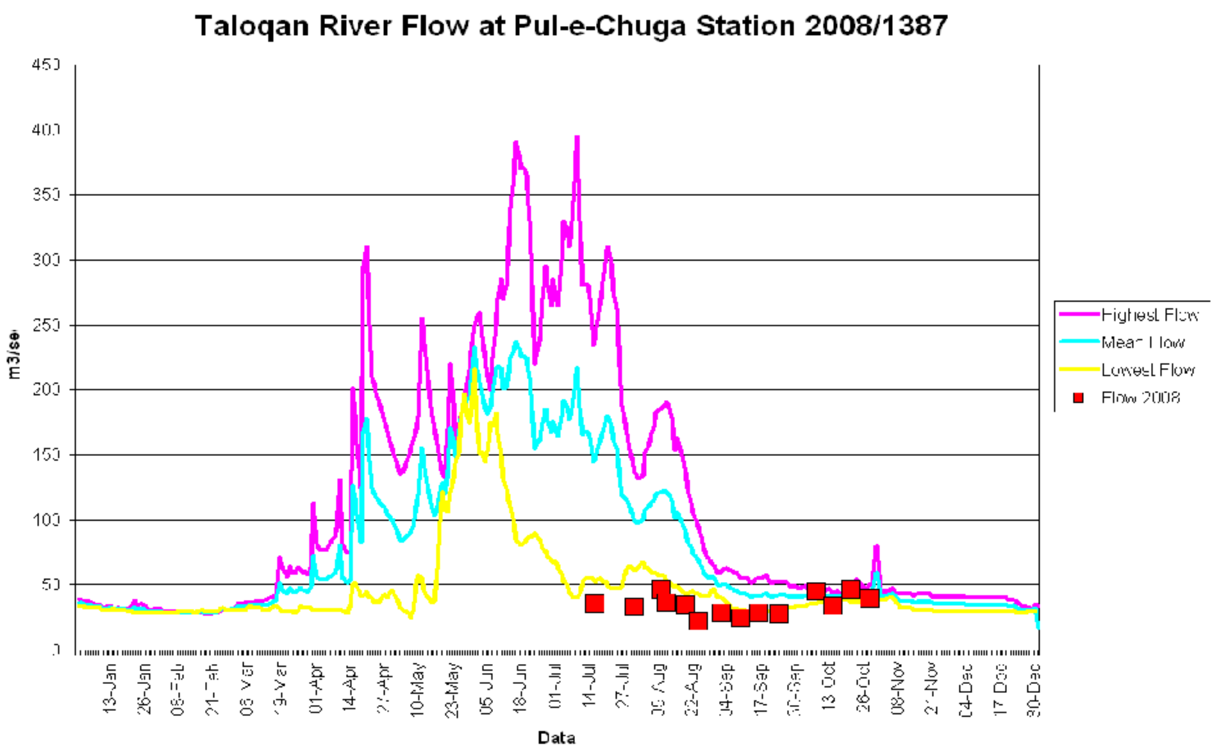


Figure 4: Historical high, mean and low flows and measured flows in the Taloqan River during 2008

