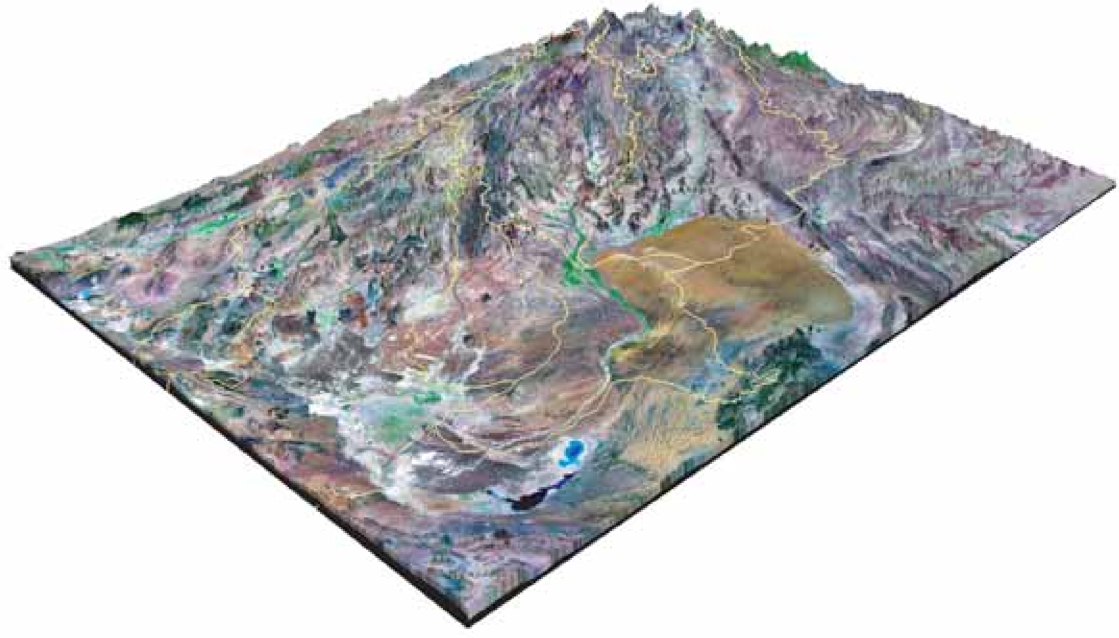

History of Environmental Change in the Sistan Basin

Based on Satellite Image Analysis: 1976 – 2005

UNEP Post-Conflict Branch
Geneva, May 2006

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Cover image: 3D model of the Sistan Basin catchment

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Naming conventions

Several versions of geographical names are widely used in the Sistan basin: not only may a geographical feature have different names in different languages and dialects, but there are also several different spellings for these names in Latin characters. In this document, the following approach to nomenclature is used:

- Wherever possible, the local name is used for the geographical feature;
- The same orthography is used throughout the report, except where this is technically not possible (e.g. maps taken from different sources). *Table 1* indicates the different orthographic versions of some of the region's main geographical sites and features.

Table 1 Orthography used in the present report

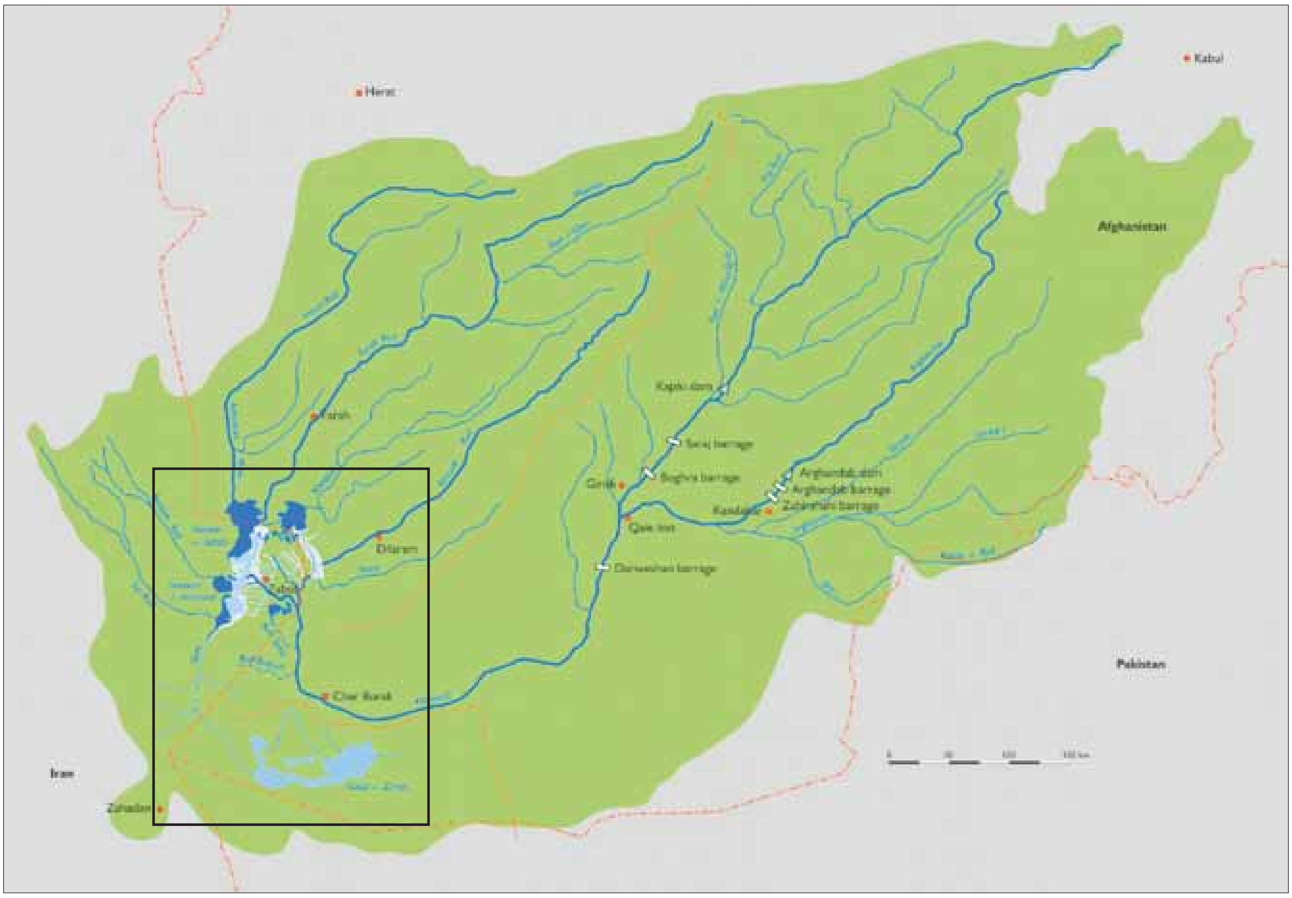
Orthography used in the present report	Other versions
Hamoon	Hamoun, Hamun
Helmand	Hirmand, Hilmand
Khash river	Khasah Rud
Farah river	
Ardaskan river	Harut River
Arghandab river, Dam, reservoir	
Musa Qala river	
Kajaki Dam, reservoir	
Gowd-e-Zareh	Goud-e-Zareh, Gudzareh, Gaud-e-Zireh
Hamoon-e-Puzak	Hamun-i Puzak
Hamoon-e-Saberi	Hamoun-e-Saburi, Hamoon Saberi
Sistan area, basin, river	Seistan
Common Parian river	
Quala-i-Bust	
Chah Nimeh reservoir	
Chonge Sorkh	
Hamoon Baringak	
Kang	
Zaranj	
Dasht-e-Margo	
Chakhansur	

1 Introcution – Rivers bring life to the desert

The Sistan area is located at the tail end of a large closed inland (endorheic) basin, in one of the driest regions of the world. It is comprised of three geographical sub-units: (i) the upper plain of the inland delta of the Helmand (Hirmand) river, which is mostly drained and used for agriculture; (ii) the wetlands (Hamoons) covering the lower delta plain and (iii) a hypersaline lake (Gowd-e-Zareh) in the lowest part of the basin, which collects the overspill from the wetlands and – in case of extreme floods – from the Helmand River. There is no outflow from this terminal lake; water is lost from Gowd-e-Zareh only by evaporation.

The Helmand River comprises the largest watershed in the Sistan basin, but other smaller rivers also feed the Hamoons, which are, from an environmental perspective, the most important parts of the Sistan area (*Figure 1*).

Figure 1 Sistan basin (approximated by the black rectangle) and its watershed



The natural boundary of the basin is uncertain in some regions (e.g. flat deserts), so some sources show somewhat different outlines of the basin (e.g. Kamal 2004). Note the superimposition of administrative borders subdividing the system

The annual precipitation in the lower Sistan basin is about 50 mm (WAPCOS 1975). Under such conditions, life is only possible if an 'external' water source is also available to nourish the region. The Helmand River plays that major role in the Sistan area, by draining the snowmelt waters from the mountains of the southern Hindu Kush. Three smaller rivers also contribute considerable flows: the Khash, the Farah and the Arashkan (Harut) rivers, which collect waters from the western part of the Hindu Kush. The ecology and economy of the refgion hence rely on the snowmelt and rainfall in the high mountains. This water supply, however, is characterized by severe fluctuations which have historically caused fundamental problems for human settlement and civilization. The turn of the second millennium has been marked by an extreme drought lasting six years, and it is not yet certain that this phase is over.

In the Sistan region, as well as around the lower stretch of the Helmand River, the population depends on agriculture: intensive crop production and horticulture provide the basis of daily existence (ICARDA Assessment Team 2002), especially on the Iranian side. In Afghanistan, the war has severely damaged agricultural production (both infrastructure and human resources) in the last two decades.

2 A vulnerable ecosystem

In the lower Sistan basin, life depends on the inland delta of the Helmand River and the associated wetlands and lakes, the Hamoons. Water cover is extensive but shallow: the average depth of the Hamoons even at the highest water levels does not exceed 3 m. Waste but shallow water cover in a very dry region where potential evapo-transpiration is more than 3 m annually makes for a system that is very vulnerable to climatic fluctuations and modifications of water inflow by humans.

The large water surface with its reed beds has a positive effect on the local climate: the intensive evaporation decreases the enormous heat while decreasing the humidity of the air. It is unlikely that life would have been possible in the region without these wetlands. Due to its location in the midst of a vast desert, this wetland complex is extremely important for migrant and wintering waterfowl. A large part of the Hamoons in Iran, approximately 60 000 ha, has been designated as a protected site under the Ramsar Convention. The Hamoons on the Afghanistan side do not have any special protected conservation status, although they represent the more permanently inundated and vegetated part of the wetlands.

2.1 History

The Sistan basin has been continuously inhabited by complex cultures for more than 5,000 years. One of the key archaeological sites on the Iranian side is the Burnt City, founded next to a presently dried-up branch of the Helmand River in 3100 B.C., and abandoned approximately a millennium later. The most probable explanation for this population displacement is a change in climate that resulted in, *inter alia,* an alteration of the watercourse of the nearby former branch of the river. The historical name of this site is unknown. It is referred to as the Burnt City, because the ruins reveal at least three periods distinguished by signs of major fires. Intensive agriculture, most probably fruit production, was the main economic activity of the inhabitants. This assertion is supported by a large amount of pottery found at the site. These jars, which bear figural ornamentation depicting goats and fish (Persian Journal 2005a), were mainly used for fruit conservation. They are evidence of a climate more suitable for agricultural production than the present. Only a few fragments of the Burnt City's historical puzzle have been discovered so far. The sands still cover many secrets, stimulating continuous archaeological digs (Persian Journal 2005b). The recent drought has also caused damage to this important site too, as reported by the Iranian Cultural Heritages News Agency (Payvand 2005).

Archaeological site of the 4-5000 year-old Burnt City

Broken pottery covers the ground in some parts of the Burnt City

On the Afghanistan side, there are two major medieval cultural centres, Kang and Zaranj, that now stand isolated by drifting sand. Other ruins of settlements and forts dot the surrounding desert (UNEP 2003a). Traces of historical irrigation works, including the Zarcan and Zoorcan canals, are still visible in the Dasht-e-Margo and Chakhansur areas. Other canals have long been silted up, and fields covered by shifting sand. As a result, the countryside is now sparsely populated.

2.2 Socio-economic importance

Livelihoods in this region are strongly interlinked with and dependent on the wetland products and services. The reed beds provide fodder for livestock, fuel for cooking and heating, and raw materials for handicraft and constructions. Fishing and hunting represent an important source of income for many households.

This fundamental dependence on the wetlands has resulted in the collapse of the local economy during this latest drought period. Severe water shortages have destroyed the ecological system of the wetlands and caused damage to agriculture in the delta, which is primarily based on irrigation from the Helmand River. The estimated population in the region is several hundred thousand, mostly living in Iran. On the Iranian side, the government has made considerable efforts to stabilize and maintain the local population by providing food, work and other services to meet the basic needs of the people. Loss of traditional livelihoods has resulted in emigration and a major expansion of the unofficial economy, particularly the smuggling of oil products.

2.3 The environmental problem

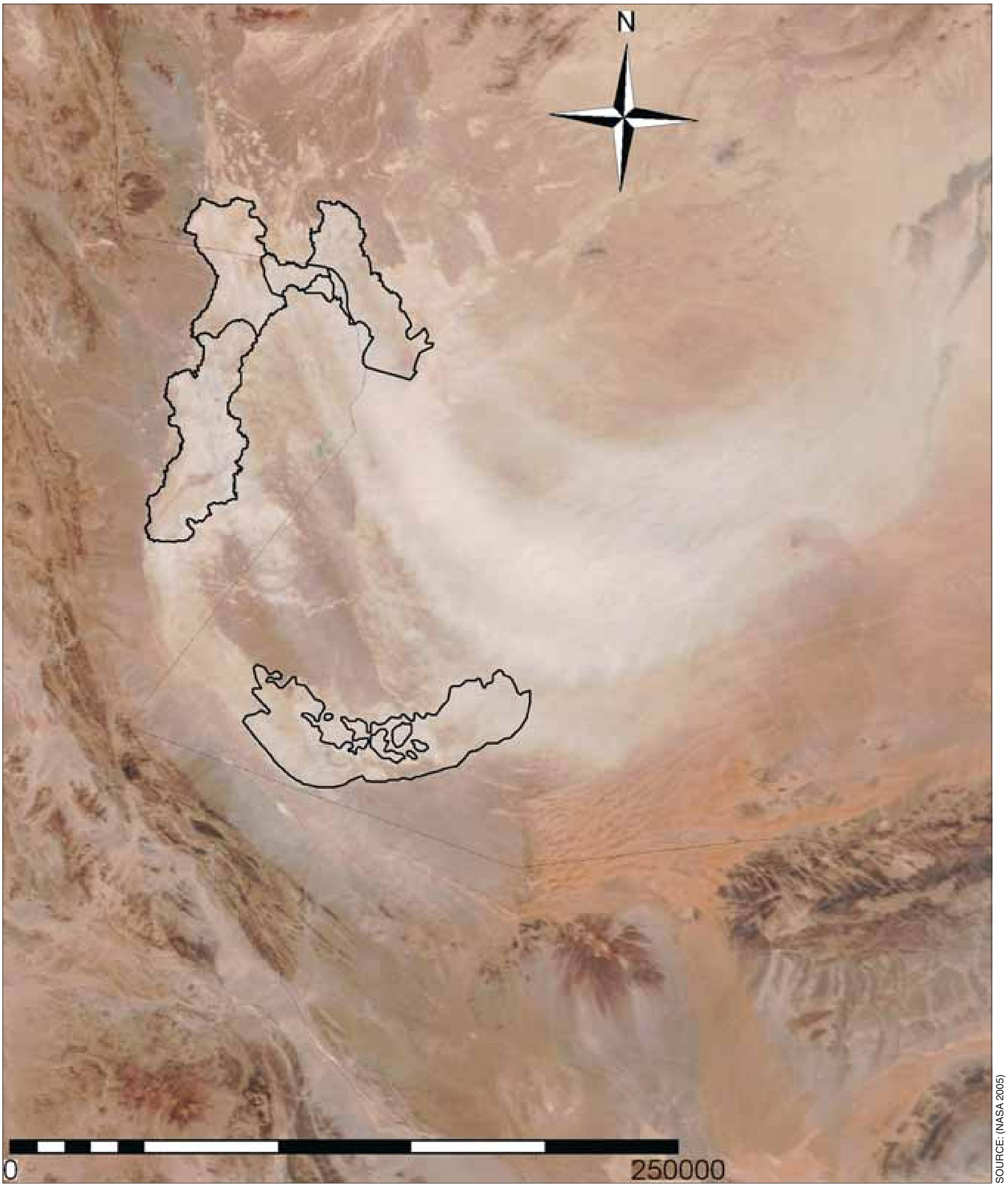
Prolonged droughts - when the rivers fail to bring sufficient water to fill up the lakes and wetlands, and hence supply the irrigation-based agriculture - have occurred in the late 1960s, mid-1980s, and between 1999 and 2005. The last drought was exceptionally long, transforming the lakebeds into barren desert. The summers in the region are characterized by the infamous '120-day wind': by the end of the season, wind-blown sand originating from the lakebeds covers the surrounding villages. The 1 September 2004 MODIS image (Figure 2), indeed, reveals that the primary source of the dust plumes is the lakebed of the Hamoons. In Iran, local authorities have constructed hundreds of kilometers of windbreakers to control sand movement. Unfortunately though, this protection traps only part of the sand and has little effect on the finer dust.

Windbreaker in Baringak. The dune behind the windbreaker was formed within a few years by wind-blown sand

The Hamoons have a natural annual hydroperiod: each year the water level rises in the spring and falls from April to January, and large parts of the wetlands dry out regularly. In this system, droughts have an important ecological role, e.g., in maintaining reeds as the dominant plant species the ecosystem's succession dynamics. The population also takes advantage of these changing water levels, notably by adjusting the grazing schedule of their animals to them. Nevertheless, in extreme cases, both the natural ecosystem and human society are affected adversely by prolonged dry periods. When the wetlands dry out for exceptionally long periods, water birds migrate elsewhere, fishing is not possible and wetland vegetation dries up. In order to minimize the negative effects of water flow fluctuations, it is imperative to understand how the system works.

Hundreds of kilometres of windbreakers have been constructed in the lakebeds to trap wind-blown sand

Figure 2 Wind-blown sand originating from the lakebed of the Hamoons



Captured in MODIS (Terra) image on 1 September 2004. Several satellite images show that sand plumes can cross the Persian Gulf and reach the Arabian Peninsula


Dead reed stems in Hamoun-e-Puzak

2.4 Objectives of the study

The main objective of this study is to gain insight into the environmental dynamics of the Sistan basin, based on a systematic analysis of archived and recent satellite images.

This remote sensing survey represents a first step towards a comprehensive understanding of the causes of environmental change, which ought to be based on a thorough climatic and hydrological analysis. Substantial resources have been allocated under a joint Dutch-Iranian project to carryout a detailed analysis of integrated water resources management in the Sistan Basin, which was completed in January 2006.

2.5 Antecedent and parallel studies

To our knowledge, there is no publication in international literature that addresses the Sistan basin as a single ecosystem. However, the wetlands have been studied – especially on the Iranian side – and the results of these studies have been discussed in several reviews. Remote sensing methods were used to support data acquisition and analysis in many of these studies.

Scott (1995) gives an overview of the important wetlands of the Middle East, including the Hamoons of the Sistan basin on both sides of the border. This comprises a collection of facts and data about the physical, socio-economic, ecological and management aspects of the wetlands. It refers to a number of reports, including unpublished internal documents, which deal with the Sistan wetlands. Noteworthy in this reference list are (Petocz *et al.* 1976), (Scott *et al.* 1992), (Moser *et al.* 1993) and (Evans 1994).


Abandoned fishing net in the dry bed of Hamoon-e-Puzak

UNEP's Post-Conflict Branch conducted an environmental assessment mission in Afghanistan in 2002 (UNEP 2003a). The survey team visited numerous sites in the country, including the Helmand valley and the desiccated Hamoon wetlands. Its report, based on satellite image analysis, shows that the water and vegetation cover in the Hamoons are very dynamic. It is not possible, however, to draw far-reaching conclusions from the statistics presented in this study, as it was based on a limited set of images which was insufficient to present a historical perspective of environmental change in the region.

One of the most important issues at stake is the transboundary water management of the Helmand River. A water-sharing arrangement between Iran and Afghanistan was agreed in 1973, according to which Iran was to receive a discharge of 22 m^3/s and be permitted to purchase an additional four m^3/s. After a hiatus of several decades, discussions on this treaty were reactivated with the reconvening of the Iran-Afghanistan Water Commission in September 2005.

A study of the use of space technology for environmental security (Lovett 2004) identified visible/infrared, multi-spectral and microwave remote sensing techniques as those suitable for environmental monitoring in Afghanistan. As neighbouring countries depend on waters originating inside Afghanistan, information about the state of these resources is of primary interest to them as well. From this point of view, space technology offers significant advantages and timely information to help improve environmental management planning and sustainable development.

