

## 15 APPENDIX

### 15.1. Urbanisation of Ouagadougou, Burkina Faso

(<http://earthobservatory.nasa.gov/IOTD/view.php?id=8870>)

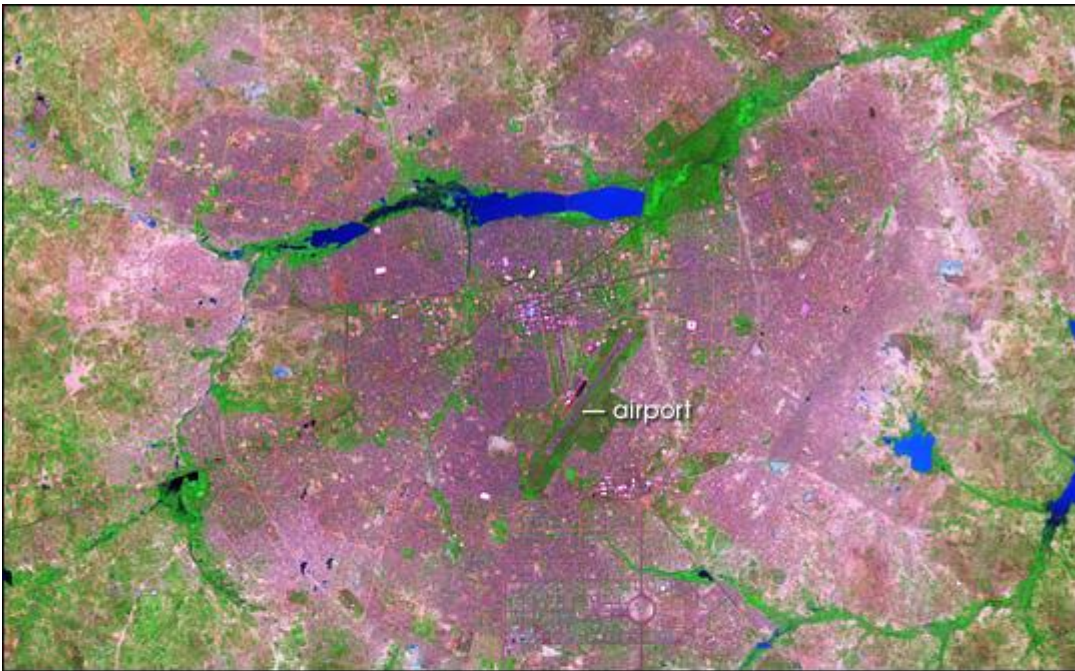
In western Africa, just south of the Sahara Desert, lies the landlocked nation of Burkina Faso. Despite the limited natural resources in this arid savannah, the nation experienced a 200 per cent increase in urban population between 1975 and 2000. Much of that growth occurred in the capital city of Ouagadougou, where unplanned settlements sprang up along the city's perimeter. Between 1960 and 1993, Ouagadougou experienced a 14-fold increase in area.

Over the years, NASA's Landsat satellites have observed the increase in Ouagadougou's extent. The Landsat 7 satellite captured the top image on October 16, 2006, and the Landsat 5 satellite acquired the bottom image on November 18, 1986. In these false-colour images, vegetation appears bright green, bare or sparsely vegetated ground ranges in colour from beige to grey-green, and water ranges in colour from navy to electric blue. Paved surfaces and buildings appear pink-purple.

The 2006 image shows how urbanisation radiated out from the city centre, filling nearly the entire frame. Urbanisation has increased especially in the east and south; in the 1986 image, random shapes of green and brown fill the area; in the 2006 image, that area is predominantly pinkish purple. Likewise, a crooked line of vegetation that is visible north of Bois de Boulogne in 1986 has all but disappeared in 2006.

In both images, the Ouagadougou airport appears as a conspicuous diagonal line near the centre of the image. In 1986, the airport lies fairly close to the city's outskirts. In 2006, continued urbanisation has surrounded the airport with cityscape. Southwest of the airport, the beginnings of urbanisation appear in 1986, and that urbanisation is more pronounced in 2006.

Lakes and rivers near the top and right edges of the image show different colours between 1986 and 2006; the colour change likely results from differences in sediment or organic matter suspended in the water.



October 16, 2006



November 18, 1986

## 15.2. Dramatic Deforestation: Gishwati Forest, Rwanda

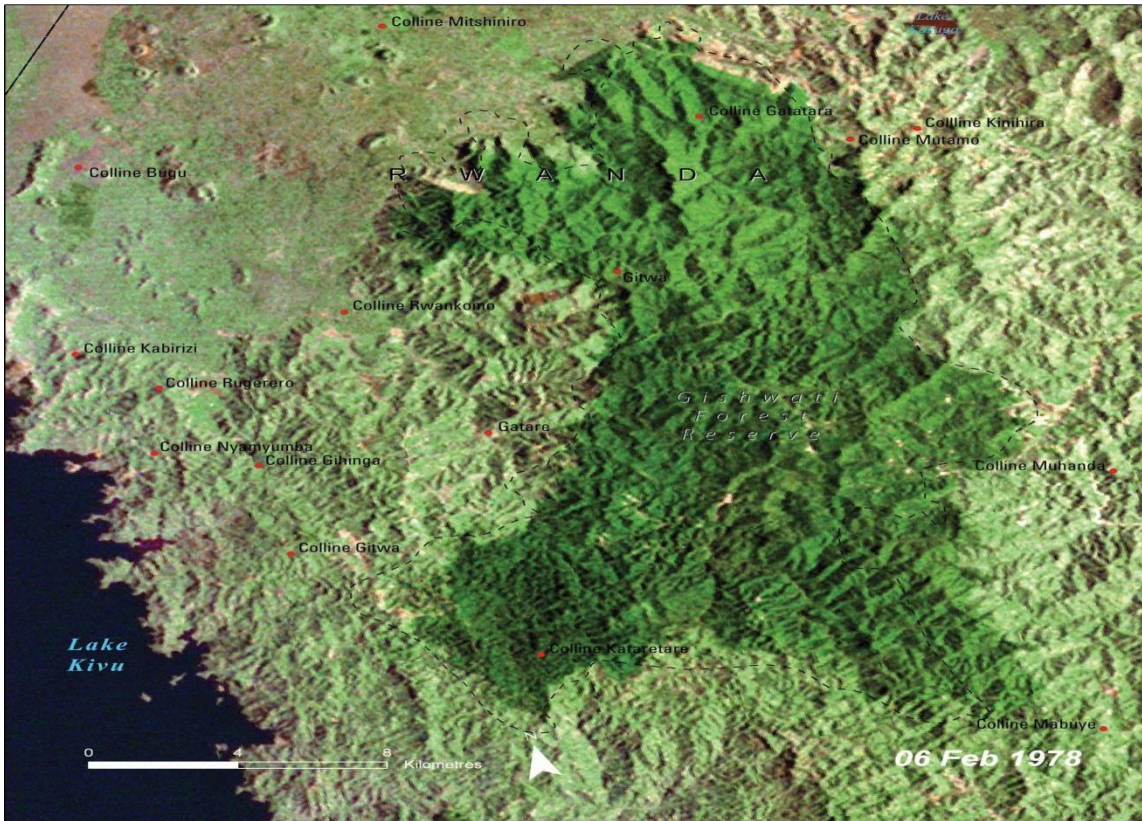
[http://na.unep.net/AfricaAtlas/AfricaAtlas/site\\_images.php](http://na.unep.net/AfricaAtlas/AfricaAtlas/site_images.php)