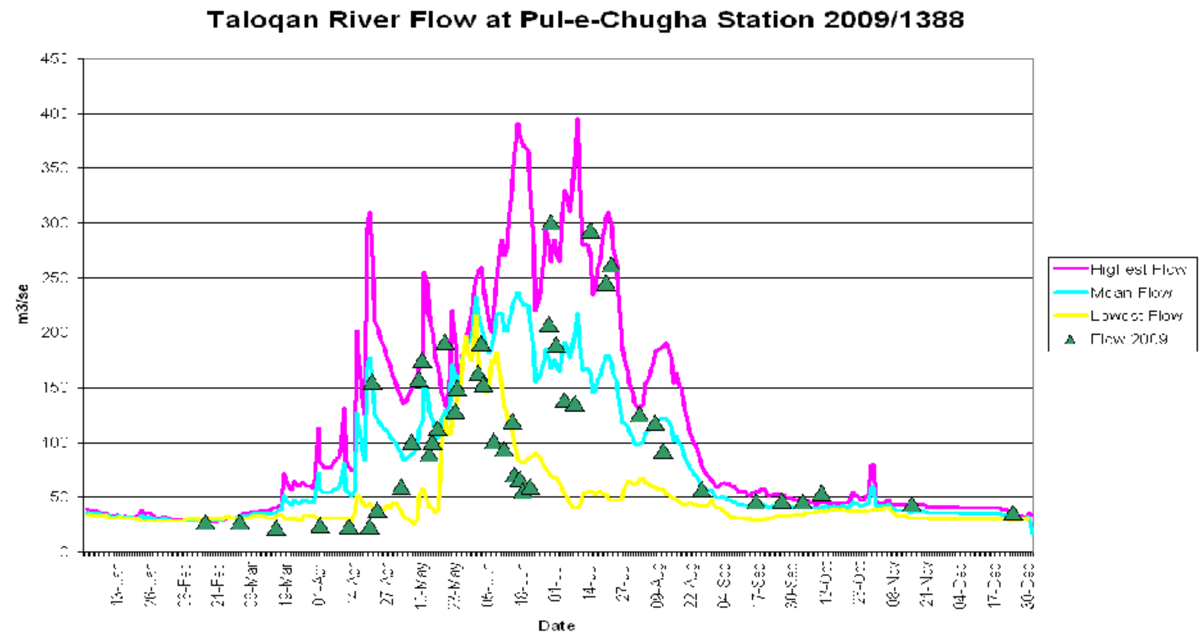


Figure 5: Historical high, mean and low flows and measured flows in the Taloqan River during 2009

The observed flows in 2009 were high in the early summer due to massive flash-floods in the entire sub-basin. This peak was followed by a dip due to low temperatures that resulted in reduced snow-melt. Due to the late snow-melt, a second peak was observed, accompanied by high discharges, later in the season. This effect was especially pronounced in the Kunduz River, where a relatively long period of high discharges occurred. This can also be clearly observed in the satellite-based discharge measurements of the Dartmouth Flood Observatory (figure 6). Another interesting phenomenon shown in figure 6 is the hysteresis of the system. Although the winter was relatively snow rich, measured discharges remained below the lowest historical discharges until late April 2009. This is probably due to the effect of the drought of 2008.

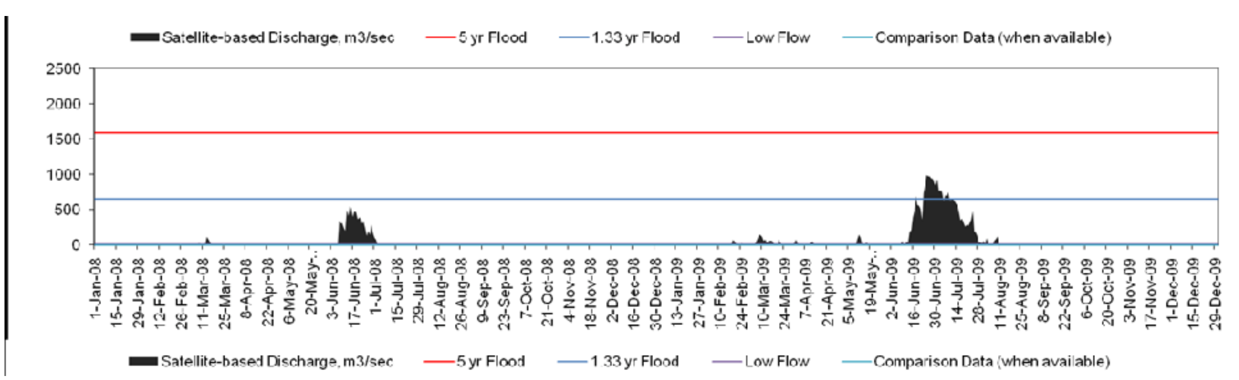


Figure 6: The remotely sensed discharge in the lower Kunduz sub-basin; Dartmouth Flood Observatory, http://floodobservatory.colorado.edu/index.html