A global satellite atlas was published by UNEP, illustrating extensive changes of the land cover in different parts of the world (UNEP 2003b). One section of the Asia chapter dealt with the Hamoons.

Integrated water resources management (IWRM) is one of the leading concepts for harmonizing water sharing both among the key sectors of society and between countries. Due to emerging environmental problems in the Sistan area, the Iranian Government launched a project co-financed by the Netherlands Programme Partners for Water. The terms of this project were set in an agreement between the Iranian Ministry of Energy and the Dutch Ministry of Agriculture, Nature and Food Quality (hereafter referred to as the 'Iranian-Dutch Sistan Project'). The main task of the project was to develop an integrated water resources management plan for the Sistan basin. It comprised a detailed hydrological model of the whole Sistan catchment, and an ecological, socio-economic and irrigation study of the Sistan plain and the Hamoons. The results were integrated into a water-balance model of the Helmand basin and the Sistan irrigated areas. The project was coordinated by Delft Hydraulics (The Netherlands) and the Water Research Institute (Iran, Ministry of Energy) and was be completed in Janaury 2006.

The present study would not have been possible without close cooperation with the above-mentioned project.

3 Major units of the Sistan basin

The Sistan basin wetlands receive the water its life depends on from the Hindu Kush mountains. The largest of the catchments is the Helmand river, which is located almost entirely in Afghanistan. In the present study, we consider three of the Helmand's main parts: the Upper Helmand, the Lower Helmand and Arghandab (*Table 2*, *Figures 47* and *49*).

The Adrashkan, Farah and Khash rivers discharge considerably less water and are parched during dry periods. There are other smaller catchments, from which only temporary rivers reach the Hamoons or runoff takes place only occasionally (mentioned as 'Hirmand West' and 'Common Parian right bank' in the table). To provide complete coverage, *the irrigated inland delta has been included in Table 2 as 'Sistan Irrigated*'.

Table 2 Size of the Hamoons and its catchments

Country	Afghanistan		Iran		Pakistan	
Units	**km²**	**%**	**km²**	**%**	**km²**	**%**
Hamoons						
Baringak			208	100 %		
Chonge Sorkh			62	100 %		
Hamoon Hirmand			1842	100 %		
Hamoon Saberi	479	41 %	682	59 %		
Hamoon-e-Puzak (Afghanistan)	1154	100 %				
Hamoon-e-Puzak (Iran)			60	100 %		
Catchments						
Adrashkan	21068	77 %	6418	23 %		
Arghandab	71958	93 %			5350	7 %
Common Parian right bank	1904	100 %				
Farah	39945	100 %	9	0 %		
Hirmand West	642	4 %	13747	96 %		
Khash	24487	100 %				
Lower Helmand	36307	99 %			418	1 %
Sistan Irrigated			2474	100 %		
Upper Helmand	59918	100 %				
Total	**257860**	**89%**	**25502**	**9%**	**5768**	**2%**

3.1 Rivers and reservoirs

Afghanistan is rich in hydropower potential, but only four major dams have been constructed in the country and only ten percent of the population is supplied with electricity. In the Helmand basin, two dams provide electricity and irrigation water. Sedimentation and lack of maintenance, however, does not allow these dams to work at full capacity.

The Kajaki dam (approx. 70 m high, max. storage capacity 1800 million m^3) is the main construction in the Upper Helmand River (*Figure* 3). Several irrigation schemes are fed from its reservoir. The dam was damaged by an air strike during the 2001 conflict, but was repaired in 2002. At the request of Iran, an emergency water release was made from the dam starting 25 October 2002 to respond to the severe drought conditions; but the discharge was stopped after ten days (UNDP 2003).

The Arghandab dam is a smaller structure (about 45 m high, max. storage capacity 480 million m^3). It stores water mainly for irrigation in the lower Arghandab valley near Kandahar (*Figures 4* and *5). Figures 3 and 5* are taken at the same scale so the water reservoir areas can be compared.

Figure 3 Kajaki reservoir on Landsat TM mosaic

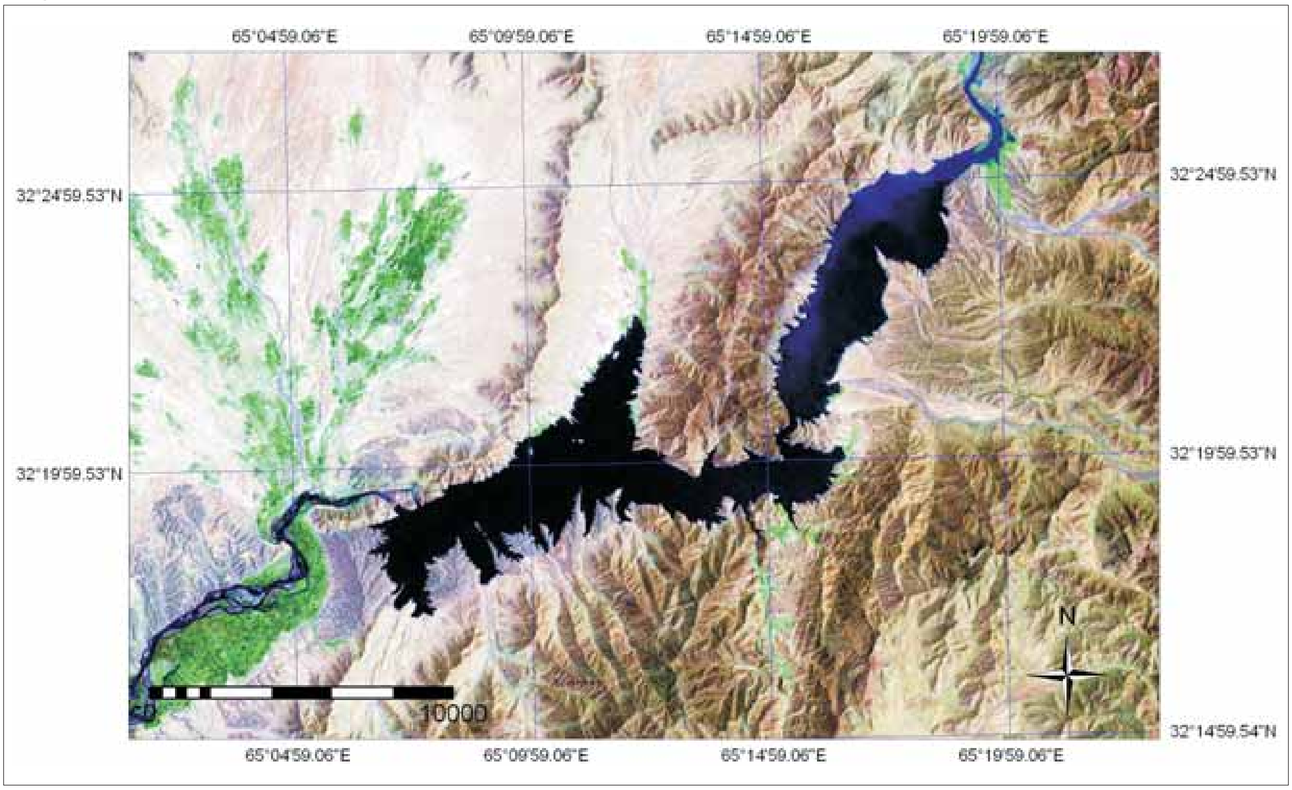
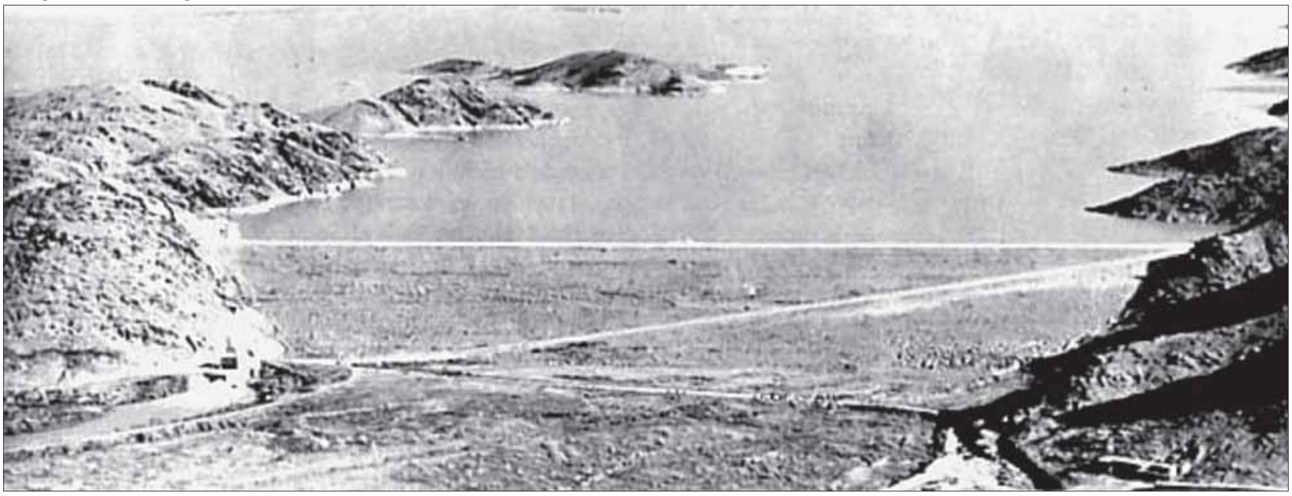


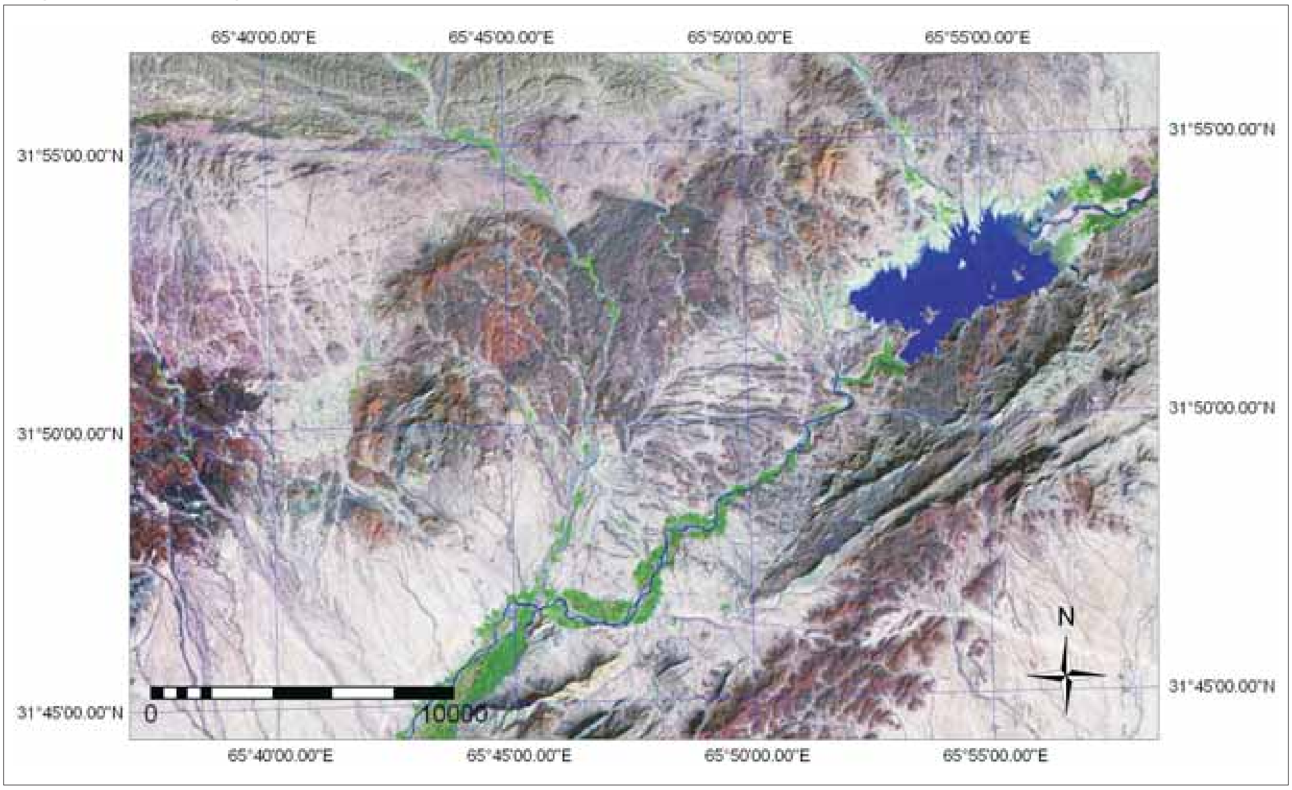
Figure 4 Arghandab dam



SOURCE: (CULLATHER 2002)

The local population uses river water for irrigation wherever possible. According to a survey conducted by Water and Power Development Consultancy Services (India) Ltd. (WAPCOS 1975), the total irrigated area in Afghanistan in the first half of the 1970s was approximately 132 000 ha, and could potentially be tripled. Decades of conflict have undermined improvements in irrigation. An estimate based on the MODIS Terra normalized differential vegetation index (NDVI) time series (January-April 1991 and February-June 2005) showed irrigated areas in the basin to be practically the same for the two investigated years: between 95 000 and 105 000 ha (*Figure 6*). One striking observation is that the Sistan irrigated area in Iran has much lower NDVI values than the upstream regions in Afghanistan, indicating that there is significantly less living surface biomass on the Iranian side compared to Afghanistan. This is due to the high salinity of the soil in the Iranian part, which forces farmers to use only a portion of the land at a time and practice mosaic-like cropping.

Figure 5 The Arghandab reservoir on Landsat TM mosaic



It is suspected that irrigation contributed to the desiccation of the Hamoons in the period between 1999 and 2004. However, incontrovertible scientific evidence supporting this has not been provided so far. More information on this issue may be obtained from the Dutch-Iranian integrated water resources management project (*Section 2.5*).

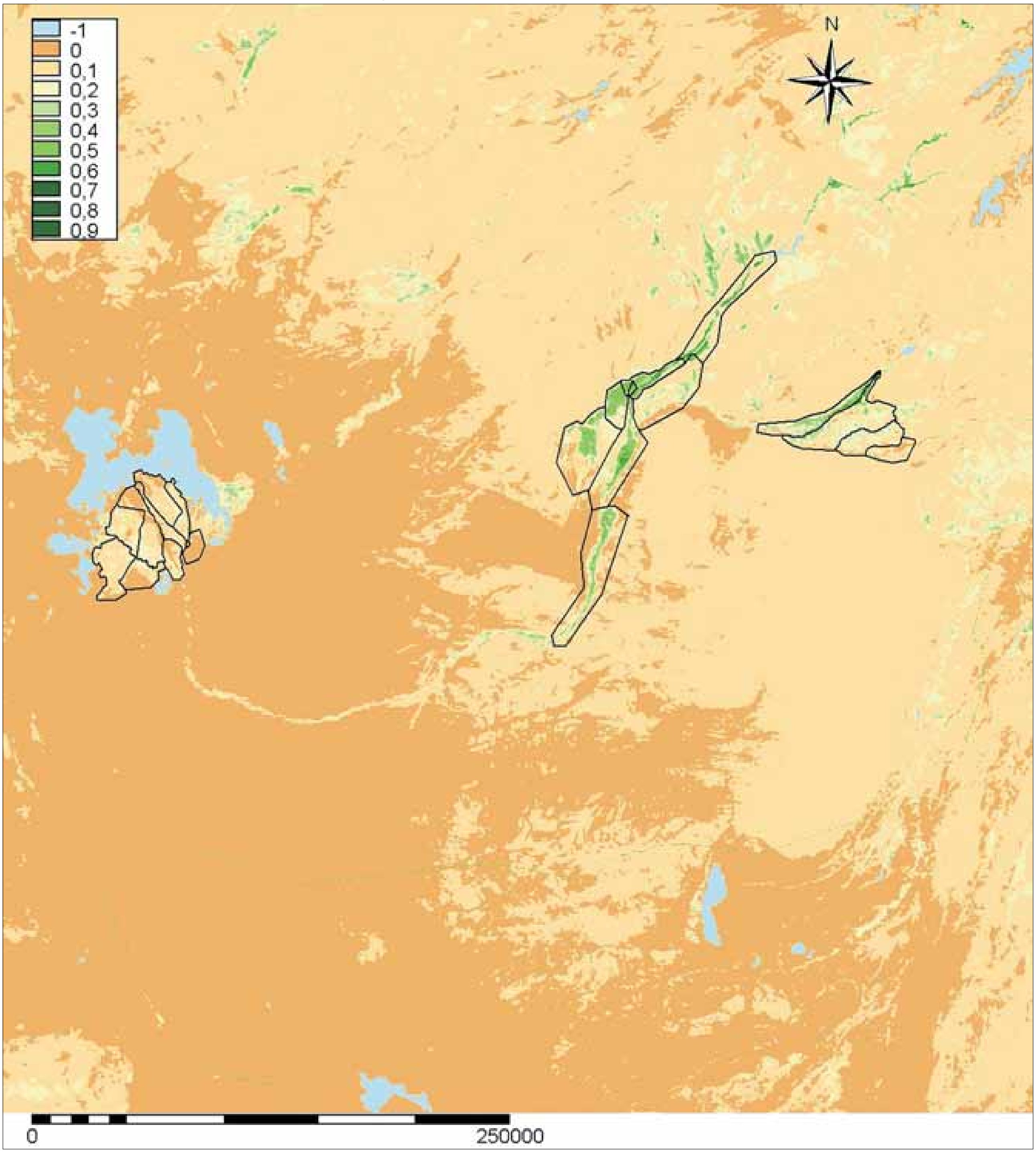
The lower reaches of the Helmand River flow through desert terrain. This section of the river valley is sparsely populated, but studies indicate that it is a potentially irrigable area. There are plans to revive the longstanding Kamal Khan Flood Control Project in Afghanistan, which would divert water directly from the Helmand River to the Gowd-e-Zareh with two – most probably contradictory – goals: flood control and water supply for irrigation in Afghanistan and Iran. Reservations about the sustainability of such plans include their potential impact on water quality. Gowd-e-Zareh is the final destination of all surface runoff in the basin. Salt transported from the catchment is deposited on the lakebed. The very high reflectivity of the dry surface on the satellite images suggests that considerable amounts of salt have accumulated on the lakebed, making it doubtful that Gowd-e-Zareh could be used as a reservoir for irrigation.

Some signs of the old construction work can be identified on Landsat and Aster satellite images (30 m and 15 m resolution, respectively), but recent Aster imagery (from 2004) does not show any resumption in construction.

3.2 Chah Nimeh reservoir

For better control over the distribution of the water reaching the Sistan irigated plain, the Chah Nimeh reservoir was constructed on the Iranian side immediately downstream from the Hirmand fork, where the Helmand river separates into the Sistan and the Common Parian rivers (*Figures 30* and *31*). Three units of the reservoir, linked by canals, are clearly visible on the Aster satellite images. A fourth basin is under construction (*Figure 7*). Once completed, the storage capacity will reach a total of 1530 million m^3 (*Table 3*), making Chah Nimeh the second most important water storage reservoir in the Helmand basin.