'Gishwati Forest Reserve in north-western Rwanda is one of the most severely deforested areas in the country. Exploitation of the forests for commercial products such as charcoal, timber, medicine, and food has been the main driver of this deforestation. The 1978 satellite image shows the Gishwati Forest Reserve as a dark-green carpet of dense forest nearly covering the entire protected area. The 2006 image shows that most of the forest has been cleared; patches of pink and light green have replaced the dark-green areas where the vegetation has been largely removed. Only a fraction of the forest that was intact in 1978 remains; what is left is in a degraded condition.

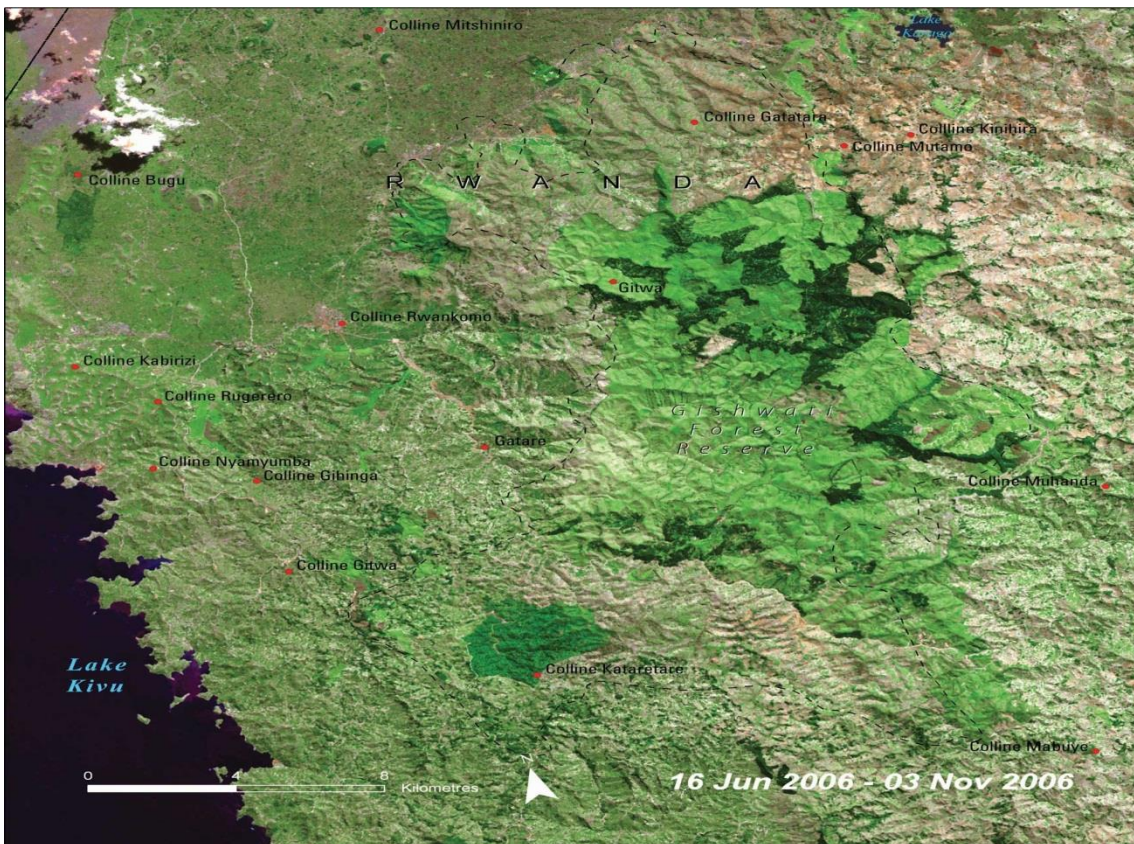
On a positive note, reforestation efforts in parts of the region, using agroforestry techniques such as radical terracing, progressive terracing, and live mulches, are currently being researched and implemented. Seedlings of species such as *Calliandra calothyrsus* and *Leucaena diversifolia* are being planted in several provinces of the country with collaboration from stakeholders and the local community. If such efforts continue and are successful, the Gishwati Forest Reserve may experience considerable regeneration within the next five to ten years.