In the Panj-Amu River Basin Programme, the predictions made on the basis of the Afghanistan snow cover products of the Famine Early Warning Systems Network and published SWE estimates, in combination with published USGS precipitation data, are routinely shared with water users and line ministries through multistakeholder platforms (Landell Mills Ltd 2009). We believe that the development of these information sharing mechanisms in all basins can form an important mechanism to improve flood preparedness. The current Water Law provides the entire institutional and legal basis to develop and institutionalize such mechanisms.

Apart from better information and drought and flood preparedness, a number of structural measures could be taken to reduce the impact of flash-floods and, at the same time, reduce the vulnerability to drought. These include increased water storage and management facilities in the river basins, as well as large-scale water harvesting in catchments. This is supported by the studies of Bhattacharya et al. (2004) and Eriyagama et al. (2009). Other measures to reduce flood damage in the flood-plain include carrying out an assessment that clearly zones those areas that should be precluded from settlement and large infrastructure due to flood risks. Flood-plain maps indicating the flooded areas along rivers from the Dartmouth Flood Observatory website (http://floodobservatory.colorado.edu/index.html) could be a strong advantage in mapping and be supplemented by more detailed satellite imagery.

4.4. Glaciers in Afghanistan

Detailed surveys have been carried out by the USGS in the high-elevation regions of the Wakhan panhandle, but other significantly glaciated parts of Afghanistan, such as parts of Badakhshan Province and high-elevation regions of the Kunduz basin, have received little attention to date. Brief surveys in 2008 revealed evidence of down-wasting glaciers in the district of Warsaj (figure 7), and comparison of satellite imagery over a 34-year period has shown a reduction in ice extent and the formation of new lakes due to glacial melt. A systematic investigation of glacier status over the whole of Afghanistan has not been performed.