Figure 6 Normalized differential vegetation index[1] map of the Helmand basin (16 April 2005)

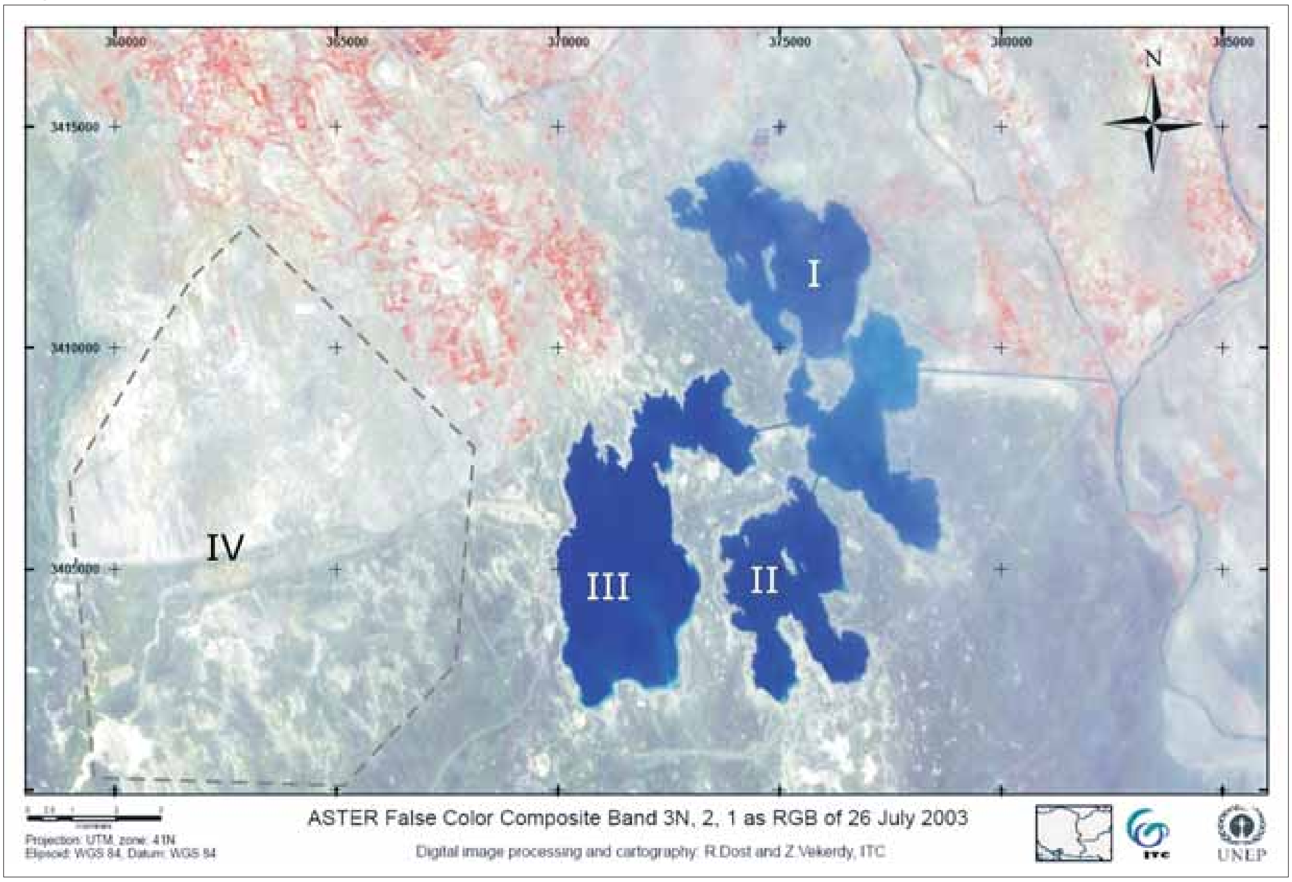


The outlines delineate the different active irrigation units

Table 3 Storage capacity of the Chah Nimeh reservoir

Basin	Volume (million m3)
I	200
II	110
III	320
IV (planned)	900
Total	**1530**

Figure 7 The Chah Nimeh reservoir



The dashed line approximates the location of the construction of the reservoir's fourth basin

3.3 The Hamoon system

The Hamoons constitute an integral system that can be divided into sub-units connected to each other at high water levels, and disconnected at low water levels (*Figure 8* and *Table 4*). Some of the sub-units receive direct inflow from rivers; others get water only from neighbouring sub-units.

The political boundary between the Islamic Republic of Iran and Afghanistan splits the Hamooon system, further complicating management possibilities in the area. Ninety percent of the watershed is located in Afghanistan and practically all of the wetlands' water sources originate there. The Iranian part is desert, and produces runoff only in rare cases of significant local rainfall.

The Hamoons are classified as freshwater wetlands, although in cases of long water stagnation, not only is salt dissolved from the soil, but the water's salt concentration is increased through evaporation. Another source of salt is the saline return drainage from irrigation schemes. In Iran, the Department of Environment initiated construction of a reservoir downstream of the main collectors, to separate the highly saline irrigation waters from the Hamoons; evaporation removes the water from this reservoir, leaving remaining salts to be safely excavated and stored. The most effective purification system, however, is provided by nature, when big floods flush the water through the Hamoons, transporting the dissolved salt into the Gowd-e-Zareh Lake in Afghanistan, via the Shile River.

The Hamoons are very shallow. Local experts were interviewed in January 2005 to estimate the volume of water stored in the lakes at maximum water stage. *Table 4* summarizes these estimates.

Figure 8 Subdivision of the Hamoons with the main directions of water flow

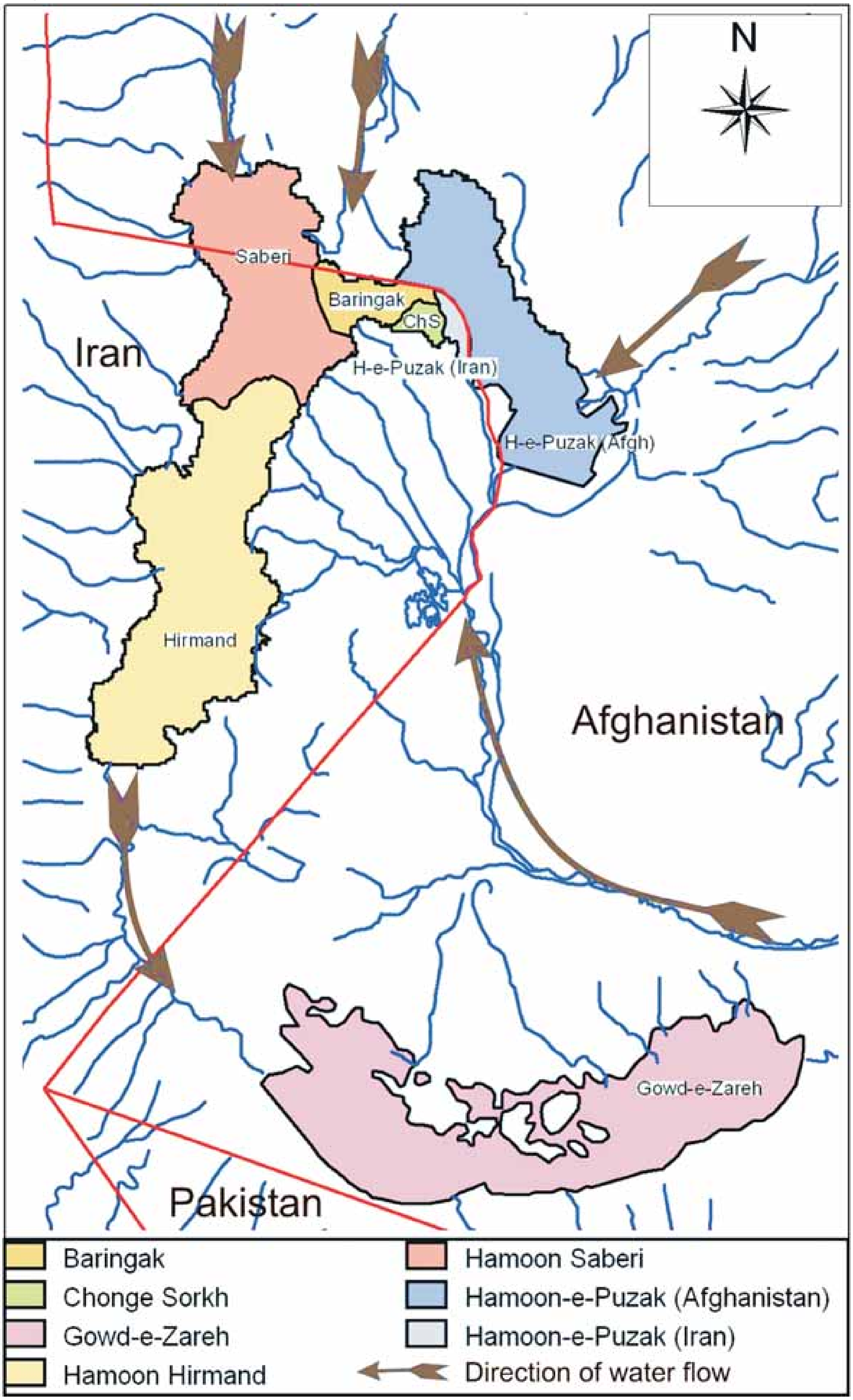


Table 4 Volume estimates of the Hamoons

Units	Average depth* (m)	Area** (km2)	Volume (million m3)
Baringak	1	221.6	221.6
Chonge Sorkh	1	59.8	59.8
Hamoon Hirmand	2	2388.8	4777.5
Hamoon-e-Puzak (Afgh)	3	1453.4	4360.3
Hamoon-e-Puzak (Iran)	2	61.0	122.0
Hamoon Saberi	3	1161.5	3484.5
Total		**5346.0**	**13025.6**
Gowd-e-Zareh	10	2417.5	24174.9
* *Estimated by local experts for the highest water stages*			
** *Largest water cover observed in satellite images*			

The volumes shown in *Table 4* are reliable estimates. Average depth values at the highest water stage were cross-checked by interviewing additional experts and comparing the results to declining rates of water cover mapped from satellite images.

3.4 The spillway of the Hamoons and Lake Gowd-e-Zareh

A threshold controls the outflow from Hamoon Hirmand at the origin of the Shile River. Overflow leaves the Hamoon only if the water level exceeds a certain stage[2].

As explained above, Gowd-e-Zareh is a saline lake. Temporary vegetation cover is limited along its shore-line, where the relatively fresh water of the Hamoon overspill enters the lake.

Control structure at the outflow of Hamoon Hirmand

4 Inundation and vegetation cover dynamics

Satellite images of the region are available as of the early 1970s. This assessment of the wetland inundation dynamics used mainly Landsat and NOAA AVHRR data, but brief studies of IRS and Landsat images were also included in the analysis. The objective was to record the water cover on each image and – wherever possible – to map the vegetation cover. On a number of images, a supervised image classification was carried out to obtain masks of characteristic inundation patterns. When a series of masks of different characteristic inundation percentages were produced, visual comparison of the masks with the satellite image was used to estimate the inundation extent. This method is slightly less accurate[3] but considerably faster than standard image classification.

It is more difficult to estimate the vegetation cover with the method described above. The coarse spatial and spectral resolution of NOAA AVHRR causes significant uncertainties. Thus, the time series created for the vegetation cover contains fewer images, which were selected according to the estimated reliability of the vegetation map.

The water and vegetation cover of the Hamoons are analysed in the following sections.

4.1 Water and vegetation cover dynamics in the Hamoon system

Four rivers account for most of the inflow into the Hamoon system. These are, in order of importance: the Helmand, Farah, Adrashkan (Harut) and Khash rivers. The seasonality of the inflow is well reflected in the fluctuations of the estimated volume[4] of stored water in the lakes (*Figure 9*). The chart contains some erratic jumps in the curve, which are due to the inaccuracy of the inundation mapping/estimate as well as to the uneven temporal availability of the satellite images. The errors do not affect the overall picture.

From 1985 to 2005, four periods can be identified:

1. A low-water period from 1985-1988: the Hamoons dried out or shrunk to a very small size almost every year, but there was some inflow every year.

2. A high-water period from 1989-1993: there was considerable inflow for five years, during which the Hamoons only shrunk below the previous period's maximum levels for a very short time.

3. A medium-water period from 1994-1999: a dynamic balance of inflow and outflow maintained a reasonably high minimum water volume every year.

4. A dry period from 2000-2004: the inflow ceased and a catastrophic drought ensued. The end of this phase is marked by a flood in 2005, comparable in volume to the maximum water level of the dry period.

The vegetation cover (Figure 10) does not reflect this same periodicity, but rather an annual dynamic (although inaccuracies in the individual estimates distort the picture to some extent). The most alarming observation to be made from the chart is that there was a clear overall decline in total vegetation cover until the end of 1999, as indicated by the trend line. Subsequently in 2000, the drought caused a rapid collapse of the entire wetland vegetation, after which the very little remaining vegetation was restricted to small pockets where rivers brought effluent waters from the irrigation schemes. The drought ended with medium-level floods in the beginning of 2005 (*Figure 11*), which resulted in partial recovery of the vegetation (*Figure 12*).

The overall situation can be interpreted in greater detail by analysing the Hamoon sub-units individually.

Figure 9 Volume of water in the Hamoons 1985-2005

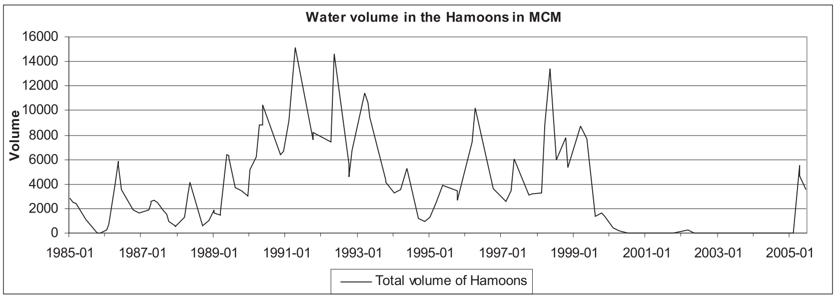


Figure 10 Vegetation cover of the Hamoons 1985-2005

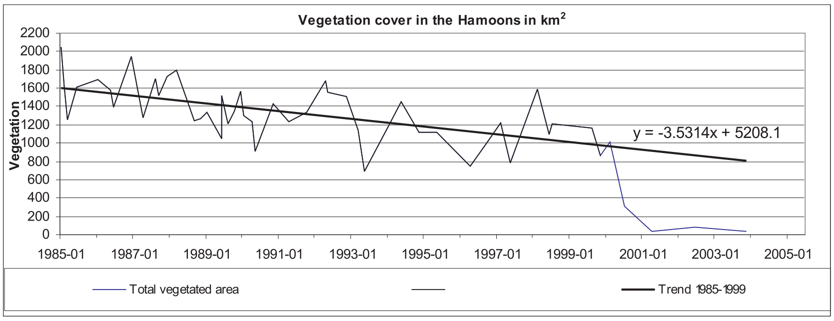
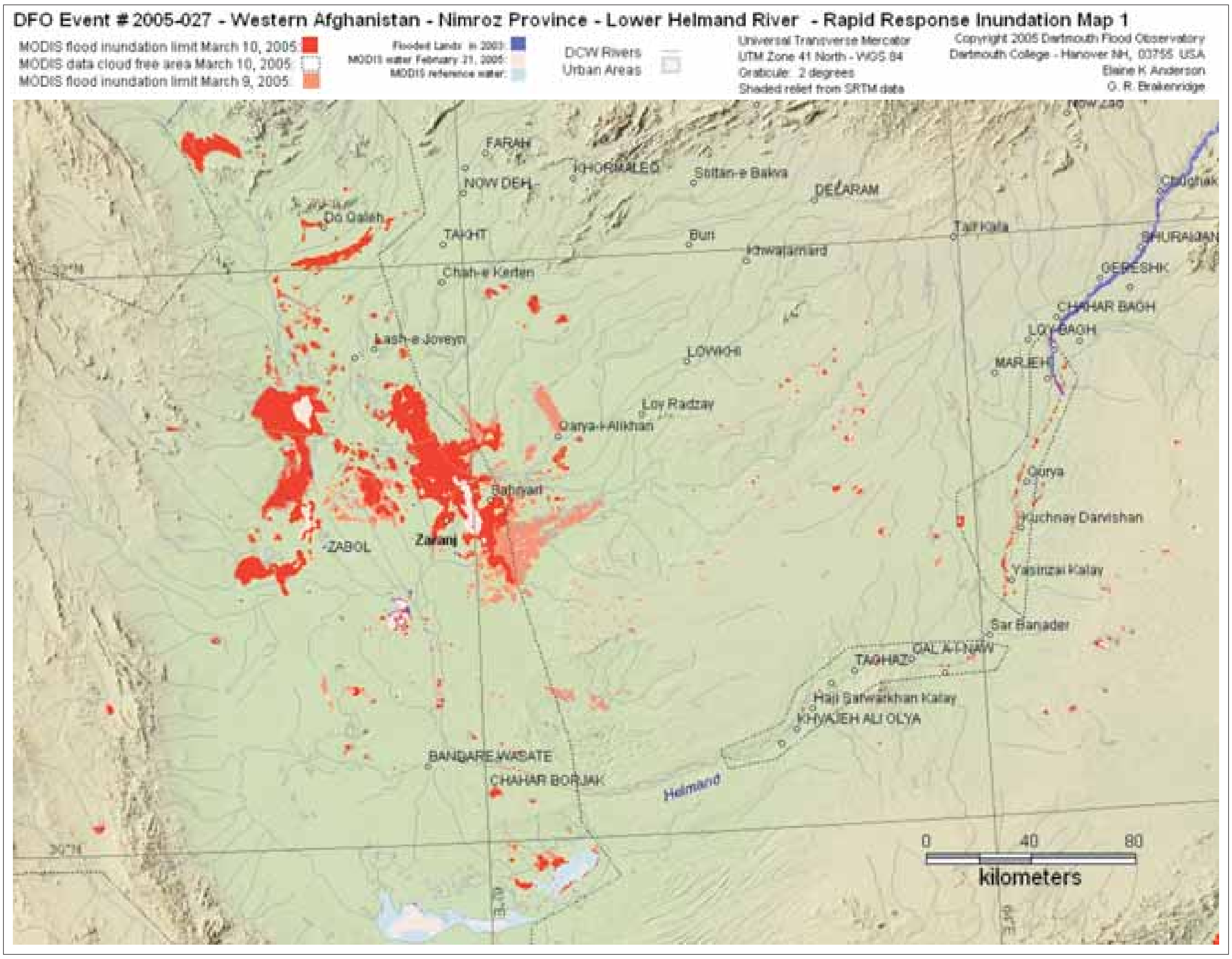
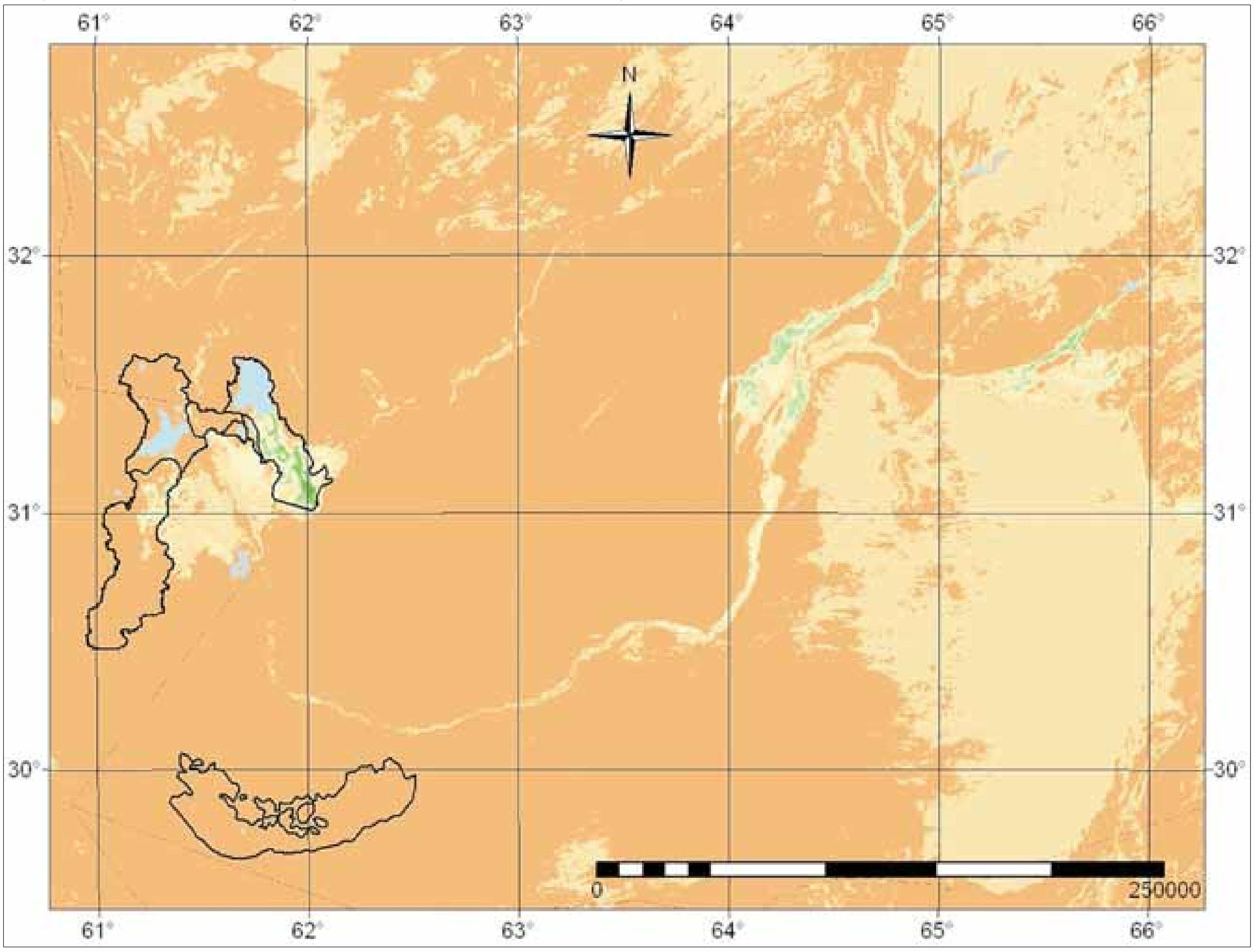


Figure 11 Flood map of 10 March 2005



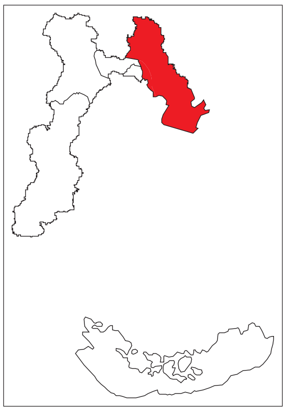
SOURCE:(DARTMOUTH FLOOD OBSERVATORY 2005)

Figure 12 Post-flooding normalised differential vegetation index map



A rapid recovery of wetland vegetation took place in Hamoon-e-Puzak following the flood in early 2005

4.2 Hamoon-e-Puzak



Hamoon-e-Puzak is the most vegetated wetland on the eastern fringe of the Helmand delta. The Afghanistan-Iran border runs through it: the Iranian portion is approximately 61 km^2 (four percent) and the Afghanistan part is 1,453 km^2 (96 percent). The average depth at the highest water stages is about 3 m on the Afghanistan side, and slightly shallower in Iran (2 m). The Iranian part of Hamoon-e-Puzak was designated as a Ramsar Site in 1975; the Afghanistan side is not formally protected.