1978



2006



### 15.3. Habitat Regeneration: Sidi Toui National Park, Tunisia

[http://na.unep.net/AfricaAtlas/AfricaAtlas/site\\_images.php](http://na.unep.net/AfricaAtlas/AfricaAtlas/site_images.php)

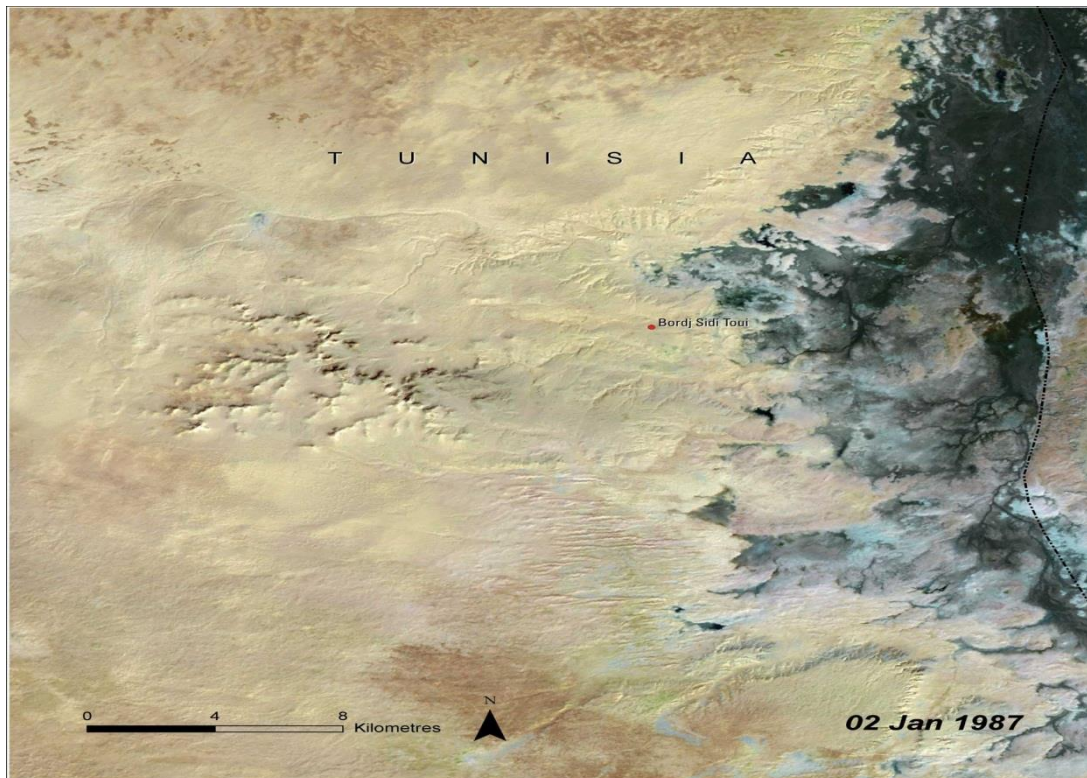
'Habitat Regeneration: Sidi Toui National Park, Tunisia - 02 January 1978. The semi-arid Sahelian grassland and scrub of southern Tunisia has been profoundly altered by human activities during the last century. Located on the northern fringe of the Sahara Desert, this ecosystem is susceptible to erosion and desertification brought on by droughts, overgrazing, and agriculture. In 1993, Sidi Toui National Park was established. Within the bounds of this protected area, natural vegetation began to return. The 1987 image shows the barren condition of the region before the park was created. In the 2006, image the outline of the park, which is protected from the effects of grazing cattle, contrasts markedly with the surrounding landscape. Protection substantially increased the vegetation density and species diversity, particularly of the grasses.

Habitat Regeneration: Sidi Toui National Park, Tunisia - 14 January 2006. The Scimitar-horned oryx (*Oryx dammah*) and five other species of gazelles and antelope native to this area had been brought to near extinction by lack of habitat and overhunting throughout the 20th century. Classified as critically endangered in 1996, a small population of Scimitar-horned oryx was introduced into Sidi Toui Park in 1999. If the population inside the park thrives, it may enable future reintroductions of Scimitar-horned oryx elsewhere, Sidi Toui also provides habitat for several native species of antelope, as well as a variety of bird species.'

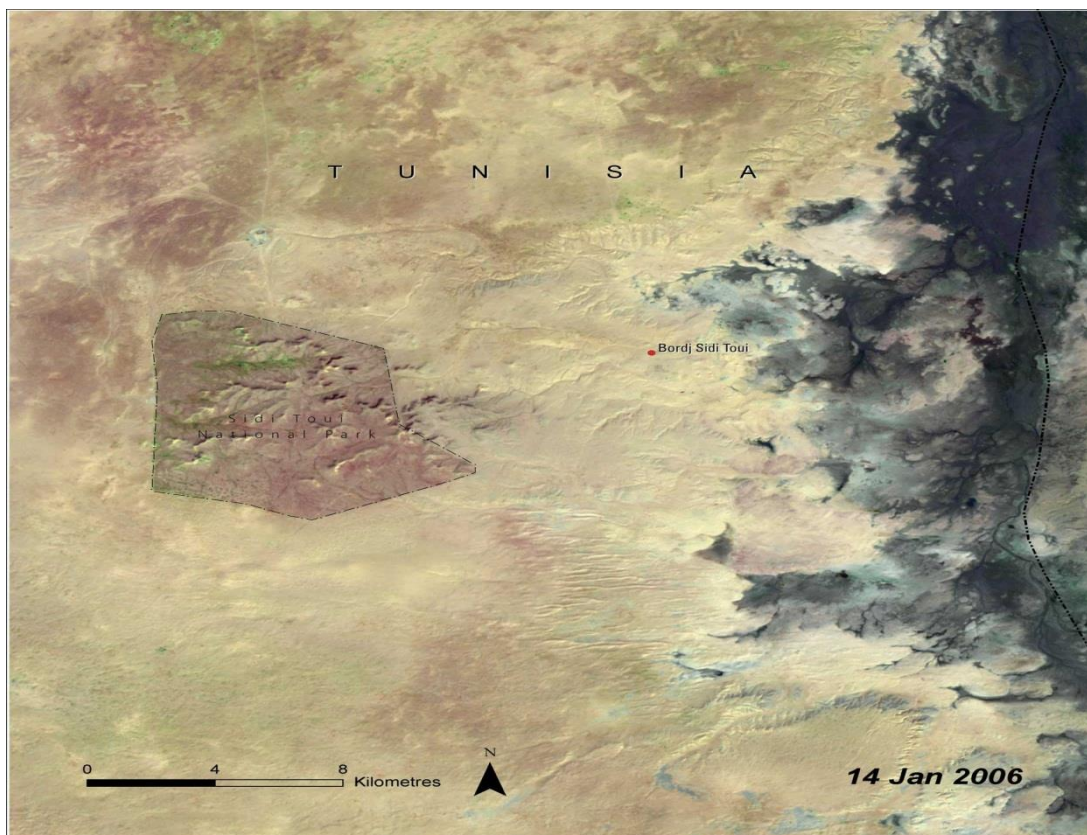
(<http://www.unep.org/dewa/africa/africaAtlas/graphics/index.asp>)