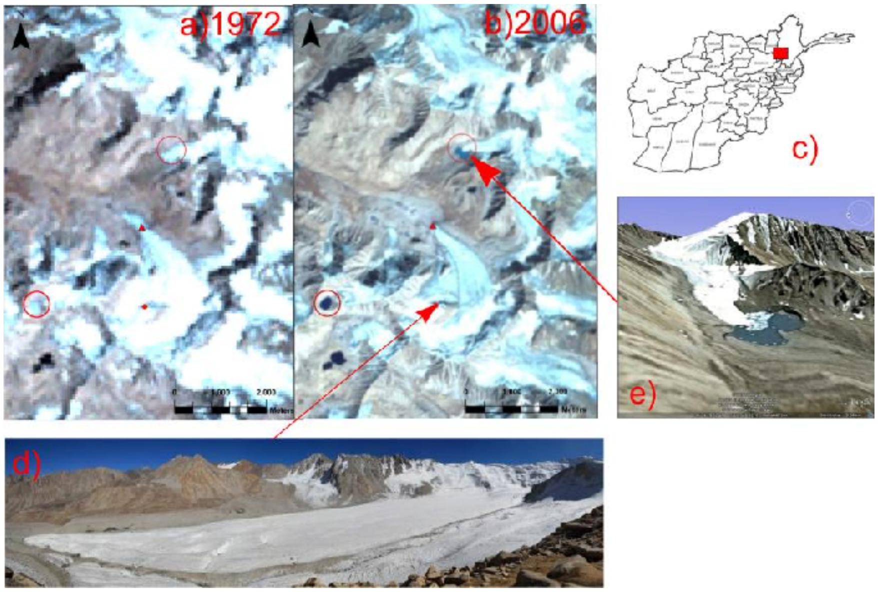


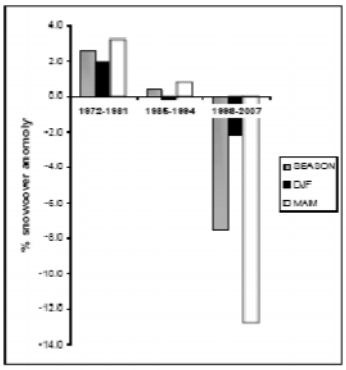
Figure 7: Landsat imagery of (a) September 1972 and (b) September 2006 of the upper reaches of Darai Emend, Warsaj District. All glaciers show reduction in extent. The firn line can be seen to have risen in altitude (the division between blue ice and white seasonal snow). The glacier pictured in (d) has retreated 550 metres over this period (red triangle [in (a) and (b)] = position of terminus in 2008). Red circles indicate newly formed glacial lakes resulting from melt. (d) Photo (30 September 2010) taken from red dot 180-degree panorama clockwise from due north to south (elevation, 5050 metres above sea level). (e) Google Earth can be a useful aid in assessing natural hazards such as potential glacial lake outburst floods. Pictured is the new glacier lake outlined by the right-hand circle (in [b]). It is approximately 450 square metres in area.

4.5. Recent trends in snow cover area

Snow and ice make up the largest proportion of annually renewable water in Afghanistan. The study of Fiddes (2007) is the most complete. Fiddes presents an analysis of a 35-year time series of data on the extent of snow cover during winter and spring in the Kunduz river basin, together with hydrology and regional climatology. Fiddes finds it highly likely that the upper catchment areas of the Kunduz river basin experienced a rise in mean temperature of 1.32°C over the 20th Century during the spring months of March to May. There are indications that a temperature rise of 1.37°C occurred during the winter months of December to February. These values are almost twice the global mean in 1904–2005 of 0.74°C. This is consistent with regional temperature increases elsewhere in Central Asia that were above the global average (Christensen et al. 2007).

4.5.1. Inter-decadal change in snow cover area

Snow cover has decreased by 10 percent, on average, in the Kabul river basin over the whole snow season (December–May) between 1972 and 2007 (figure 8a). This constituted a 4 percent reduction in winter snow cover and a much greater 15 percent reduction in spring.

a)


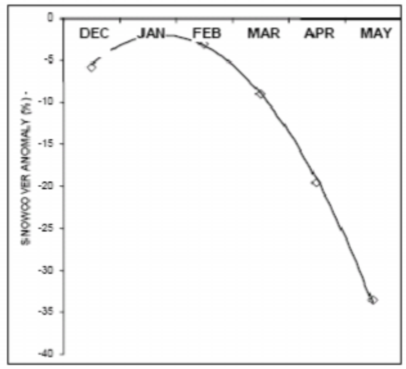
b)


Figure 8: Snow cover anomalies from a reconstructed 35-year mean for the Kunduz river basin. (a) Decadal anomalies show a clear negative trend in December–February (DJF), March–May (MAM) and for the whole season. (b) Snow cover anomalies for 1998–2007 compared with the long-term mean. Spring months show a significantly greater deviation from the long-term mean relative to winter months.

This is consistent with the negative correlation found between spring snow cover and temperature, together with an observed increasing temperature trend. This is confirmed by Haritashya et al. (2006), who observed an increase in the snowline in the central Hindu Kush of 200 metres over the last 30 years. It is therefore reasonable to suggest that increasing spring temperatures in the upper watershed areas of the Kunduz river basin over the course of the 20th Century contributed to a decrease in the extent of spring snow cover over the observed period 1972–2007.

4.5.2. Intra-annual variation in snow cover

A decadal mean for 1998–2007 reveals that the extent of snow cover has been below the long-term average in all winter and spring months. The percentage snow cover was found to deviate from the long-term mean to an increasing extent as the snow season progressed (figure 8b). The minimum anomaly was in January (−1.6 percent), and the maximum in May (−33.5 percent). This can be explained as follows: because spring snow cover is closer to the melt-point over greater areas, small increases in temperature have a greater impact on snowpack in spring than in winter. This is consistent with observed global trends (Brown 2000, Dye 2002, Stewart et al. 2004).