In high-water periods, vast reed beds of *Phragmites australis* cover most of the wetland, while open water surfaces, which host a rich growth of submerged vegetation, principally *Ceratophyllum demersum* (Scott 1995).

This Hamoon is fed directly by the Common Parian and Khash rivers, and partially by the Farah River. The four distinct periods discussed in the global assessment of the Hamoons are not clearly visible for this wetland (Figure 13): at least 40 percent of Hamoon-e-Puzak was inundated up until the drought. The Iranian part of the wetland appears to be more vulnerable to drying out. In spite of relative water abundance, the cessation of inflow left the wetland completely dry. The 2005 floods did not completely fill this Hamoon.

A general decline in vegetation cover in the period between 1985 and 1999 is clearly noticeable in Hamoon-e-Puzak. In the time series analysis, the 1985 drought does not appear to have had identifiable effect, as the vegetated area did not change. This does not imply that the vegetation did not suffer from the lack of water and one may assume that the individual plants did show signs of water stress. However, there was no substantial loss of plant biomass, so the vegetation was able to recover rapidly and flourish until 1999. A sharp collapse in the vegetation cover, however, occured with the start of the drought in 2000. Only following the floods in early 2005, did signs of wetland vegetation reestablishment begin to reappear.

Detailed mapping (*Figure 35*, *36* and *37*) allows for land cover comparison between the mid-1970's to 2002. It further substantiates observations in the declining trend of vegetation cover described above.

Figure 13 Inundated area changes in Hamoon-e-Puzak 1985-2005

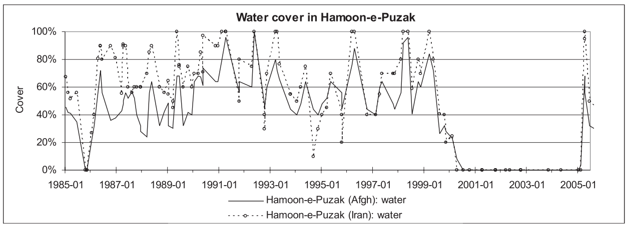


Figure 14 Vegetation cover changes in Hamoon-e-Puzak 1985-2005

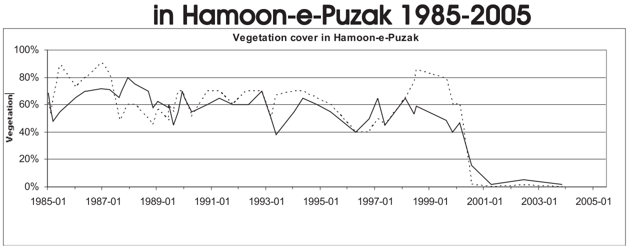
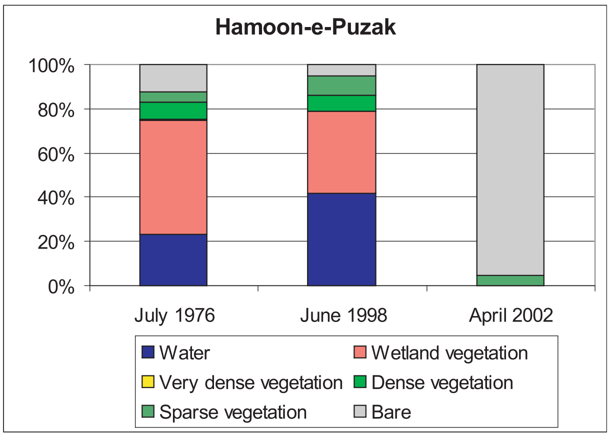
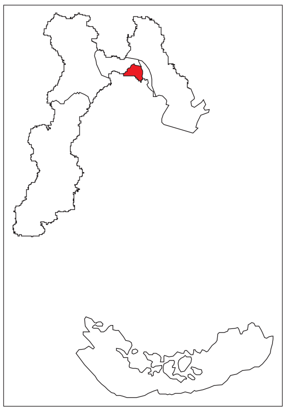


Figure 15 Land cover changes in Hamoon-e-Puzak 1975-2002



4.3 Chonge Sorkh



Chonge Sorkh is a relatively small wetland (60 km^2 with a maximum average depth of 1 m). Its large eastern neighbour is Hamoon-e-Puzak, separated by a thin "peninsula" of higher ground on which a series of villages is located. The separation from its western neighbour (Baringak), with which it shares many characteristics, is less pronounced. Nonetheless, it is meaningful to categorize Chonge Sorkh separately because – as local experts emphasized during a field visit in early 2005[5] – it has a high potential for restoration by water control measures.

Chonge Sorkh does not receive direct inflow from any major river, but acquires water through neighbouring wetlands. Data for Chonge Sorkh shows considerable fluctuation in water cover (Figure 16), although the wetland appears to have dried out completely only twice in the 1985-1999 period. Furthermore, even during the low-water period, it was filled to a minimum of 60 percent, while in the medium-water period, it was completely full in the Spring. The same situation occurred again in 2005, following the flood.

Analysis of the vegetation cover between 1985 and 1995 does not reveal a clear trend, but overall a decline is perceptible (Figure 17) despite the fact that there is sufficient water in (delete: the) Chonge Sorkh. Indeed, the maximum vegetation cover does not exceed 30 percent, even during the high-water period. This differs drastically from the situation in the mid-1970s (Figure 18), for which a detailed vegetation map shows 47 percent vegetation cover (Figure 35).

Figure 16 Inundated area changes in Chonge Sorkh 1985-2005

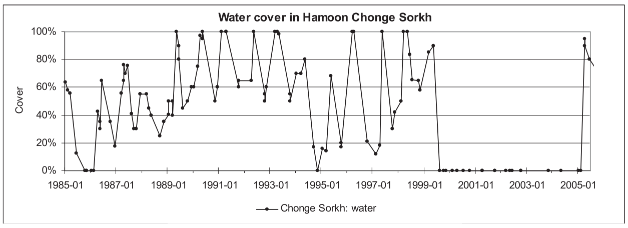


Figure 17 Vegetation cover changes in Chonge Sorkh 1985-2005

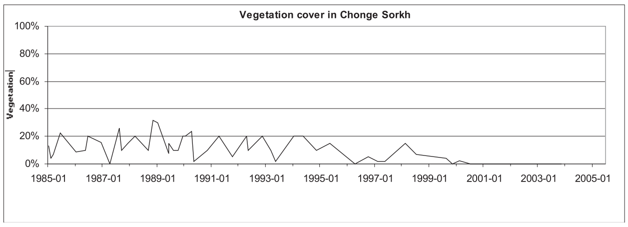
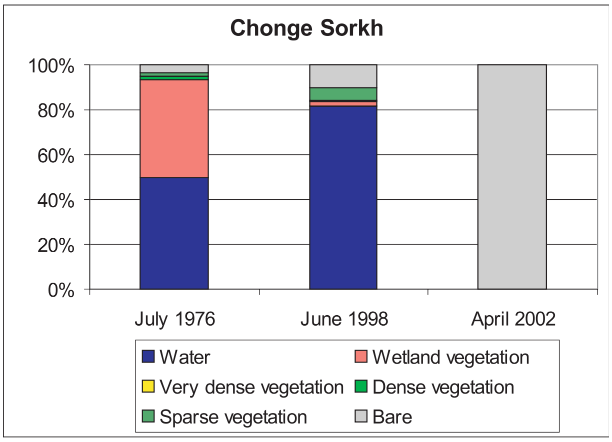
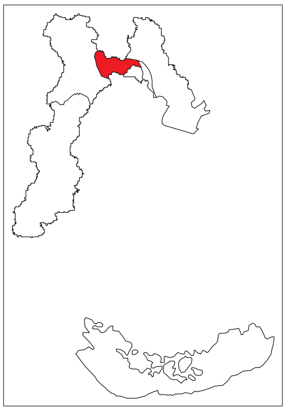


Figure 18 Land cover changes in Chonge Sorkh 1976[6]-2002



4.4 Baringak



Baringak (222 km^2 with a maximum average depth of 1 m) links Hamoon-e-Puzak and Hamoon Saberi. In the medium- and high-water periods, it was the most dynamic part of the Hamoon system: it filled rapidly to maximum extent, but dried out more frequently than Chonge Sorkh (*Figure 19*). During the dry period, there was little water cover, indicating that the wetland is highly vulnerable.

A gradual decline of wetland vegetation cover in the Baringak is noticeable during the 1985-1999 period (Figure 20), although it did not have as significant a vegetation cover in the 1970s as its neighbour Chonge Sorkh (Figures 21 and 35). Some vegetation remained in 2000, but the cover was minor.

Figure 19 Inundated area changes in Hamoon Baringak 1985-2005

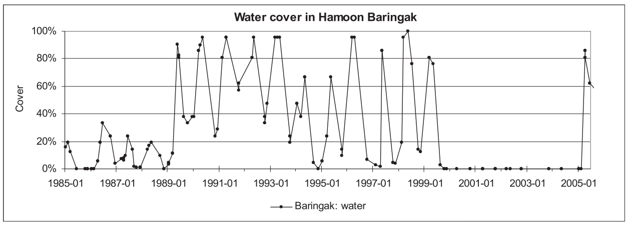


Figure 20 Vegetation cover changes in Baringak 1985-2005

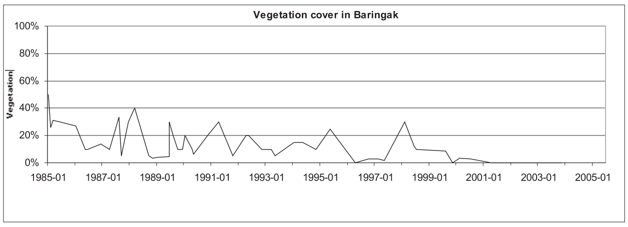
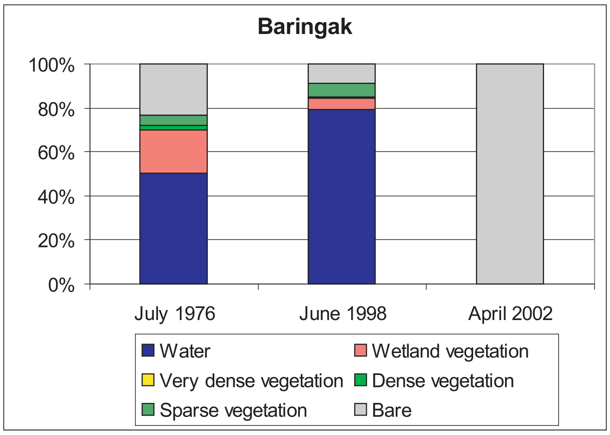
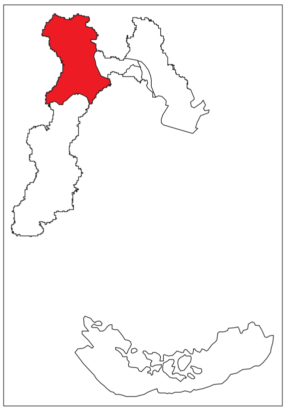


Figure 21 Land cover changes in Baringak 1976-2002



4.5 Hamoon Saberi



The main inflow into Hamoon Saberi (1,162 km² with a maximum average depth of 3 m) comes from the Adrashkan (Harut) and partly from the Farah river. The northern branch of the Sistan River, which flows into the southern tip of the Hamoon, also contributes to the wetland. During high-water periods, water from Hamoon-e-Puzak overflows into Hamoon Saberi via Baringak. Satellite images consistently show lighter water tones than those of the other Hamoons. Water quality differences (suspended sediments, etc.) and the lack of submerged vegetation may explain this variance.

Hamoon Saberi's water regime is different from the aforementioned wetlands (*Figure 22*): the lake filled and emptied rapidly during the low-water period, but hardly shrank at all in the high-water period and changed relatively little in the medium-water period. At the beginning of 2002, runoff filled 25 percent of Hamoon Saberi. This was the only inundation in the Hamoon system during the drought.

Analysis of satellite data sets reveals that vegetation only ever covered a small part of Hamoon Saberi and even that coverage started gradually decreasing before the onset of the drought (*Figure 23*). Vegetation cover was around ten percent in the mid-1970s. It completely disappeared as a result of the drought, causing people to abandon their villages along the shores and on the islands. During the field work in January 2005, local experts reported that more than a hundred villages in the Saberi and Baringak region had been deserted.

Figure 22 Inundated area changes in Hamoon Saberi 1985-2005

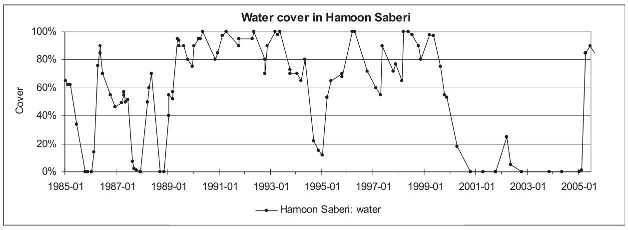


Figure 23 Vegetation cover changes in Hamoon Saberi 1985-2005

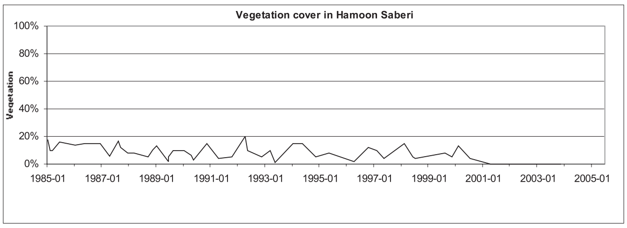
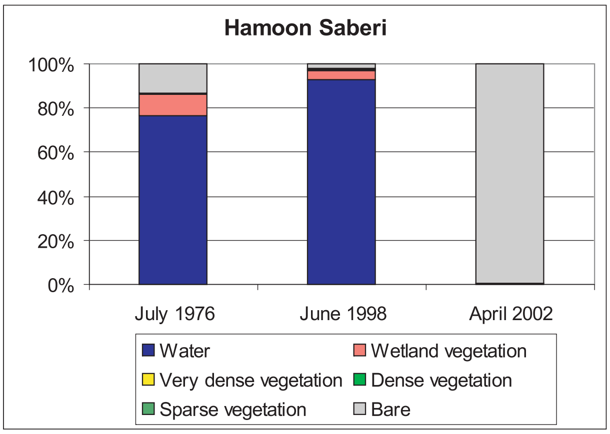
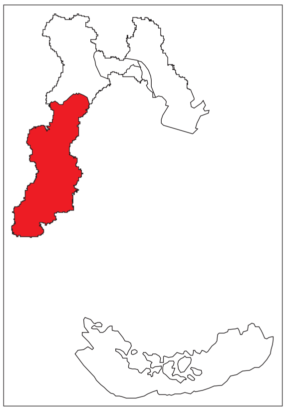


Figure 24 Land cover changes in Hamoon Saberi 1975-2002



4.6 Hamoon Hirmand



Hamoon Hirmand is the largest lake in the system (2,389 km^2 with a maximum average depth of 2 m). It receives water from Hamoon Saberi in the north as well as some inflow and return drainage from the Sistan-irrigated areas through the Sistan River. Excess water exits the system at the southernmost point of this lake via the Shile River. The lake's relatively low water cover indicates its short residency time (Figure 25). Water cover was limited in the low-water phase, and while the Hamoon never shrunk to less than 60 percent of its maximum size during the high-water period, it dried out once during the medium-water period, and attained less than 20 percent capacity after the 2005 floods.

The decrease in vegetation cover is similar to the general trend discussed above (*Figure 26* and *27*).

Figure 25 Inundated area changes in Hamoon Hirmand 1985-2005

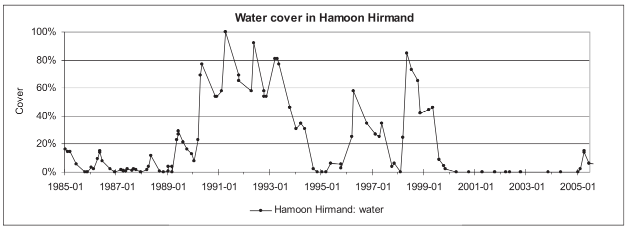


Figure 26 Vegetation cover changes in Hamoon Hirmand 1985-2005

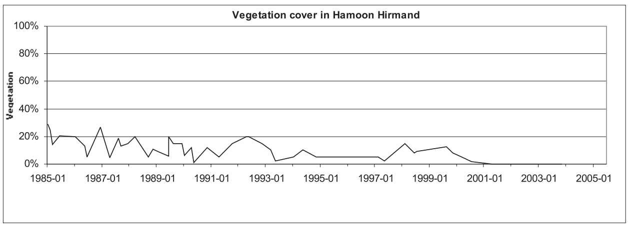
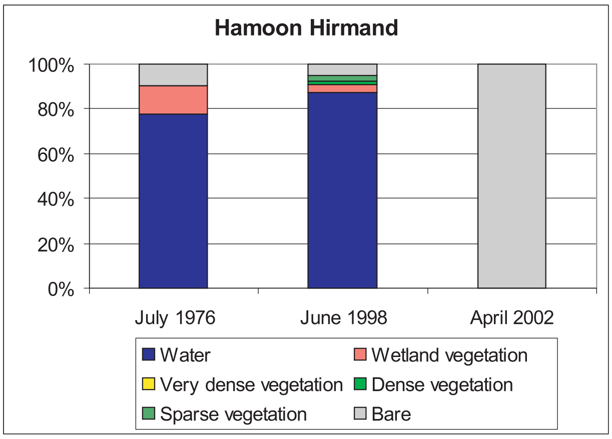
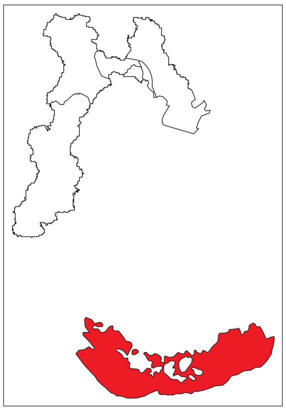


Figure 27 Land cover changes in Hamoon Hirmand 1976-2002



4.7 Gowd-e-Zareh

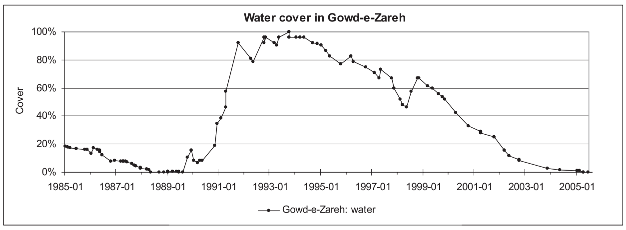


The overspill from the Hamoon system collects into Lake Gowd-e-Zareh in Afghanistan (2,418 km^2, with an estimated maximum average depth[7] of 10 m). The Hamoon system acts as a buffer: water flows reach the lake only in the event of a large discharge into the Hamoons (*Figure 28*). It is reported that direct inflow from the Helmand River can also take place during exceptionally major floods. It was not possible to prove this with the available satellite images.

Lake Gowd-e-Zareh is saline and deeper than the Hamoons. Once it is full, it takes approximately 8-10 years for the water to evaporate completely (*Figure 28*). With an estimated 3-3.5 m annual evaporation rate, water depth could reach 25-30 m at the deepest points. Gowd-e-Zareh reached its maximum extent in 1993-94.

Vegetation does not occur in the water; it can only be found along the shores, particularly in the western corner of the lake. Vegetation-related graphs for Lake Gowd-e-Zareh are therefore unnecessary.

Figure 28 Inundated area changes in Gowd-e-Zareh 1985-2005



5 Environmental challenges in the Sistan region

Sistan is located in an extremely arid region, which is entirely dependent for its water source on rivers originating in remote headwaters. The region's main environmental challenge is that these rivers often fail to bring this most necessary life sustaining resource. Strong fluctuations have always been a distinguishing characteristic of the area's natural hydrological cycle, in which even low-water periods play an important ecologycal role. Serious degradation occurs when dry periods extend over unusual durations, threatening not only the ecosystem but limiting the possibilities for human settlements and livelihoods as well.

What are the causes of low water flows and droughts?