1987



2006

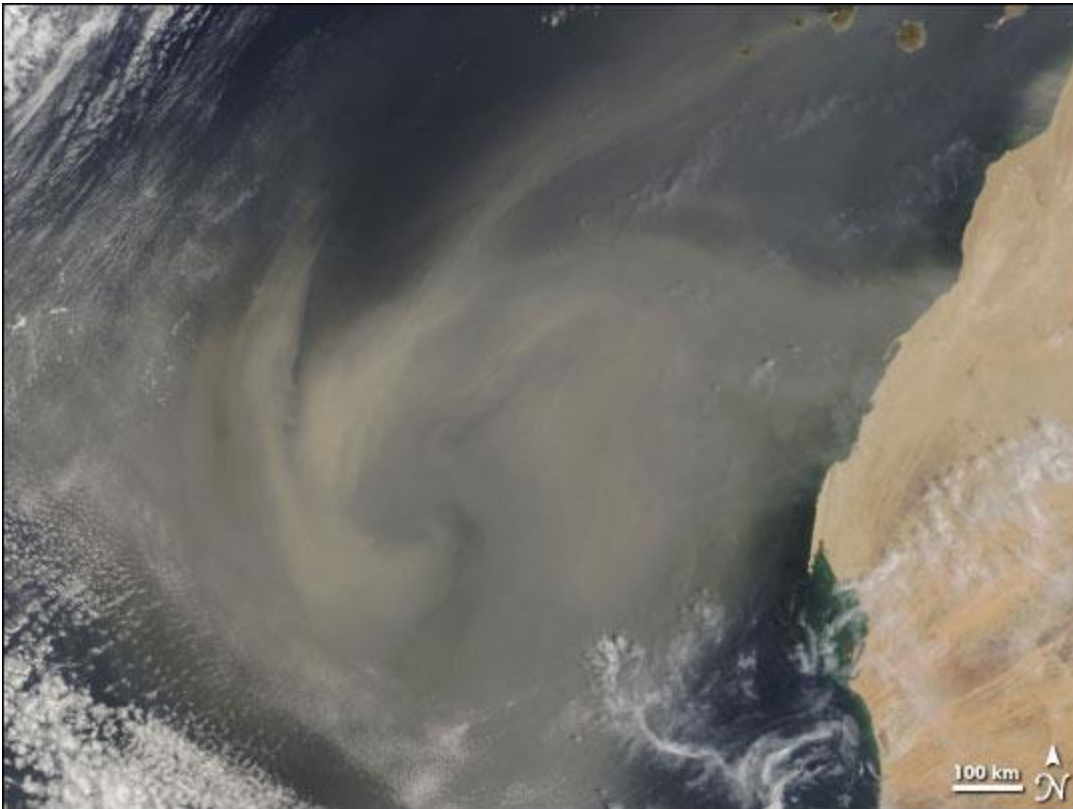


#### 15.4. Dust Storm off West Africa

<http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=15520>

'A dust storm, several hundred kilometers across, swirled off the west coast of Africa and over the Atlantic on September 4, 2005. The Moderate Resolution Imaging Spectroradiometer (MODIS) flying onboard the Terra satellite captured this image the same day. The dust storm covers almost the entire image, its colour ranging from tan to pale beige. The dust appears to concentrate in the center of the storm. To the west, clouds fringe the edges of the dust storm. To the east are the coastlines of Mauritania and Western Sahara, and the Canary Islands.

Areas lacking vegetation, such as the Sahara, experience extreme daytime heat. This heat leads to turbulence in the lowest 1 to 2 kilometers of the atmosphere, known as the boundary layer. That turbulence can loft dust particles off the ground. So in places like the Sahara, dust storms result not only from abundant dust but also from conditions favourable to throwing the dust into the air.'



## 15.5. Shrinking Aral Sea

[http://earthobservatory.nasa.gov/Features/WorldOfChange/aral\\_sea.php](http://earthobservatory.nasa.gov/Features/WorldOfChange/aral_sea.php)

"In the 1960s, the Soviet Union undertook a major water diversion project on the arid plains of Kazakhstan, Uzbekistan, and Turkmenistan. The region's two major rivers, fed by snowmelt and precipitation in faraway mountains, were used to transform the desert into farms for cotton and other crops. Before the project, the Syr Darya and the Amu Darya rivers flowed down from the mountains, cut northwest through the Kyzylkum Desert, and finally pooled together in the lowest part of the basin. The lake they made the Aral Sea, was once the fourth largest in the world.

Although irrigation made the desert bloom, it devastated the Aral Sea. This series of images from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite documents the changes. At the start of the series in 2000, the lake was already a fraction of its 1960 extent (black line). The Northern Aral Sea (sometimes called the Small Aral Sea) had separated from the Southern (Large) Aral Sea. The Southern Aral Sea had split into eastern and western lobes that remained tenuously connected at both ends.

By 2001, the southern connection had been severed, and the shallower eastern part retreated rapidly over the next several years. Especially large retreats in the eastern lobe of the Southern Sea appear to have occurred between 2005 and 2009, when drought limited and then cut off the flow of the Amu Darya. Water levels then fluctuated annually between 2009 and 2015 in alternately dry and wet years. In 2014, the Southern Sea's eastern lobe completely disappeared.

As the Aral Sea has dried up, fisheries and the communities that depended on them collapsed. The increasingly salty water became polluted with fertiliser and pesticides. The blowing dust from the exposed lakebed, contaminated with agricultural chemicals, became a public health hazard. The salty dust blew off the lakebed and settled onto fields, degrading the soil. Croplands had to be flushed with larger and larger volumes of river water. The loss of the moderating influence of such a large body of water made winters colder and summers hotter and drier.