Total basin peak discharge was found to be positively correlated with the extent of spring snow cover. The observed reduction in the extent of spring snow cover is therefore expected to lead to an equivalent reduction in the discharge resulting from snow-melt. However, lack of river discharge data since the 1970s do not allow for this to be accurately verified.

4.6. Traditional water management methods

Since 2003, regular risk and vulnerability assessments have been carried out in Afghanistan. These form one of the best sources of information on the situation. Water plays an important role in the lives of almost all Afghans. This is clearly demonstrated by an analysis of the shocks in households. Shocks are defined as negative incidents outside the control of households. Water is reported as a shock by almost 20 percent of the households (MRRD and CSO 2009). Improved drinking water supply and the rehabilitation of irrigation systems are top development priorities among communities.

Given the central importance of water and the development of the water sector, it comes as no surprise that Afghanistan is rich in local water management techniques. Famous are the *karezes*, which tap groundwater by means of tunnels dug in mountain fronts until the phreatic level is reached. The water flows subsequently by gravity through the tunnel from the mountain to the surrounding land and is used for irrigation and domestic consumption. Another technique is the accumulation of snow in well-isolated deep pits; the snow melts during summer and is collected below the pit, where it is accessed through a door at the bottom of a ramp. These snow pits are referred to by various local terms, such as *cha* in the south (Bhattacharya et al. 2004) and *yaghdan* in the north. In almost all communities, there is a variety of water harvesting ponds, which are also referred to by many different local terms. In the Harirod basin, longitudinal fields are seen along washes. This configuration is efficient in capturing flood flows when they occur.

There has been little attention in most development projects to building on these traditional techniques. However, there seems to be ample opportunity to use these techniques to improve water availability in rural communities; this is also noted by Bhattacharya et al. (2004). The relevance of traditional techniques is especially high in Afghanistan, because many rural communities are remote and difficult to reach. These remote villages cannot be served by any of the river projects or by pumped or piped water supply systems from distant locations. Therefore, locally applicable techniques deserve more attention in solving rural water problems, including drought mitigation and protection against flood.

4.7. Local institutions

Afghanistan has a rich tradition in local institutions. In most villages, there are traditional councils of elders, referred to as *Shuras*. Villages that have a common interest are often grouped into a *mantega*, a loose term for groups of villages; mantegas often have traditional councils of elders as well. Irrigation systems are generally managed by a water master, the *mirab*, who, on the subcanal level, is assisted by a *kok basihi*. (There is a large variety of local names for the various positions; here, we have chosen to use names that are common in the north.) The mirabs often used to organize themselves in downstream and upstream groups to negotiate for water during periods of drought.

New community organizations have been supported through various projects and programmes to address more effectively the challenges of today's economic and social realities. The most successful new organizations are the community development councils, which have been introduced through the National Solidarity Programme, and water user associations, which have been introduced through various water management programmes. These organizations build, to a large extent, on the traditional institutions mentioned above. The water user associations are officially and legally recognized through the new Water Law.

Through the formation of sub-basin and river basin councils, the new Water Law also foresees another organizational level somewhat comparable with the informal mirab groups. These sub-basin and river basin councils will, after a capacity-building period, become the decision makers in water management at the sub-river basin and river basin levels. Sub-basin and river basin agencies will form the professional bodies that carry out these decisions and provide technical advice to the councils; in some cases, the decisions will be binding.