A comprehensive answer to this question is beyond the scope of this study but by summarizing the results of the remote sensing survey, some steps can be made towards understanding how this system functions. Based on satellite image analysis, four different flow periods can be discerned over the last twenty years, which resulted in different inundation patterns in the Hamoons:

1. A low-water period in 1985-1988.
2. A high-water period in 1989-1993.
3. A medium-water period in 1994-1999.
4. A dry period in 2000-2004.

Wetland vegetation distribution, however, does not show similar periodicity. Rather, a continuous decline of the vegetation cover is observable from 1985 to the onset of the drought in 2000. This degradation was a warning sign: the pressure on the ecosystem consistently exceeded what it could tolerate. The fact that the vegetation cover extent and water inundation do not correlate indicates that other factors play a more important role in vegetation development than water supply.

There was hardly any inflow into the Sistan wetlands between 2000 and 2004, and this drought resulted in the disappearance of the vegetation cover and the consequent collapse of the ecosystem. The implementation and expansion of various water works in the basin further stressed the system. With the 2005 flood, some signs of recovery were reported from the field, but it is still not clear to what extent this recovery will be successful. Furthermore, the risk remains that the decline in vegetation cover will not reverse unless the causes of wetland degradation are understood and properly addressed. Quantifying the relative weight of the key pressures on the environment requires additional detailed analysis, which is partly under way in the 'Iranian-Dutch IWRM Sistan Project'. *Table 5* provides an overview of the key pressures impacting the Hamoon system.

Solutions to the Sistan area's environmental predicament need to be sought within the context of transboundary cooperation between Afghanistan and Iran: due to the complicated route of water flows through the Hamoons, it is not viable to develop responses on individual country basis. The Sistan region is a classic example of an environmental crisis that may only be solved through integrated and coordinated transboundary management.

It is recommended that joint efforts first focus on reaching a common understanding of the problems and issues and subsequently explore mutually acceptable water management objectives.

Table 5 Key environmental pressures in the Sistan region

Pressure	Affected region	Results / signs	Possible measures
Climate change	Sistan basin	More extreme floods Changing precipitation pattern	Better prediction / Early warning system
Population growth	Inhabited areas, Ecosystems	More domestic water demand More irrigation water demand More intensive use of environmental resources (e.g. hunting in the wetlands, excessive reed harvesting)	Increasing water use efficiency Coordinated resources management
Irrigation development plans	River valleys, Sistan plain	Less water for the downstream areas, including the Hamoons Declining water quality downstream	Increasing irrigation efficiency Change of crops
Hydropower developments	Downstream from the dams	Modified runoff pattern resulting in modified inundation pattern in the Hamoons	Proper operation rules
Improper fishing practices / introduction of exotic fisheries	Hamoons	Decline in fish population	Intensive fish ponds

Appendix A Satellite images used in the study

Several sets of satellite data were used in the present study. Some were processed in detail, whilst others were used for illustration purposes only. The following sections provide an overview of the images used and the methods of analysis applied.

A.1 Landsat image classification procedures

Images from three dates were chosen for detailed mapping of land cover to represent the characteristic stages of the environmental dynamics. A time series to cover the period of 1985-2005 was created with a more approximate method.

Table 6 Images used for land cover classification

Date	Satellite and sensor	Path / row	Pixel size
5 June 1976	Landsat MSS	169 / 39	78 m
11 July 1976	Landsat MSS	169 / 38	78 m
18 June 1998	Landsat TM	157 / 38 & 39	30 m
18 April 2002	Landsat ETM	157 / 39	30 m
21 June 2002	Landsat ETM	157 / 38	30 m

The steps followed in the processing of the images are listed below:

A.1.1 MSS 1976

- Conversion of raw image to ".img" file using ENVI conversion utilities for both dates
- Creation of FCC and NDVI using ERDAS
- Spectral enhancement using tasselled cap transformation to optimize the data for vegetation and water separation using ERDAS coefficients
- Multiplication of NDVI with tasselled cap axes brightness, greenness and wetness to exaggerate separation of vegetation classes
- Classification using various thresholds determined visually from the FCC of NDVI*tasselled cap, FCC123
- Merging of classes to produce the classified image, including marshland
- Determination of separate water class without marshland by visual interpretation of the previous class overlaid over an FCC 4,2,1 off the MSS
- Merging of the water class with the other classes to produce the classified image excluding marshland
- Visual inspection of all classifications; tweaking where necessary until optimal result was reached (no ground truth available).

A.1.2 TM 1998

- Conversion of ".tif" file to ".img" file using ERDAS
- Creation of the FCC's and a mosaic of the images
- Creation of NDVI
- Spectral enhancement using tasselled cap transformation to optimize the data for vegetation and water separation using ERDAS coefficients
- Multiplication of NDVI with tasselled cap axes brightness, greenness and wetness to exaggerate separation of vegetation classes
- Classification using various thresholds determined visually from the FCC of NDVI*tasselled cap, FCC123
- Merging of classes to produce the classified image with marshland
- Determination of separate water class using a visually determined threshold on TM Band 7

- Merging of the water class with the other classes to produce the classified image without marshland
- Visual inspection of all classifications; tweaking where necessary until optimal result was reached (no ground truth available).

A.1.3 ETM 2002

- Conversion of ".tif" file to ".img" file using ERDAS for both dates
- Creation of the FCC's and NDVI's
- Spectral enhancement using tasselled cap transformation to optimize the data for vegetation and water separation using ERDAS coefficients
- Multiplication of NDVI with tasselled cap axes brightness, greenness and wetness to exaggerate separation of vegetation classes
- Omission of tasselled cap and tasselled*NDVI due to unsatisfactory results caused by unknown algorithm coefficients
- Classification of the vegetation classes using various thresholds determined visually from the NDVI
- Determination of water class using a threshold on Band7 determined visually
- Merging of classes to produce the classified image: remainder of image classified as "Bare"
- Visual inspection of all classifications; tweaking where necessary until optimal result was reached (no ground truth available).

A.2 Inundation and vegetation cover time series

Table 7 Satellite images used for compiling the inundation and vegetation time series

No.	Date	Image type	Processing mode	Inundation	Vegetation
1	1985-01-21	Landsat MSS QL	Digital estimate	yes	yes
2	1985-02-06	Landsat MSS QL	Digital estimate	yes	yes
3	1985-03-26	Landsat MSS QL	Digital estimate	yes	yes
4	1985-06-14	Landsat MSS QL	Digital estimate	yes	yes
5	1985-10-10	NOAA 09 AVHRR	Visual estimate	yes	
6	1985-11-15	NOAA 09 AVHRR	Visual estimate	yes	
7	1985-11-26	NOAA 09 AVHRR	Visual estimate	yes	
8	1986-01-08	Landsat MSS QL	Digital estimate	yes	yes
9	1986-02-09	NOAA 09 AVHRR	Visual estimate	yes	
10	1986-04-30	Landsat MSS QL	Digital estimate	yes	
11	1986-05-16	Landsat MSS QL	Visual estimate	yes	
12	1986-05-22	NOAA 09 AVHRR	Visual estimate	yes	yes
13	1986-06-30	NOAA 09 AVHRR	Visual estimate	yes	yes
14	1986-10-05	NOAA 09 AVHRR	Visual estimate	Yes	
15	1986-12-17	NOAA 09 AVHRR	Supervised classification	Yes	yes
16	1987-03-08	NOAA 09 AVHRR	Supervised classification	Yes	
17	1987-04-17	Landsat MSS QL	Digital estimate	Yes	
18	1987-04-24	NOAA 09 AVHRR	Supervised classification	Yes	yes
19	1987-05-02	NOAA 09 AVHRR	Visual estimate	Yes	
20	1987-06-04	Landsat MSS QL	Digital estimate	Yes	yes
21	1987-08-07	Landsat MSS QL	Digital estimate	Yes	yes
22	1987-09-24	Landsat MSS QL	Visual estimate	Yes	yes
23	1987-10-10	Landsat MSS QL	Visual estimate	Yes	
24	1987-12-05	NOAA 09 AVHRR	Visual estimate	Yes	
25	1987-12-24	NOAA 09 AVHRR	Visual estimate	Yes	
26	1988-03-16	NOAA 09 AVHRR	Visual estimate	Yes	yes
27	1988-04-12	NOAA 09 AVHRR	Visual estimate	Yes	
28	1988-05-10	NOAA 09 AVHRR	Visual estimate	Yes	
29	1988-09-19	NOAA 09 AVHRR	Visual estimate	Yes	yes
30	1988-11-26	NOAA 11 AVHRR	Supervised classification	Yes	yes
31	1989-01-07	NOAA 11 AVHRR	Supervised classification	Yes	yes
32	1989-01-26	NOAA 11 AVHRR	Visual estimate	Yes	
33	1989-03-08	NOAA 11 AVHRR	Visual estimate	Yes	
34	1989-03-26	NOAA 11 AVHRR	Visual estimate	Yes	
35	1989-05-18	NOAA 11 AVHRR	Visual estimate	Yes	
36	1989-06-17	Landsat TM QL	Digital estimate	Yes	yes
37	1989-06-20	NOAA 11 AVHRR	Visual estimate	Yes	yes
38	1989-08-27	NOAA 11 AVHRR	Visual estimate	Yes	yes
39	1989-10-16	NOAA 11 AVHRR	Visual estimate	Yes	yes
40	1989-12-19	NOAA 11 AVHRR	Visual estimate	Yes	yes
41	1990-01-27	NOAA 11 AVHRR	Visual estimate	Yes	yes
42	1990-03-04	NOAA 11 AVHRR	Visual estimate	Yes	
43	1990-04-25	Landsat TM QL	Digital estimate	Yes	yes
44	1990-05-09	IRS QL	Digital estimate	Yes	yes
45	1990-05-11	Landsat TM QL	Digital estimate	Yes	
46	1990-11-09	NOAA 11 AVHRR	Visual estimate	Yes	yes
47	1990-12-16	NOAA 11 AVHRR	Visual estimate	Yes	
48	1991-02-14	NOAA 11 AVHRR	Visual estimate	Yes	yes
49	1991-04-09	NOAA 11 AVHRR	Visual estimate	Yes	yes
50	1991-04-25	NOAA 11 AVHRR	Visual estimate	Yes	
51	1991-10-01	NOAA 11 AVHRR	Visual estimate	Yes	yes
52	1991-10-25	NOAA 11 AVHRR	Visual estimate	Yes	
53	1992-04-03	NOAA 11 AVHRR	Visual estimate	Yes	yes
54	1992-05-06	NOAA 11 AVHRR	Visual estimate	Yes	yes
55	1992-10-03	NOAA 11 AVHRR	Visual estimate	Yes	

Table 7 Satellite images used for compiling the inundation and vegetation time series (continued)

No.	Date	Image type	Processing mode	Inundation	Vegetation
56	1992-10-11	NOAA 11 AVHRR	Visual estimate	Yes	
57	1992-11-05	NOAA 11 AVHRR	Visual estimate	Yes	yes
58	1993-03-17	NOAA 11 AVHRR	Visual estimate	Yes	yes
59	1993-04-19	NOAA 11 AVHRR	Visual estimate	Yes	
60	1993-05-24	IRS QL	Visual estimate	Yes	yes
61	1993-10-09	NOAA 11 AVHRR	Visual estimate	Yes	
62	1993-10-24	NOAA 11 AVHRR	Visual estimate	Yes	
63	1994-01-21	IRS QL	Visual estimate	Yes	yes
64	1994-03-19	NOAA 11 AVHRR	Visual estimate	Yes	
65	1994-05-07	NOAA 11 AVHRR	Visual estimate	Yes	
66	1994-09-12	NOAA 11 AVHRR	Visual estimate	Yes	
67	1994-11-03	IRS QL	Visual estimate	Yes	yes
68	1995-01-28	NOAA 14 AVHRR	Visual estimate	Yes	
69	1995-03-25	NOAA 14 AVHRR	Visual estimate	Yes	
70	1995-05-02	NOAA 14 AVHRR	Visual estimate	Yes	yes
71	1995-10-01	NOAA 14 AVHRR	Visual estimate	Yes	
72	1995-10-26	NOAA 14 AVHRR	Visual estimate	Yes	
73	1996-03-30	NOAA 14 AVHRR	Visual estimate	Yes	
74	1996-04-28	NOAA 14 AVHRR	Visual estimate	Yes	yes
75	1996-10-30	NOAA 14 AVHRR	Visual estimate	Yes	yes
76	1997-02-16	IRS QL	Visual estimate	Yes	yes
77	1997-04-02	NOAA 14 AVHRR	Visual estimate	Yes	
78	1997-05-11	NOAA 14 AVHRR	Visual estimate	Yes	yes
79	1997-10-10	NOAA 14 AVHRR	Visual estimate	Yes	
80	1997-11-17	NOAA 14 AVHRR	Visual estimate	Yes	
81	1998-02-03	IRS QL	Visual estimate	Yes	yes
82	1998-03-22	NOAA 14 AVHRR	Visual estimate	Yes	
83	1998-05-09	NOAA 14 AVHRR	Visual estimate	Yes	
84	1998-07-29	IRS QL	Digital estimate	Yes	yes
85	1998-10-17	NOAA 14 AVHRR	Visual estimate	Yes	
86	1998-11-13	NOAA 14 AVHRR	Visual estimate	Yes	
87	1999-03-27	NOAA 14 AVHRR	Visual estimate	Yes	
88	1999-05-02	NOAA 14 AVHRR	Visual estimate	Yes	
89	1999-08-29	IRS QL	Digital estimate	Yes	yes
90	1999-10-06	NOAA 14 AVHRR	Visual estimate	Yes	
91	1999-11-10	NOAA 14 AVHRR	Visual estimate	Yes	yes
92	2000-02-21	IRS QL	Digital estimate	Yes	yes
93	2000-04-22	NOAA 14 AVHRR	Visual estimate	Yes	
94	2000-07-02	IRS QL	Digital estimate	Yes	yes
95	2000-10-11	NOAA 14 AVHRR	Visual estimate	Yes	
96	2001-04-06	NOAA 16 AVHRR	Visual estimate	Yes	yes
97	2001-04-25	NOAA 16 AVHRR	Visual estimate	Yes	
98	2001-10-06	NOAA 16 AVHRR	Visual estimate	Yes	
99	2001-10-26	NOAA 16 AVHRR	Visual estimate	Yes	
100	2002-03-23	NOAA 16 AVHRR	Visual estimate	Yes	
101	2002-05-10	NOAA 16 AVHRR	Visual estimate	Yes	
102	2002-10-03	NOAA 16 AVHRR	Visual estimate	Yes	
103	2002-10-29	NOAA 16 AVHRR	Visual estimate	Yes	
104	2003-11-17	MODIS FCC	Visual estimate	Yes	yes
105	2004-05-29	MODIS FCC	Visual estimate	Yes	
106	2005-01-27	MODIS FCC	Visual estimate	Yes	
107	2005-02-21	MODIS FCC	Visual estimate	Yes	
108	2005-04-16	MODIS FCC	Visual estimate	Yes	
109	2005-04-29	MODIS FCC	Visual estimate	Yes	
110	2005-06-15	MODIS FCC	Visual estimate	Yes	

Appendix B Additional field photos

View from the control structure of the overspill canal of Hamoon Hirmand

Saline soils produce very high reflectivity in the satellite images

Modern irrigation canal

Dike on the western shore of Hamoon-e-Puzak

Appendix C List of image processing outputs

Image processing outputs attached to this report are available in PDF format on a DVD. Most of these have been designed based on A0 layout, and cannot be attached to this document in full size. The list below contains the file names as recorded on the DVD and the reference to the corresponding preview figures included in this document.

File name	Title	Print size	Preview figure
3D_Sistan_Catchment_A4.pdf	Bird's-eye view of the entire Sistan basin	A4	Figure 29
Chah_Nimeh_Aster2003_A4.pdf	Chah Nimeh reservoir on Aster image	A4	Figure 31
Chah_Nimeh_ETM2002_A4.pdf	Chah Nimeh reservoir on Landsat ETM image	A4	Figure 30
Classification1_ETM2002_A4.pdf	Land cover of the Sistan inland delta in 2002	A4	Figure 37
Classification1_MSS1976_A4.pdf	Land cover of the Sistan inland delta in 1976	A4	Figure 35
Classification1_TM1998_A4.pdf	Land cover of the Sistan inland delta in 1998	A4	Figure 36
Classification2_MSS1976_A4.pdf	Land cover of the Sistan inland delta in 1976 without indicating marsh vegetation	A4	Figure 38
Classification2_TM1998_A4.pdf	Land cover of the Sistan inland delta in 1998 without indicating marsh vegetation	A4	Figure 39
Classification3_MSS1976_A4.pdf	Land cover of the Sistan inland delta in 1976 with merged wetland vegetation	A4	Figure 40
Classification_3TM1998_A4.pdf	Land cover of the Sistan inland delta in 1998 with merged wetland vegetation	A4	Figure 41
Sistan_Catch_ETM_A0.pdf	Catchments of the Hamoons on Landsat ETM mosaic 1999-2001	A0	Figure 48
Sistan_Catch_ETMhydro_A0.pdf	Catchments of Sistan drainage basin with the main water courses 1999-2001	A0	Figure 49
Sistan_Catch_TM_A0.pdf	Catchments of Sistan drainage basin 1987-1990	A0	Figure 46
Sistan_Catch_TMhydro_A0.pdf	Catchments of Sistan drainage basin with the main watercourses 1987-1990	A0	Figure 47
Irrigated_Aster2003_A4.pdf	Irrigated area in 2003	A4	Figure 32
Irrigated_ETM_A4.pdf	Irrigated area in 1999-2000	A4	Figure 33
Irrigated_TM1998_A4.pdf	Irrigated area in 1998	A4	Figure 34
Overview_A0.pdf	Land cover changes in the Sistan inland delta	A0	Figure 50
Sistan_ETM_A0.pdf	The Sistan basin in 1999-2001 on Landsat ETM mosaic	A0	Figure 44
Sistan_ETMhydro_A0.pdf	The Sistan basin with its main water courses in 1999-2001 on Landsat ETM mosaic	A0	Figure 45
Sistan_TM_A0.pdf	The Sistan basin in 1987-1990 on Landsat TM mosaic	A0	Figure 42
Sistan_TMhydro_A0.pdf	The Sistan basin with its main water courses in 1987-1990 on Landsat TM mosaic	A0	Figure 43

Figure 29 Bird's-eye view of the entire Sistan basin (based on SRTM DEM and Landsat ETM mosaic 2000)