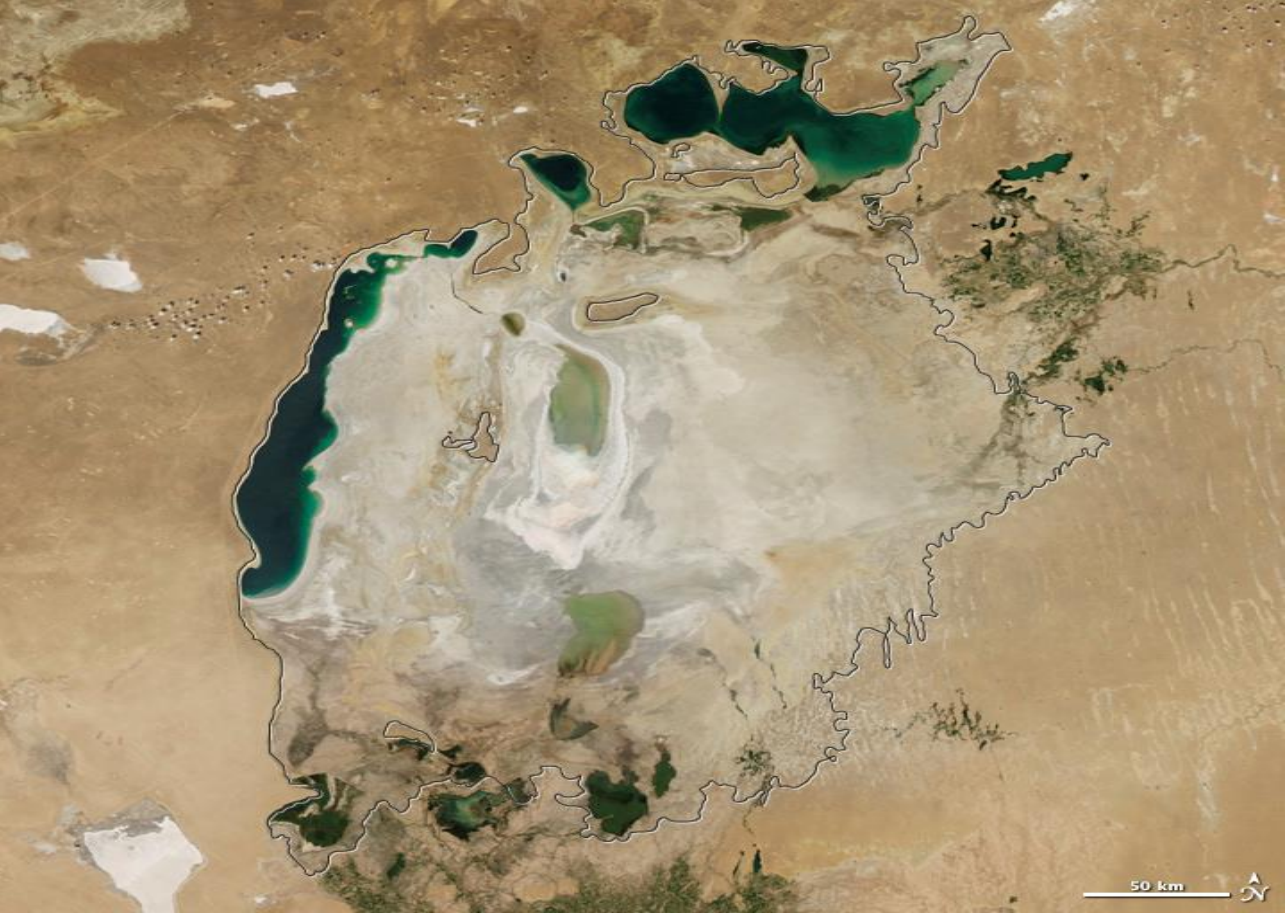
In a last-ditch effort to save some of the lake, Kazakhstan built a dam between the northern and southern parts of the Aral Sea. Completed in 2005, the dam was basically a death sentence for the southern Aral Sea, which was judged to be beyond saving. All of the water flowing into the desert basin from the Syr Darya now stays in the Northern Aral Sea. Between 2005 and 2006, the water levels in that part of the lake rebounded significantly and very small increases are visible throughout the rest of the time period. The differences in water color are due to changes in sediment" (Lindsey 2015).



2000



2015



## 15.6. Declining Water Levels in Lake Chad

[http://na.unep.net/AfricaAtlas/AfricaAtlas/site\\_images.php](http://na.unep.net/AfricaAtlas/AfricaAtlas/site_images.php)