4.8. Towards an information strategy and action framework

Drought and flood forecasts based on weather data, satellite interpretations and modelling could be prepared by river basin and sub-basin agencies, probably supported by the Ministry of Energy and Water at the national level. They could be shared with the sub-basin and basin councils, which would take decisions on preparedness strategies. According to the new Water Law, the river basin agencies can declare a drought and take decisions for drought mitigation. Flood and drought strategies and alerts, if necessary, could then be implemented among the public, and the agencies would provide information about the ways to prepare practically for these events. The agencies could also give practical support and provide coordination among water users and community organizations through the establishment of mitigation plans and by guiding the work of other actors, including through (governmental) programmes and the distribution of funds for flood and drought preparedness. Self-help and participatory preparedness strategies should be key principles because the population of Afghanistan is spread out over so many communities, many of which are remote. Effective community organizations and institutions will most probably be a key to the success of any flood and drought preparedness strategies, including preparedness for climate change.

The new legal framework and the support for community organizations provided through various development projects have laid the foundation for effective water management that is in line with best practice management principles. The importance of effective governance and participation is almost universally recognized by researchers and development specialists.

5. Conclusions and Recommendations

1. At the national level, Afghanistan is not water scarce. However, water can be classified as scarce in one basin and in many sub-basins.
2. Afghanistan is considered water scarce if the need for environmental flows is taken into consideration.
3. Afghanistan is not particularly distinct from many other countries in the dry zones of the world in terms of the outcomes measured through most drought indicators.
4. Afghanistan has a high sensitivity to drought if socio-economic conditions are taken into account, including the dependence on agriculture for income and employment generation.
5. Afghanistan is also classified as vulnerable to drought because of poor access to improved water sources and poor rural access in general.
6. Afghanistan has a greater vulnerability to floods than to drought.
7. The combined vulnerability to floods and drought and the nature of the country's climate, which is typical for (semi-)arid zones of the world and which is characterized by large inter-annual variability, warrant the development of effective early warning and drought and flood preparedness strategies. These strategies would also help cope with the gradual shifts that might result from climate change and that are less sudden than the inter-annual changes and easier to prepare for or adapt to.
8. Both flood vulnerability and sensitivity to drought should be addressed through catchment conservation and water harvesting practices. However, little attention has been paid to these in recent years.
9. A system should be developed for the timely detection of drought and flood risk. This system should not only aim to provide scientifically accurate predictions, but also focus on supplying information to the public and devising participatory preparedness strategies. The new Water Law forms an excellent enabling environment for the development of such a system.
10. The forecasts of floods and drought produced on the basis of satellite imagery and supplemented through precipitation data gathered through the Panj-Amu River Basin Programme show a good correspondence with observed discharges. This confirms the potential of the use of satellite imagery for flood and drought preparedness.

11. Remotely sensed discharges from the Dartmouth Flood Observatory website (http://floodobservatory.colorado.edu/index.html) indicate that there is promise for further development as well.
12. Remote sensing data represent a tremendous opportunity to obtain countrywide information on drought and flood risks and monitoring and can compensate for the low density of measurement locations.
13. An area-wide coverage of precipitation and automated discharge measurements at various locations is needed. More resources should be devoted to using and calibrating remote sensing information.
14. Systematic surveys of glacial resources should be undertaken throughout the high-elevation areas of Afghanistan and incorporate cutting edge techniques to account for the significant amount of debris-covered ice.
15. Closer links should be developed between international agencies and the programmes of the Ministry of Energy and Water (such as the Panj-Amu River Basin Programme) so that there is a more effective flow of information and current knowledge to public institutions.
16. Closer links should be developed with academic institutions that can provide technical support, such as the University of Nebraska and the University of Zurich, which hosts the World Glacier Monitoring Service.
17. A snow survey programme should be established to gather model validation data on SWE and snow depth.
18. A low-cost network of meteorological stations in the Hindu Kush domain should be planned. The aim should be to gather essential climatic data in complex topographies and improve the accuracy of current seasonal forecasts.
19. Long-term (20-year) NDVI time series should be constructed to allow for annual anomaly calculations and improve drought assessments.
20. Ground truthing data should be improved so as to facilitate the calibration of NDVI values to crop type patterns.

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