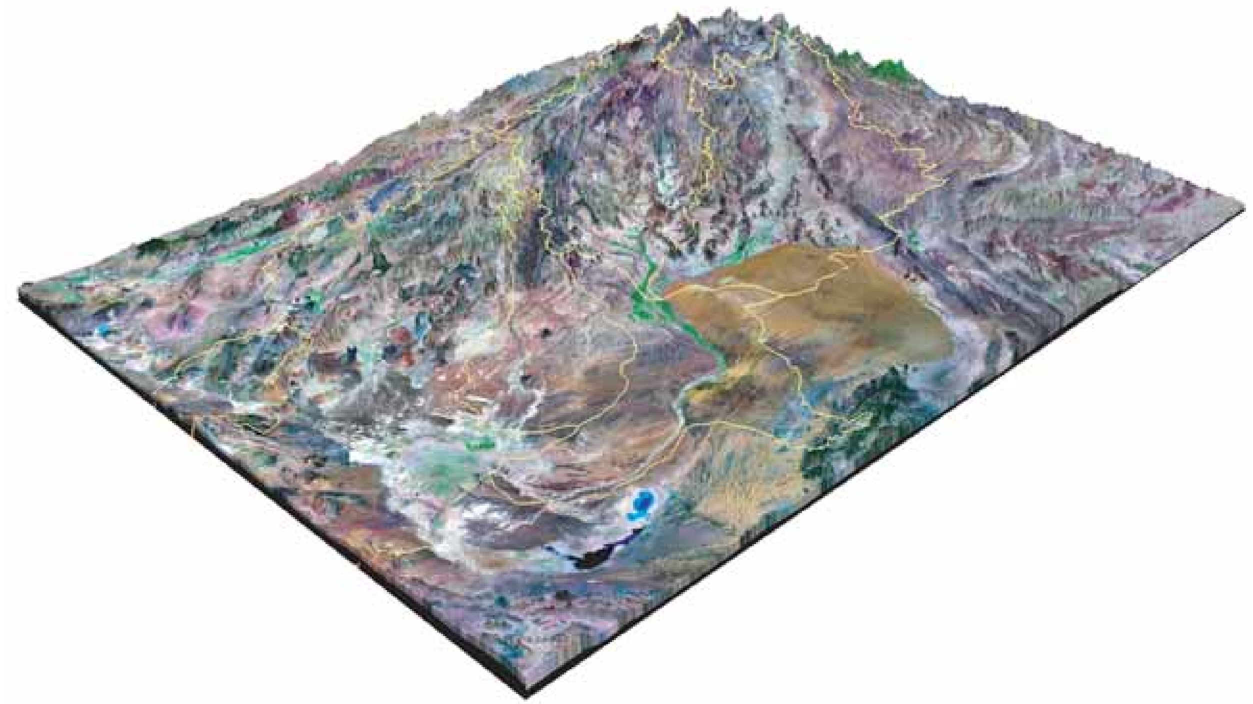


Figure 30 Chah Nimeh reservoir

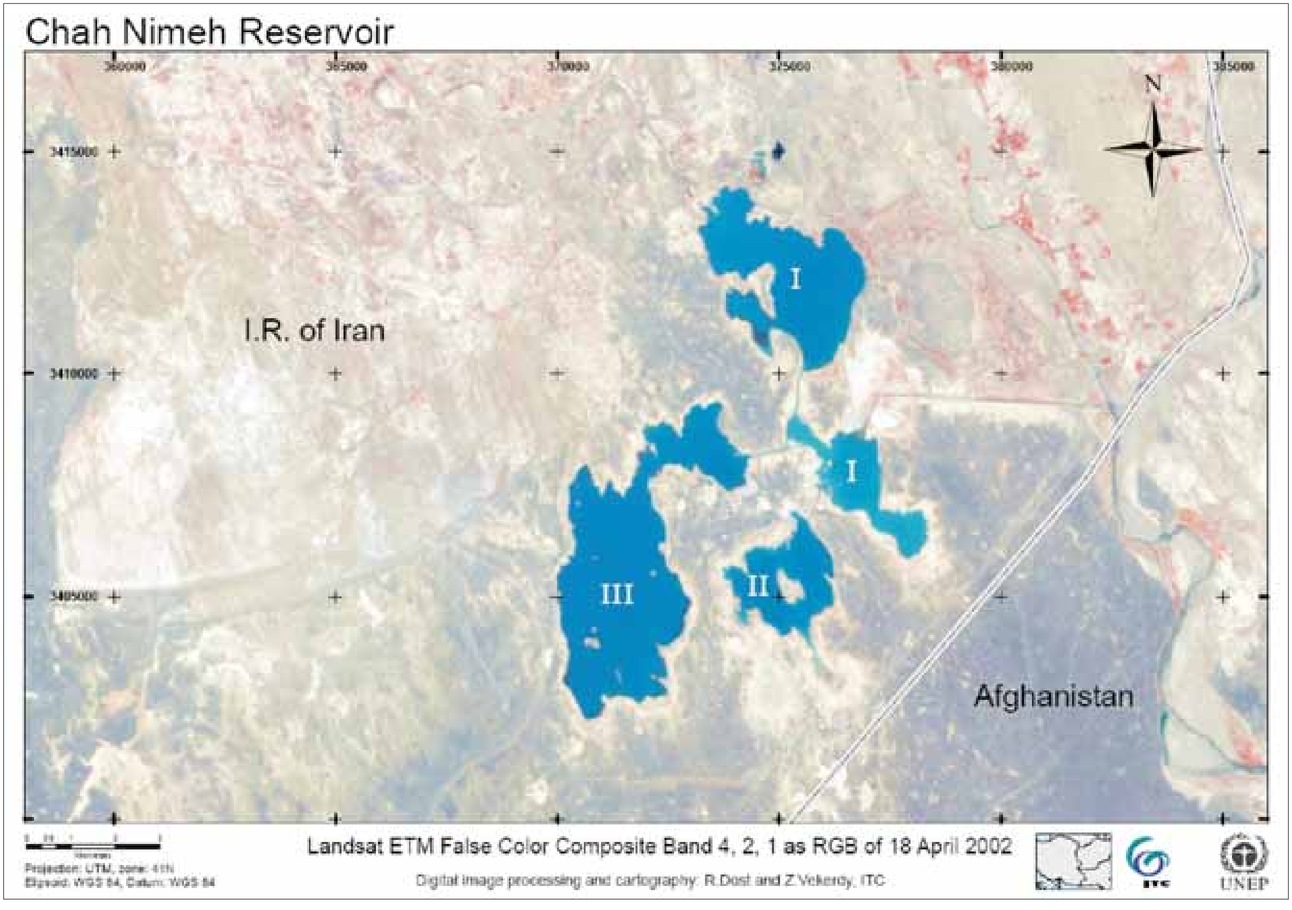


Figure 31 Chah Nimeh reservoir

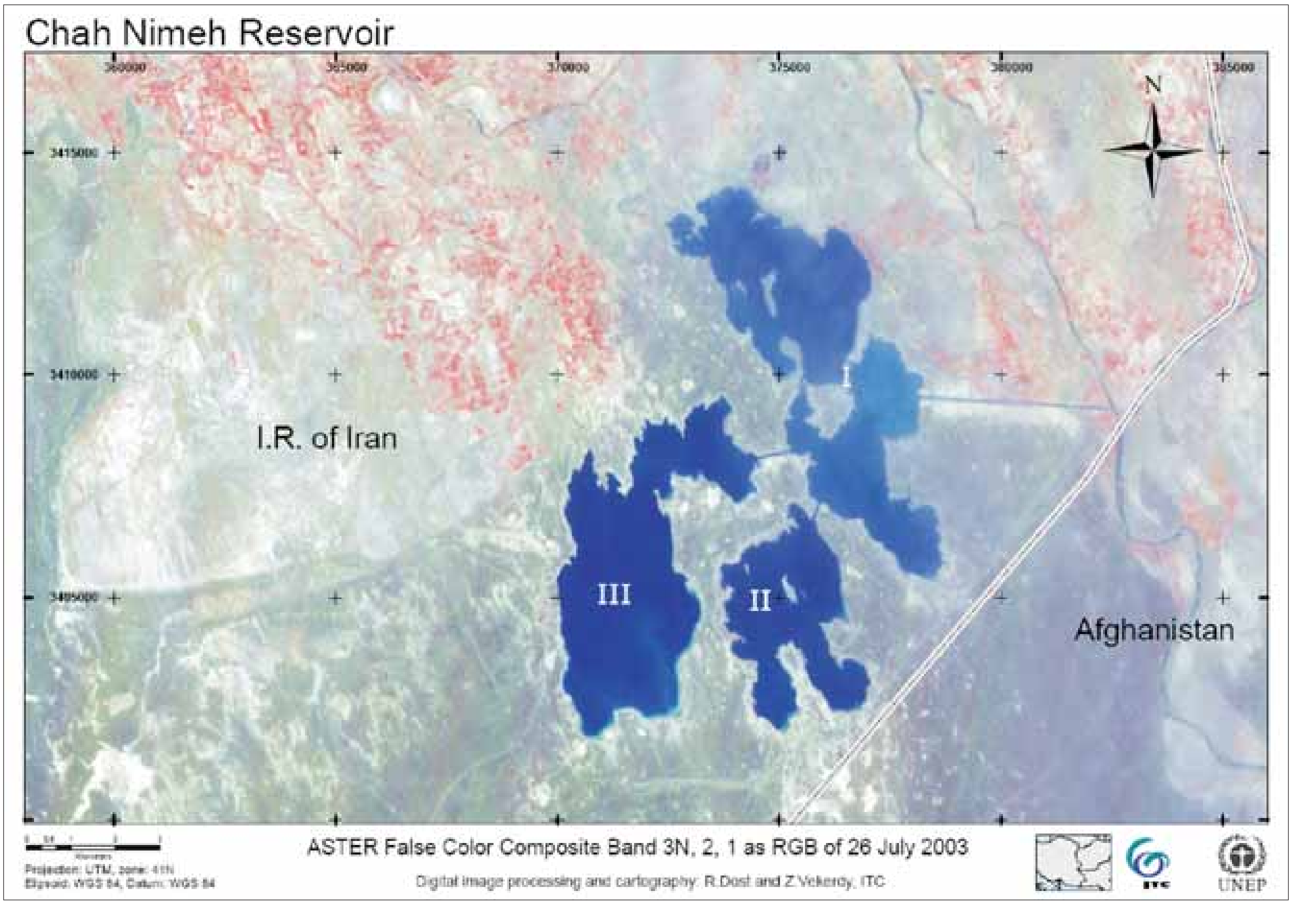


Figure 32 Irrigated area in 2003

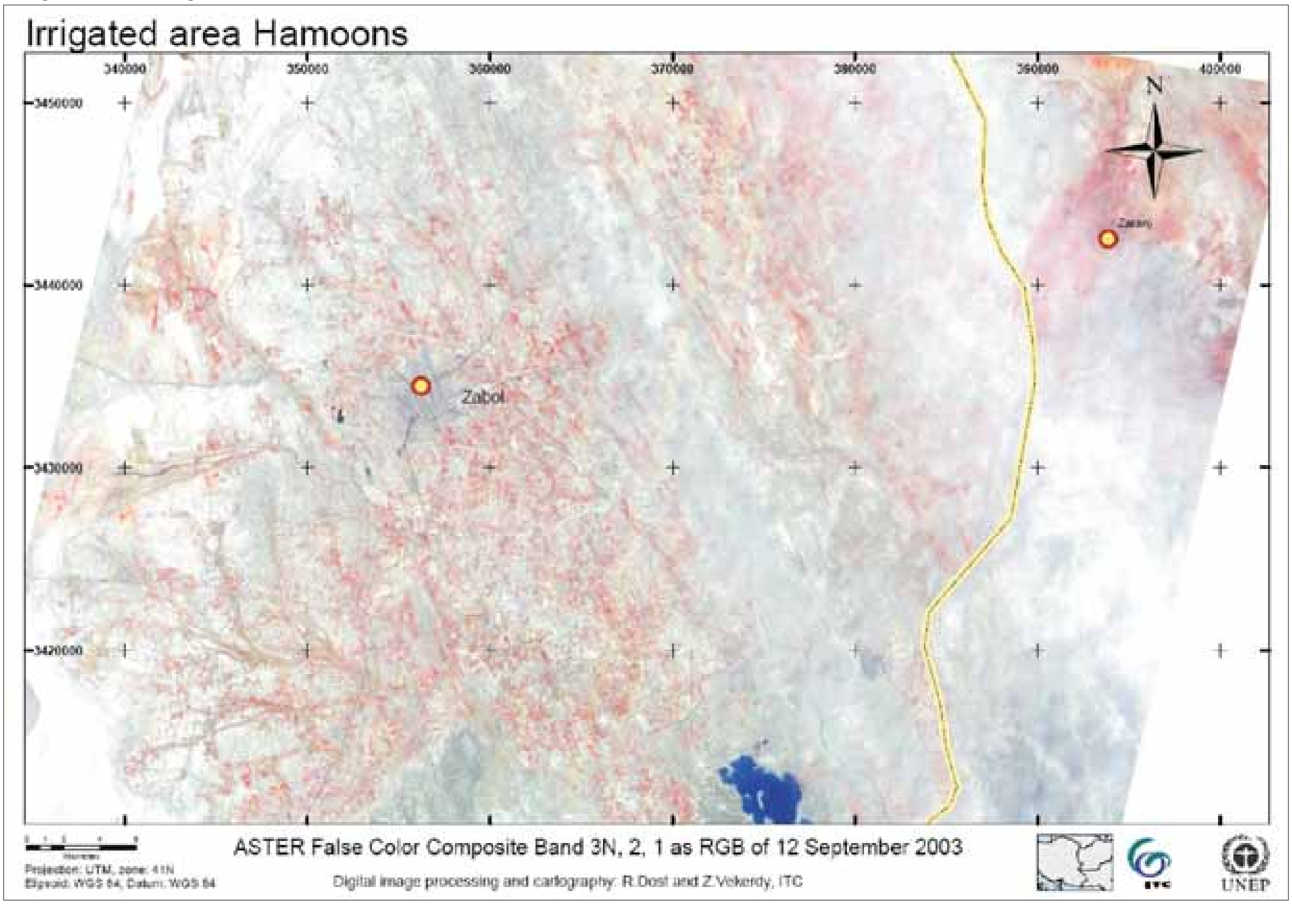


Figure 33 Irrigated area in 1999-2000

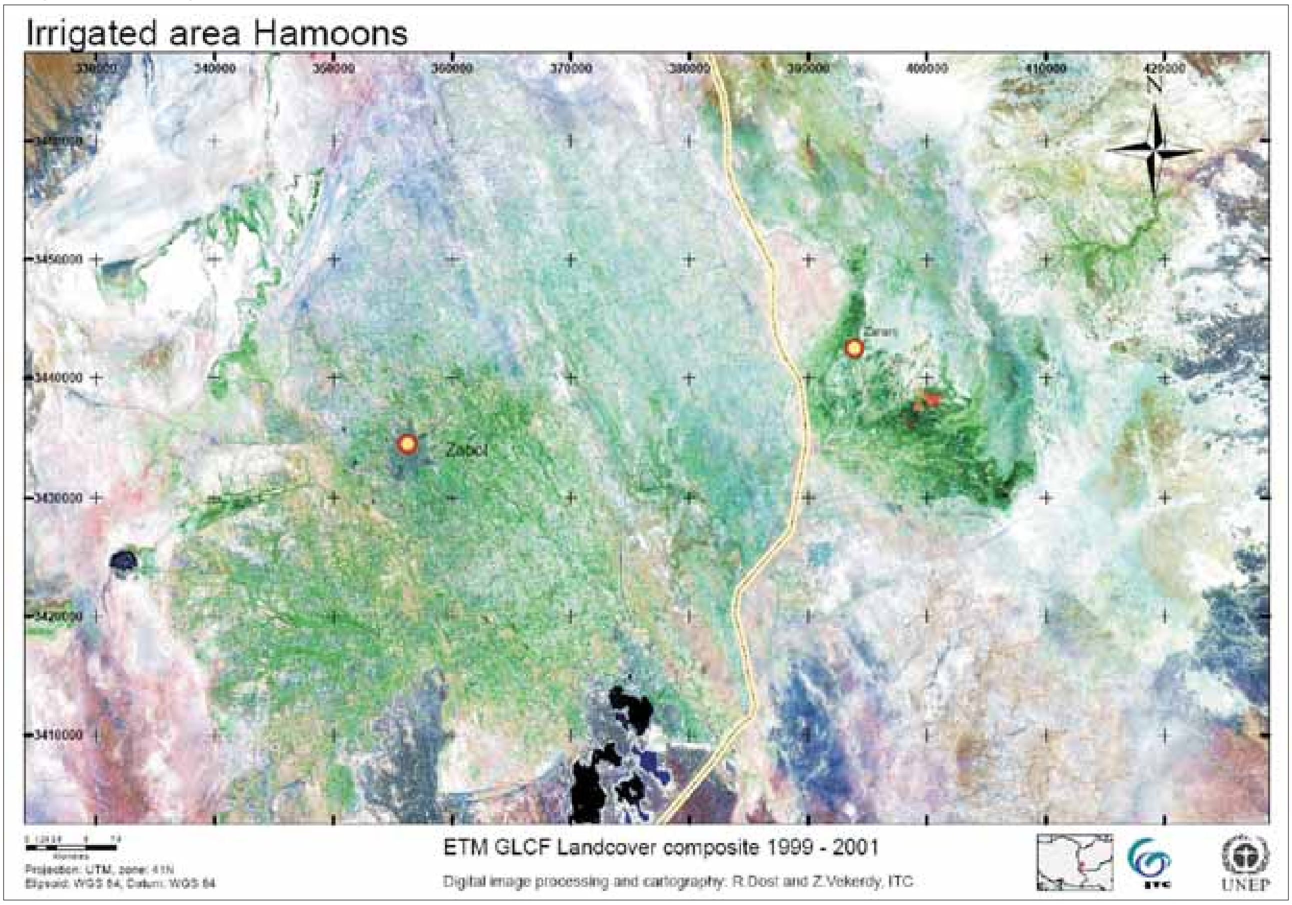


Figure 34 Irrigated area in 1998

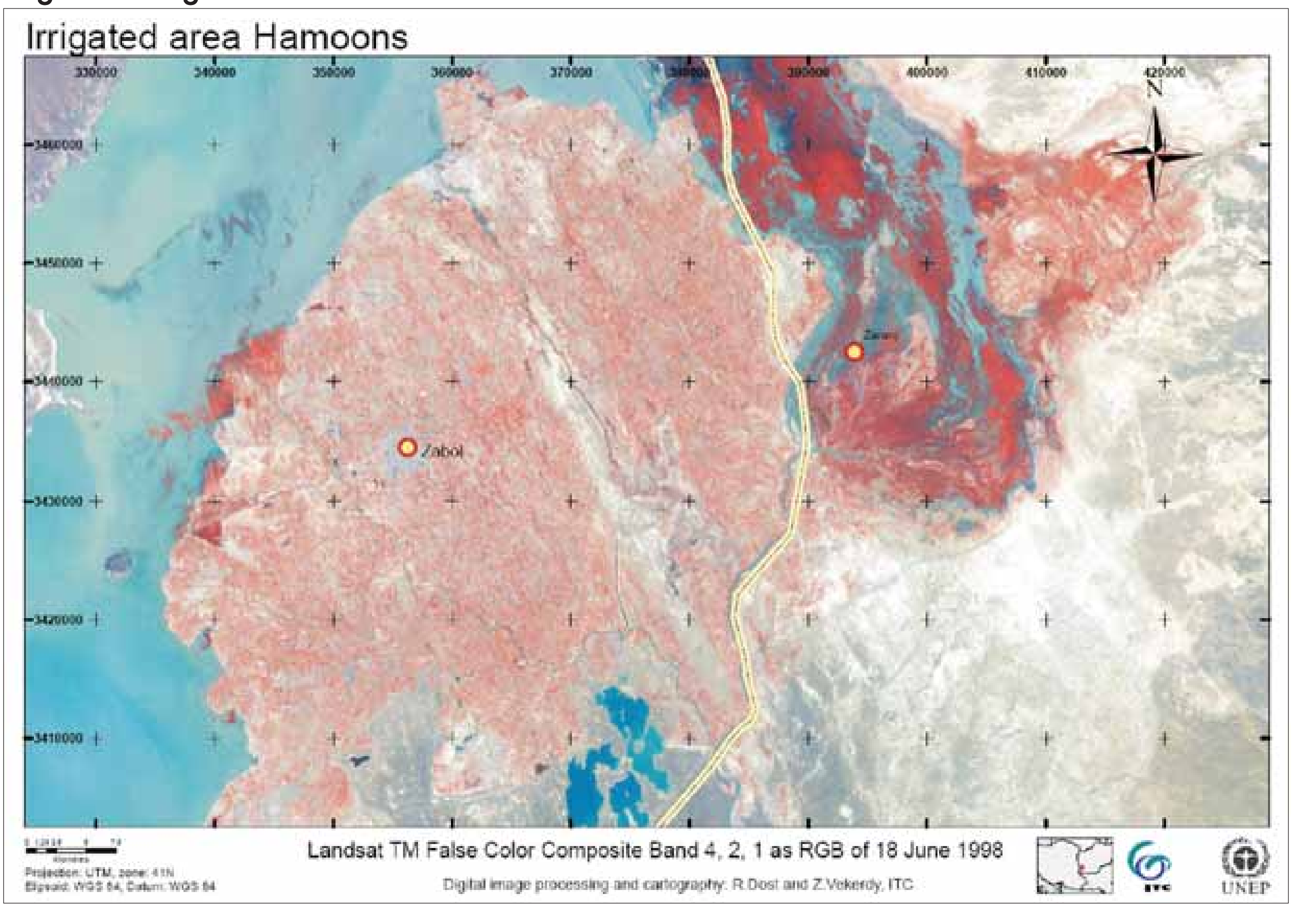


Figure 35 Land cover of the Sistan inland delta in 1976

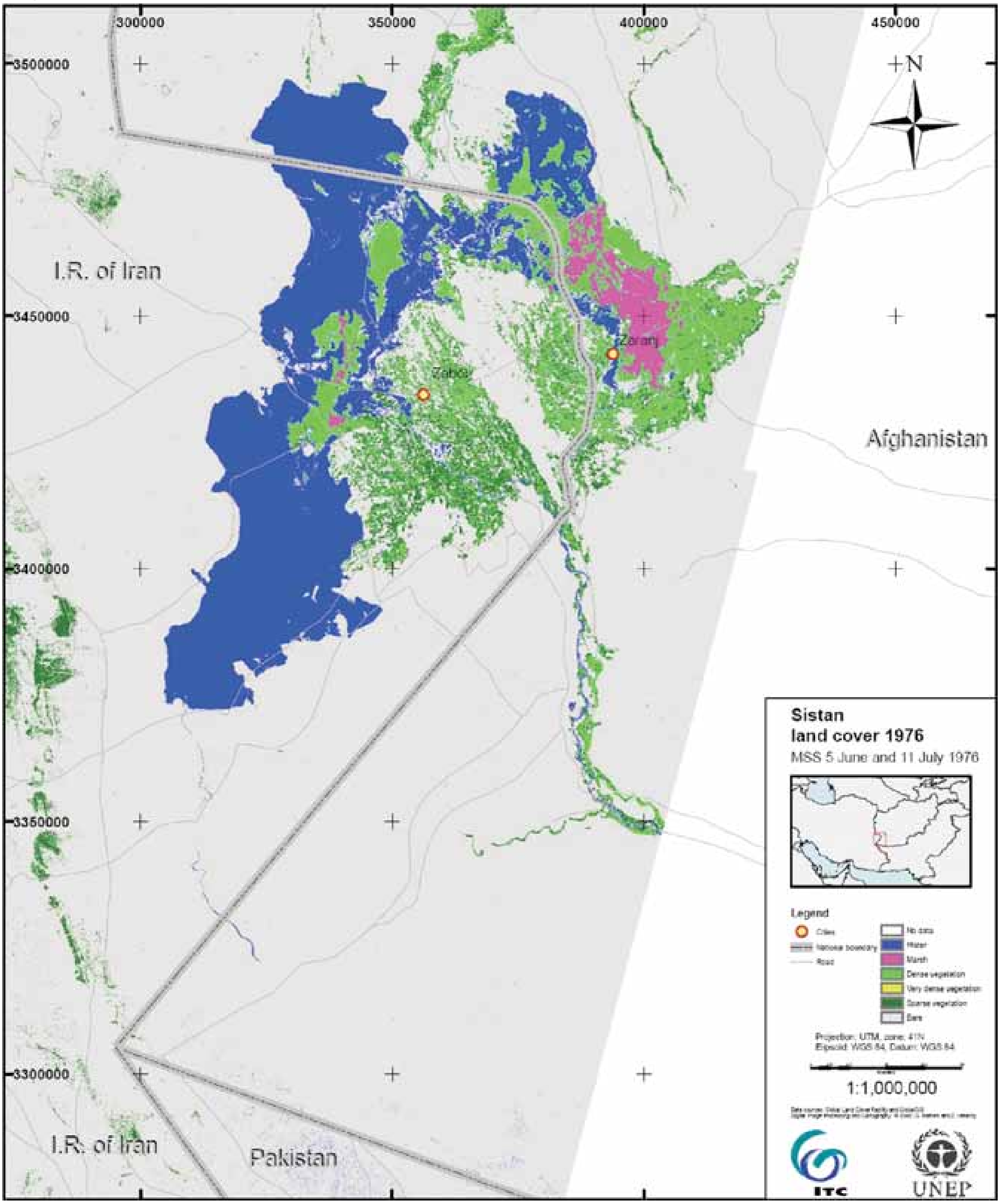


Figure 36 Land cover of the Sistan inland delta in 1998

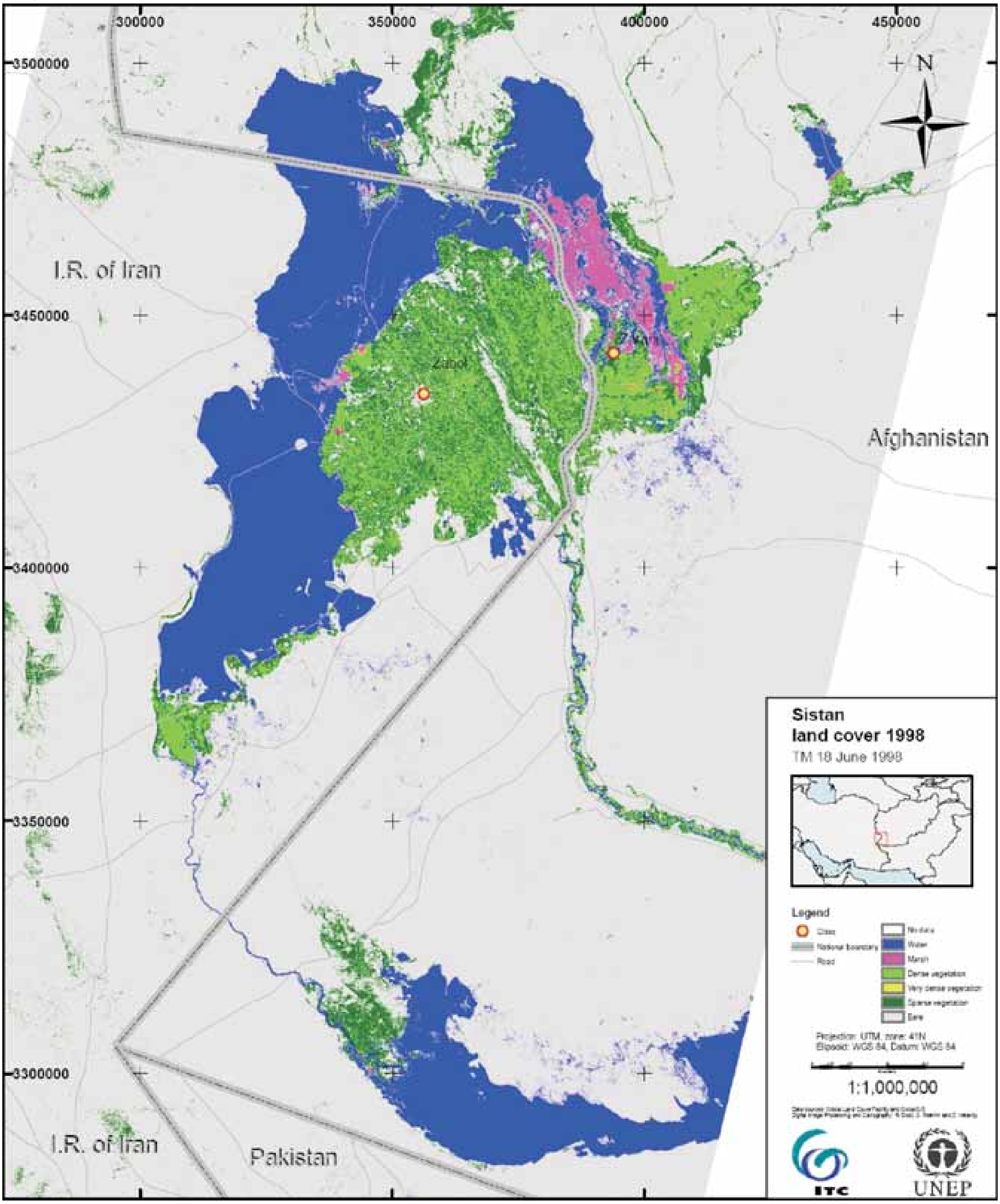