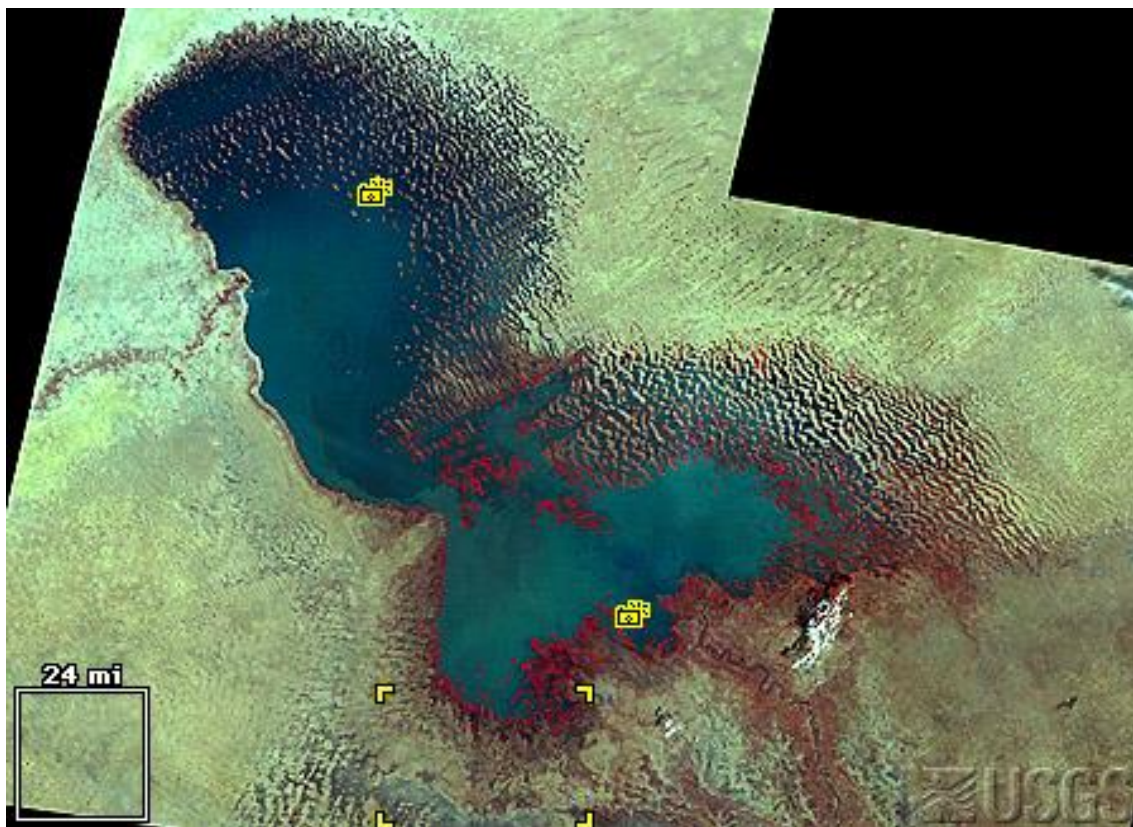
'Located at the southern edge of the Sahara Desert, Lake Chad is bordered by Nigeria, Niger, Chad, and Cameroon. The lake was once the second-largest wetland in Africa, supporting a rich diversity of endemic animals and plant life. The Lake Chad drainage basin, a 2 500 000 km<sup>2</sup> hydrologically closed catchment, extends to eight countries: Algeria, Libyan Arab Jamahiriya, Niger, Chad, Sudan, Central African Republic, Cameroon, and Nigeria. It is home to over 20 million people who derive direct or indirect livelihoods from the lake. Most of the region's rainfall occurs in the southern one-third of the Lake Chad drainage basin, contributing about 90 per cent of the basin's runoff. The northern two-thirds, however, are dominated by arid conditions.

Climate variability and increased water consumption by the area's inhabitants have changed the water balance within the Lake Chad drainage basin, and continue to do so. Since the early 1960's, rainfall over the basin decreased significantly while irrigation increased dramatically over the same period. The lake is especially susceptible to climatic variability as it is rather shallow, with an average depth of 4.11 m. As a result of decreased rainfall and increased water usage, the extent of Lake Chad decreased by 95 per cent over roughly 35 years. More recently, water levels in Lake Chad have increased slightly. But the lake still remains a remnant of its former self.

As these satellite images from 1972 to 2007 show, the surface area of the lake has declined dramatically over time.' (<http://na.unep.net/atlas/webatlas.php?id=58>)



1972



2007



## 15.7. Shrinking Water Resources: Lake Alemaya

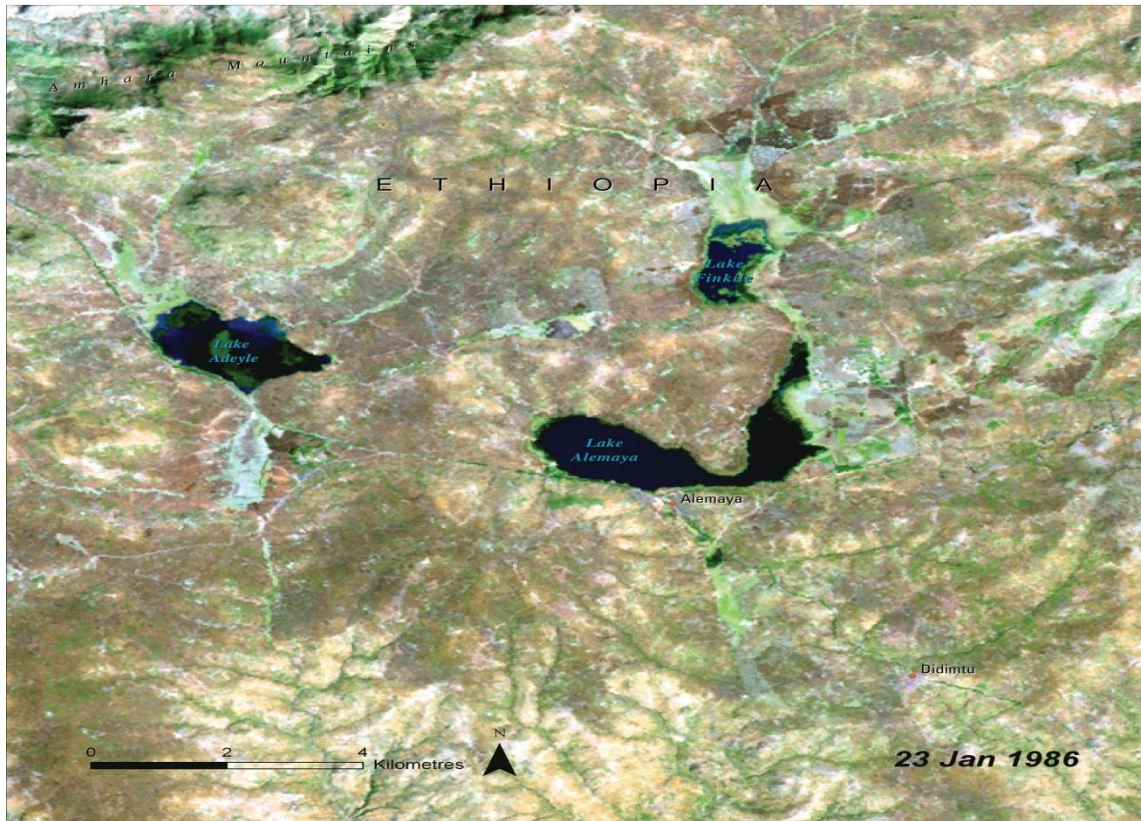
[http://na.unep.net/AfricaAtlas/AfricaAtlas/site\\_images.php](http://na.unep.net/AfricaAtlas/AfricaAtlas/site_images.php)

'Lake Alemaya in the Ethiopian Highlands has historically provided the surrounding area with water for domestic use, irrigation, and livestock and has served as a local fishery. As recently as the mid-1980s its maximum depth was around eight metres and it covered 4.72 km<sup>2</sup>. Since then Alemaya's water level and surface area have declined considerably, as is evident in these images. In recent years, low water levels have interrupted the water supply in Harar, a nearby town of over 100 000.