Figure 37 Land cover of the Sistan inland delta in 2002

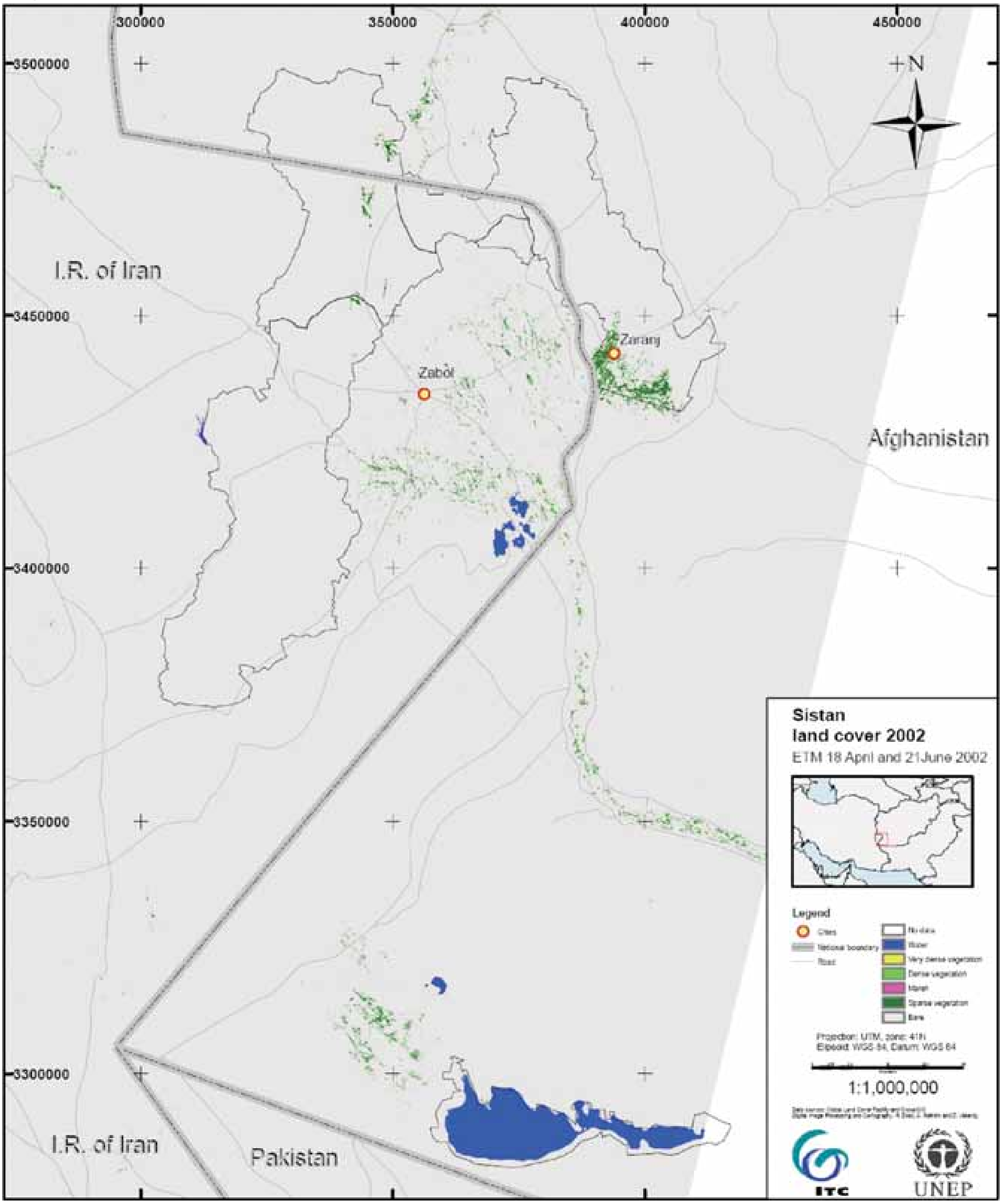


Figure 38 Land cover of the Sistan inland delta in 1976 without indicating marsh vegetation

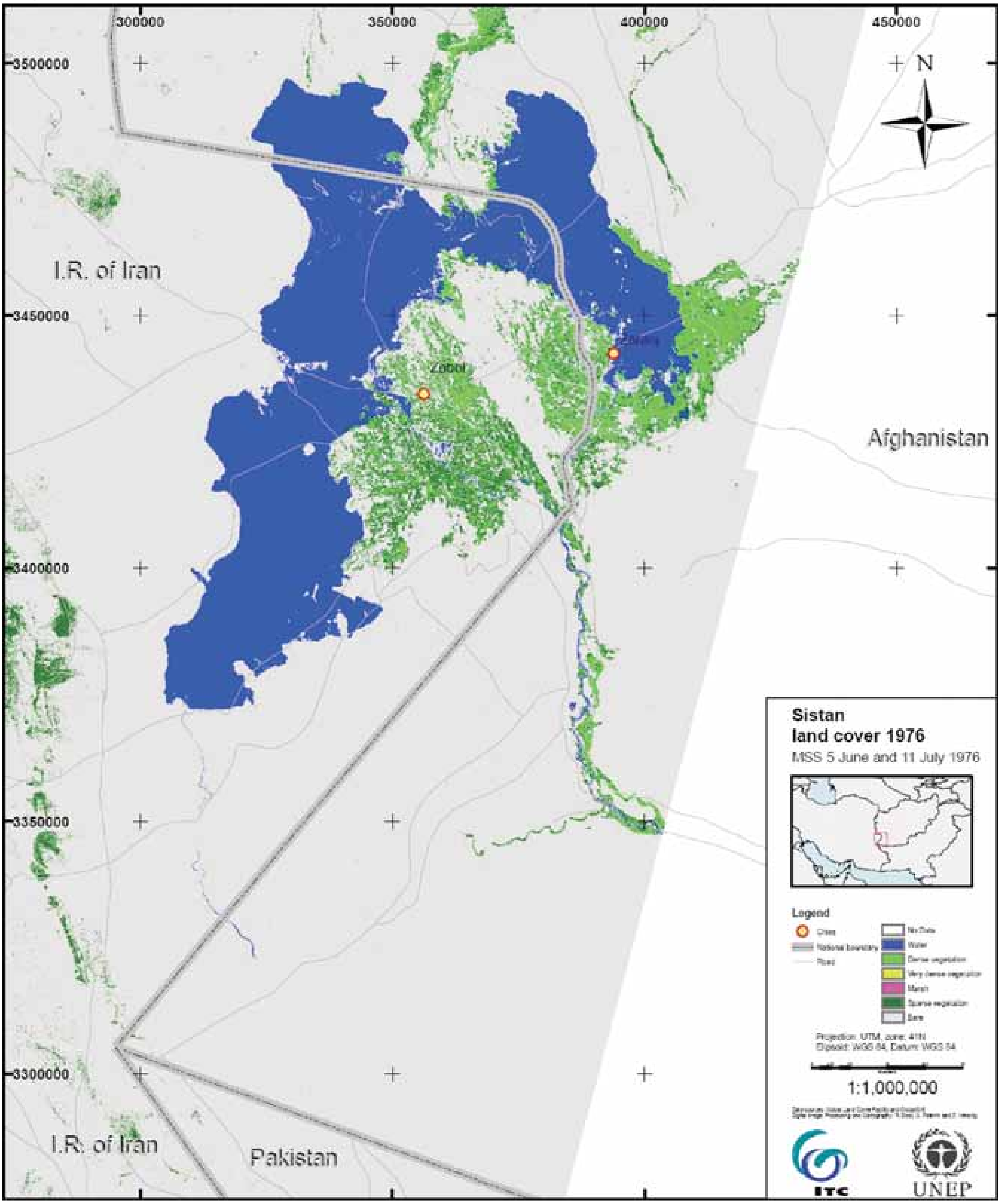


Figure 39 Land cover of the Sistan inland delta in 1998 without indicating marsh vegetation

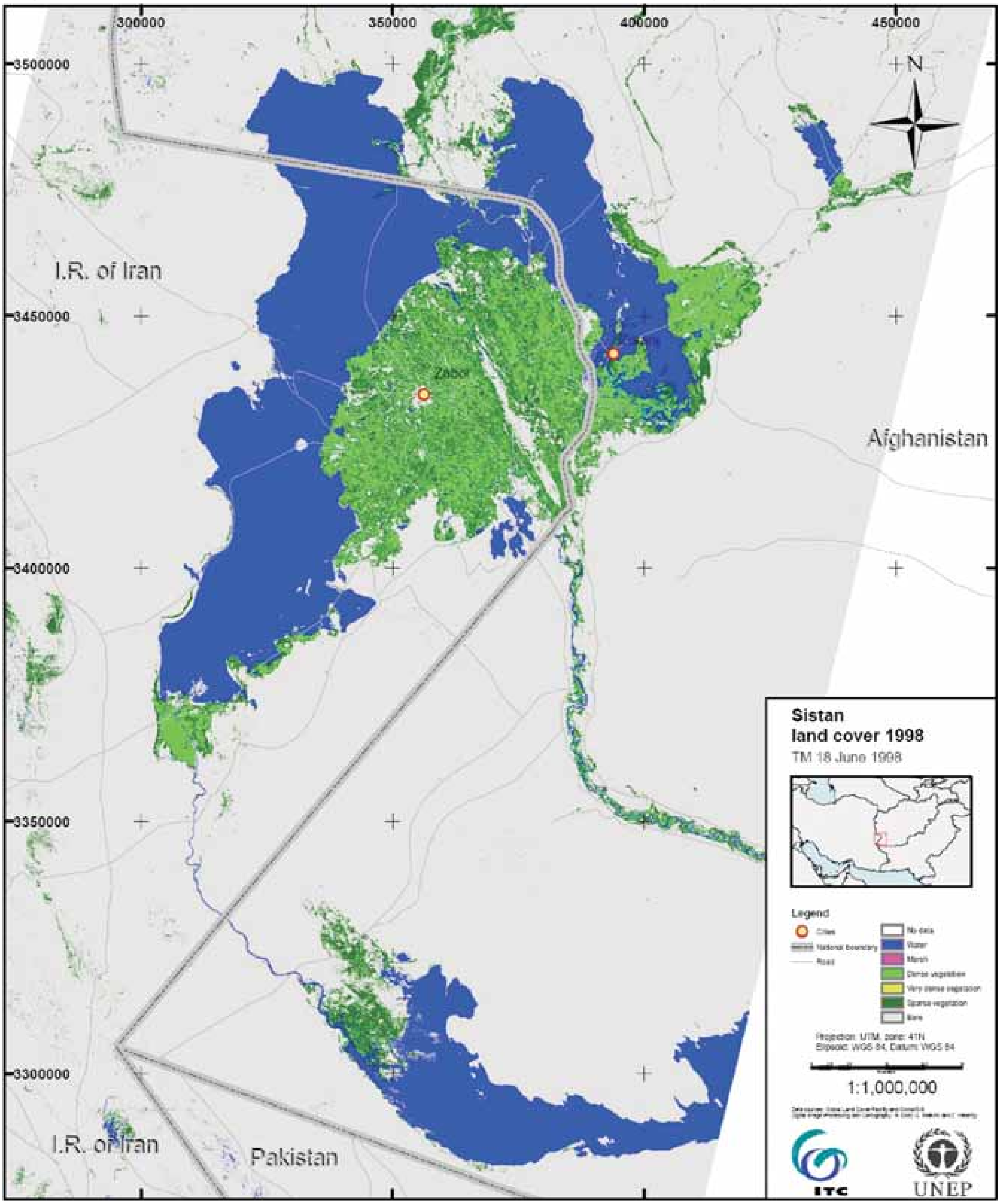


Figure 40 Land cover of the Sistan inland delta in 1976 with merged wetland vegetation

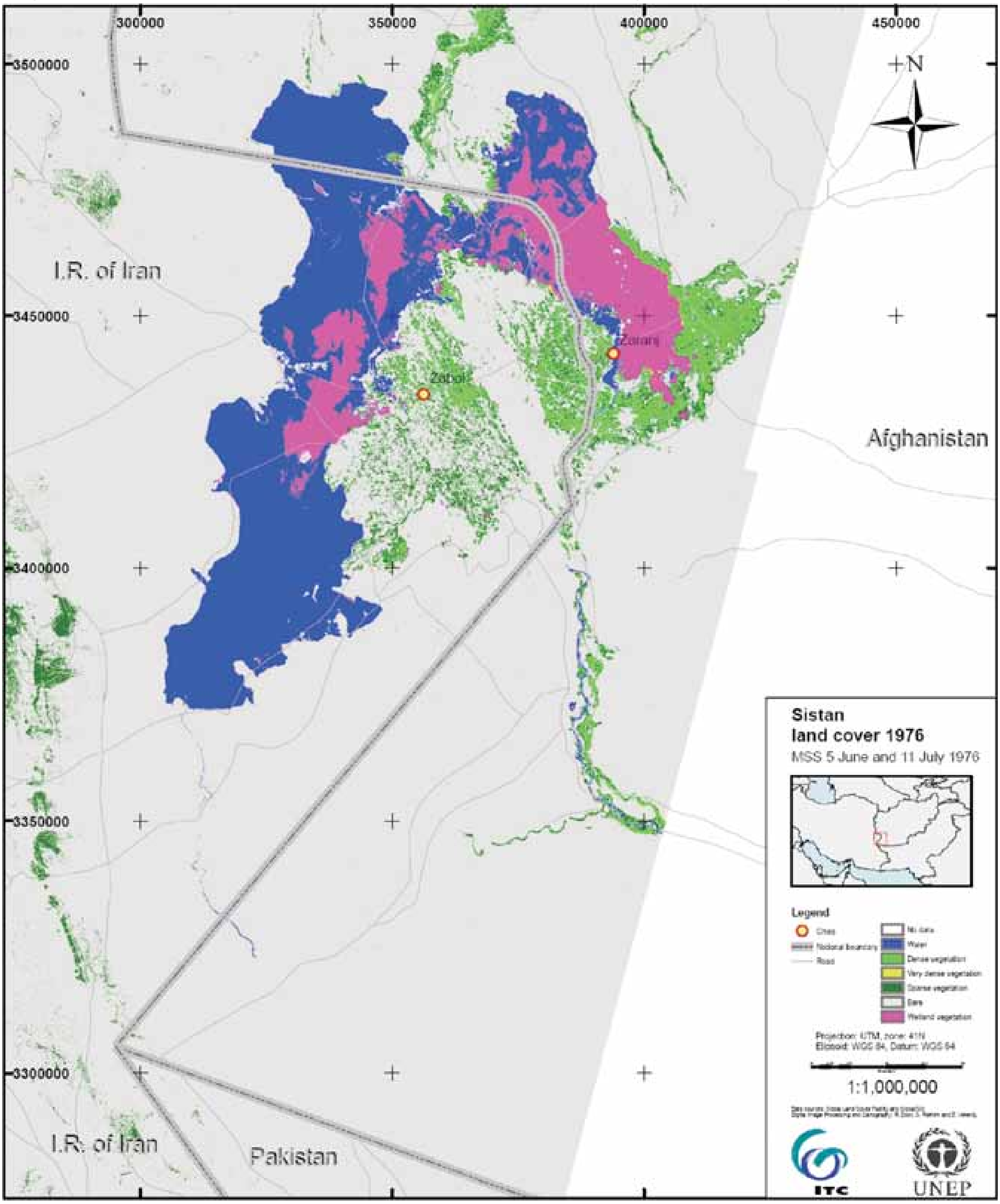


Figure 41 Land cover of the Sistan inland delta in 1998 with merged wetland vegetation