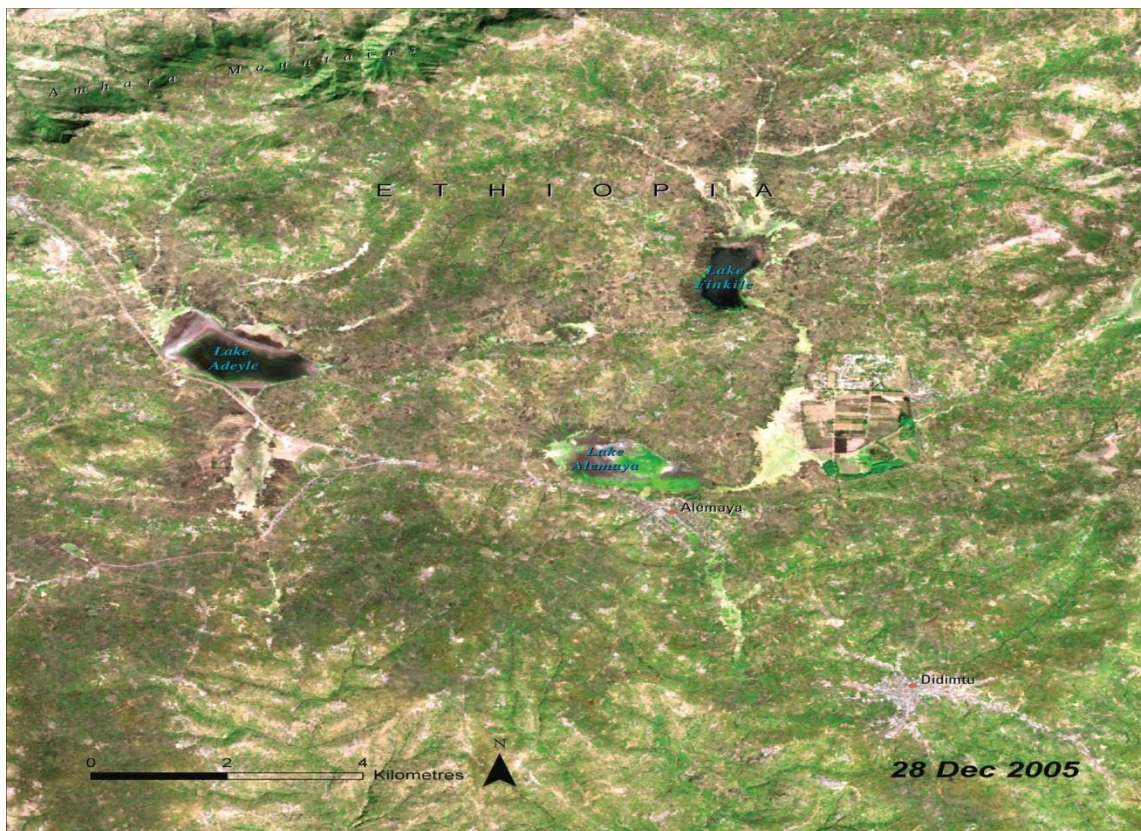
Increasing irrigation and domestic water use change in the local climate, and changes in the surrounding land cover are believed to be the causes of Alemaya's demise. Agriculture expanded dramatically starting in the mid-1970s due to improved infrastructure, increased population, and changes in government policies toward production and marketing. Among the crops grown is khat, a psychoactive leaf consumed heavily in north-eastern Africa. Khat has become an exported cash crop in recent decades and irrigation has increased as a result. In addition, siltation caused by the deforestation of the Alemaya watershed has reduced the capacity of the shallow lake. A trend of warmer temperatures since the mid-1980s may also have increased the rate of evaporation from the lake. (<http://unepatlas.blogspot.com/2008/06/lake-alemaya.html>)



1986



2005



## 15.8. Restored wetlands around Diawling National Park: Mauritania

[http://na.unep.net/AfricaAtlas/AfricaAtlas/site\\_images.php](http://na.unep.net/AfricaAtlas/AfricaAtlas/site_images.php)

'Prior to construction of Diama Dam across the Senegal River, land surrounding the Senegal Estuary was flooded with fresh water from late July to late September each year. During the dry season, these delta wetlands would become saltier than the ocean, as their waters were reduced by evaporation.