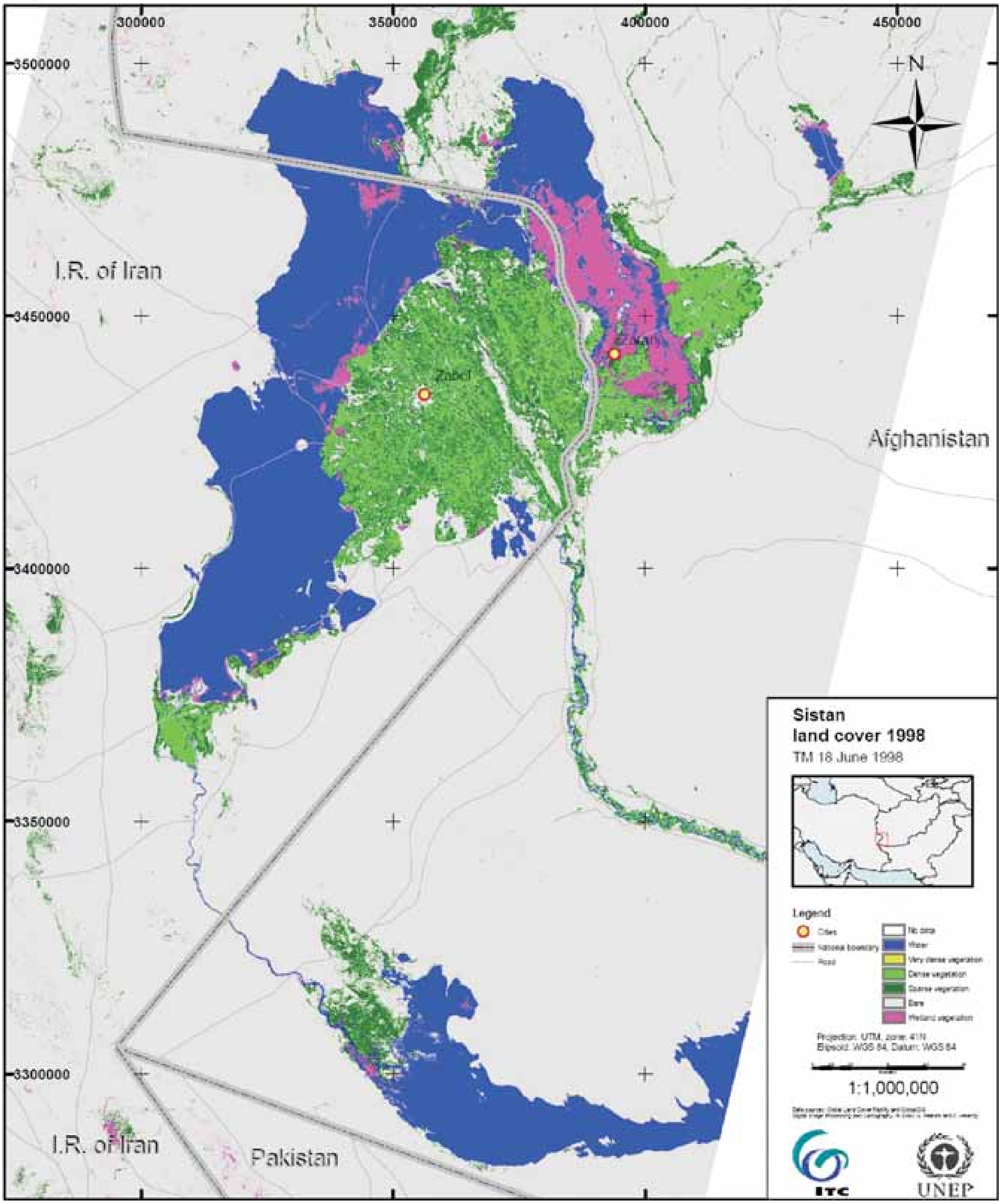


Figure 42 The Sistan inland delta in 1987-1990

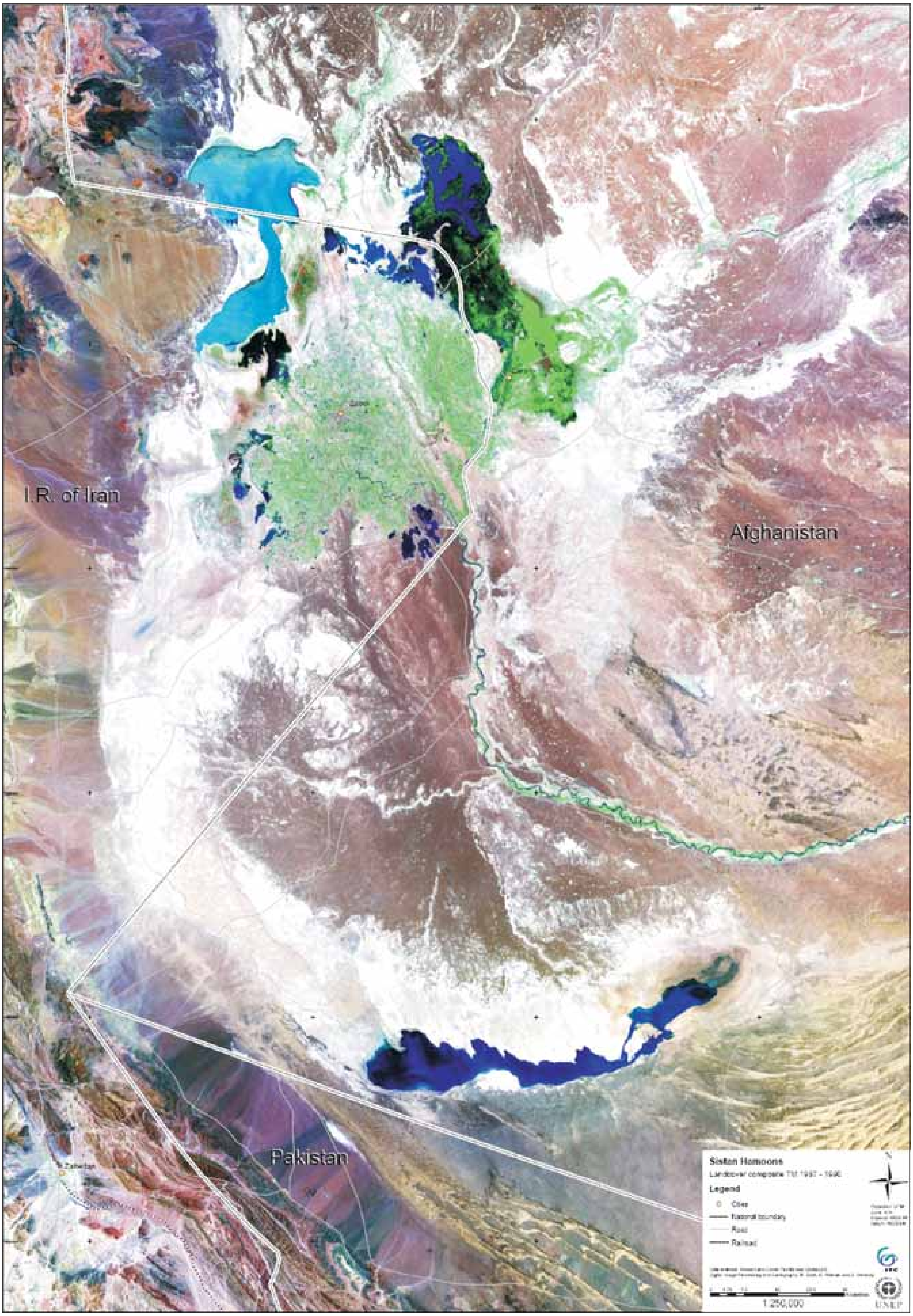


Figure 43 The Sistan inland delta with its main water courses in 1987-1990

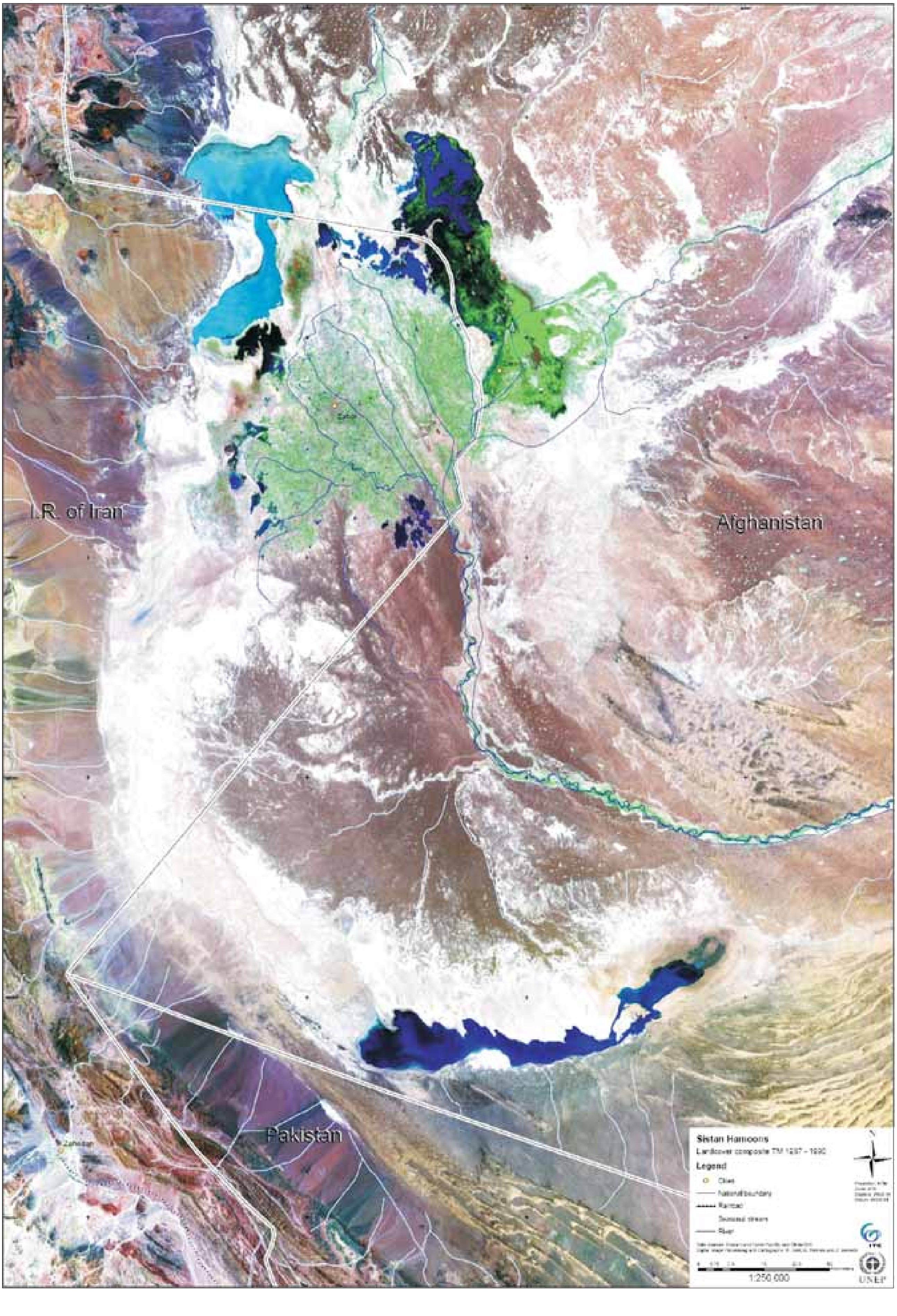


Figure 44 The Sistan inland delta in 1999-2001

Figure 45 The Sistan inland delta with its main watercourses in 1999-2001

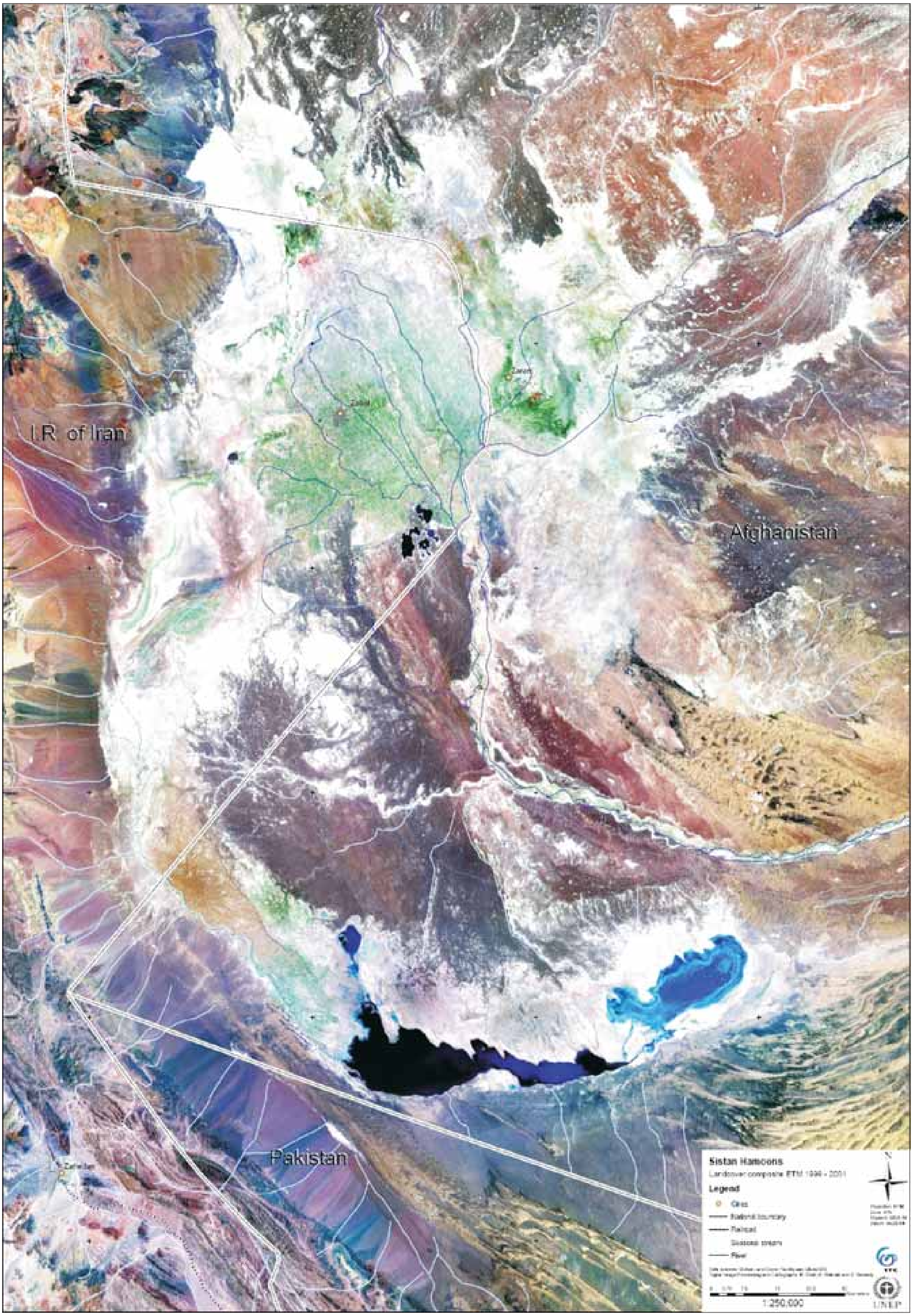


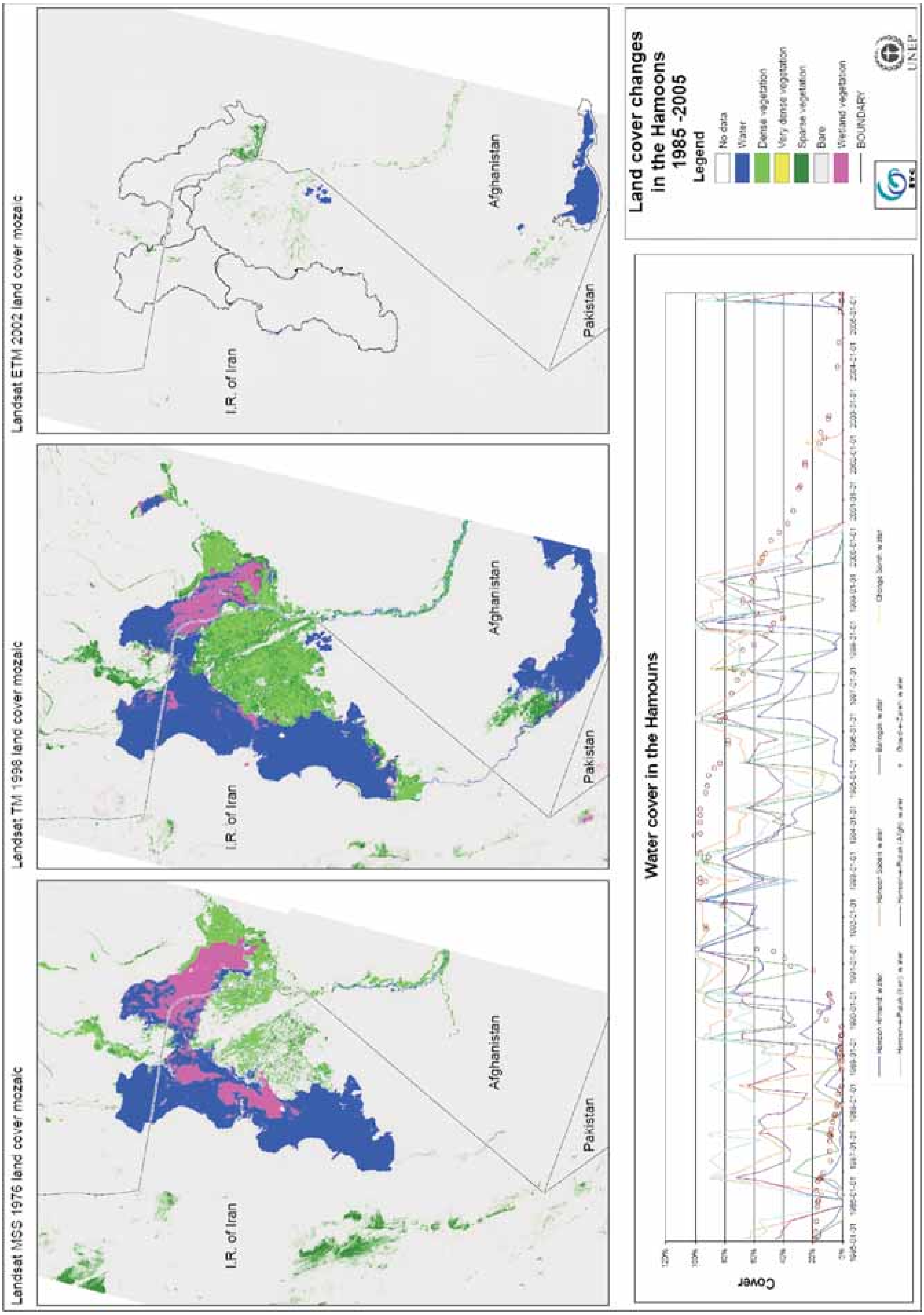
Figure 46 Catchments of the Sistan drainage basin in 1987-1990

Figure 47 Catchments of the Sistan drainage basin with the main watercourses in 1987-1990

Figure 48 Catchments of the Sistan drainage basin in 1999-2001

Figure 49   Catchments of the Sistan drainage basin with the main watercourses in 1999-2001

Figure 50 Land cover changes in the Sistan inland delta



Appendix D Endnotes and References

Endnotes

1. Higher NDVI values indicate a larger quantity of living biomass on the surface. On this image, the irrigation projects in Afghanistan show much higher NDVI values then the ones in Iran, where due to high soil salinity, only part of the lands – in a mosaic-like pattern – can be irrigated at a time.

2. There was no information available about the level of the threshold.

3. Comparison of the two methods showed that the discrepancy did not exceed ten percent.

4. For the volume estimate, it was assumed that the average water depth and the surface area were linearly related.

5. As part of the 'Iranian-Dutch Sistan Project'.

6. The first data is for July 1976.

7. This is a rough estimate based on satellite images, no field information is available.

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Further technical information may be obtained from the UNEP Post-Conflict Branch at:
http://postconflict.unep.ch
or: **postconflict@unep.ch**

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