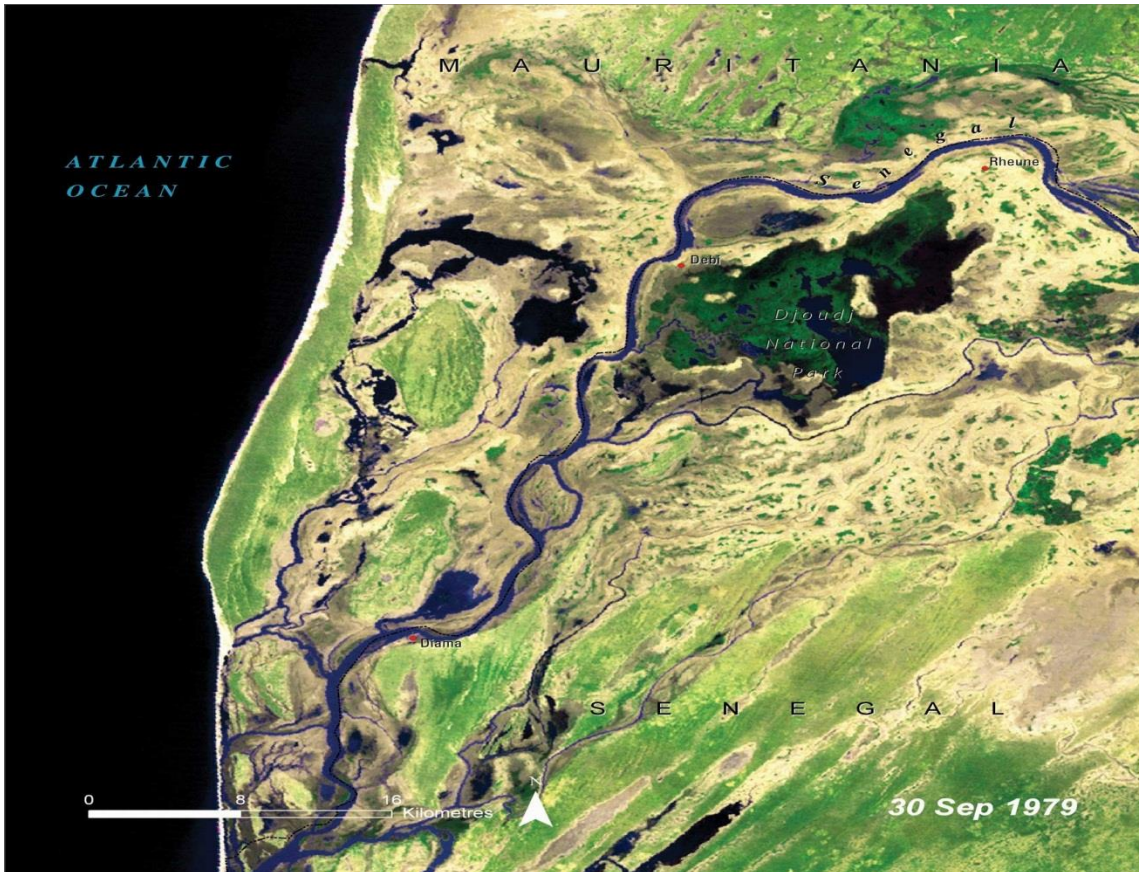
This yearly cycle was disrupted by the construction of the Diama Dam in 1986 (yellow arrow). Both the Diama Dam, and the Manantali Dam constructed upstream in Mali, were intended to regulate the flow of the Senegal River, generate hydroelectric power, and facilitate development of irrigated agriculture. However, irrigation in the delta has been less successful and less productive than planned; lacking proper drainage systems, the land is becoming waterlogged and saline after just a few years under irrigation.

Drought had already begun to impact the wetlands before construction of the dams in the 1980s (1979 image). Following their construction in the 1980s, fish stocks decreased and wetland vegetation was decimated. In the early 1990s, a restoration project began using controlled flooding of the delta by managed water releases. It has revived the wetlands and restored much of the lost flora and fauna to the area. The 2006 image shows the restored wetlands in and around Diawling National Park.'

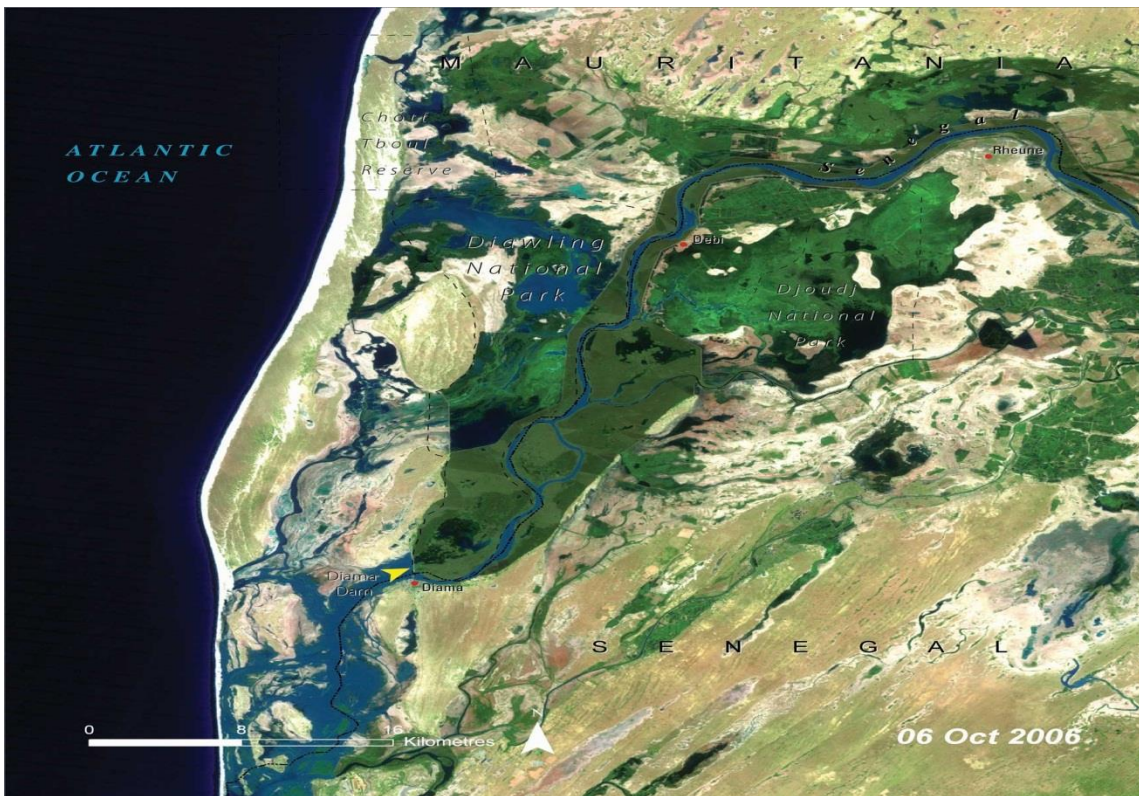
<http://unepatlas.blogspot.com/2008/06/diawling-national-park.html>



1979



2006



## 15.9. Impacts of Challawa Dam

[http://na.unep.net/AfricaAtlas/AfricaAtlas/site\\_images.php](http://na.unep.net/AfricaAtlas/AfricaAtlas/site_images.php)

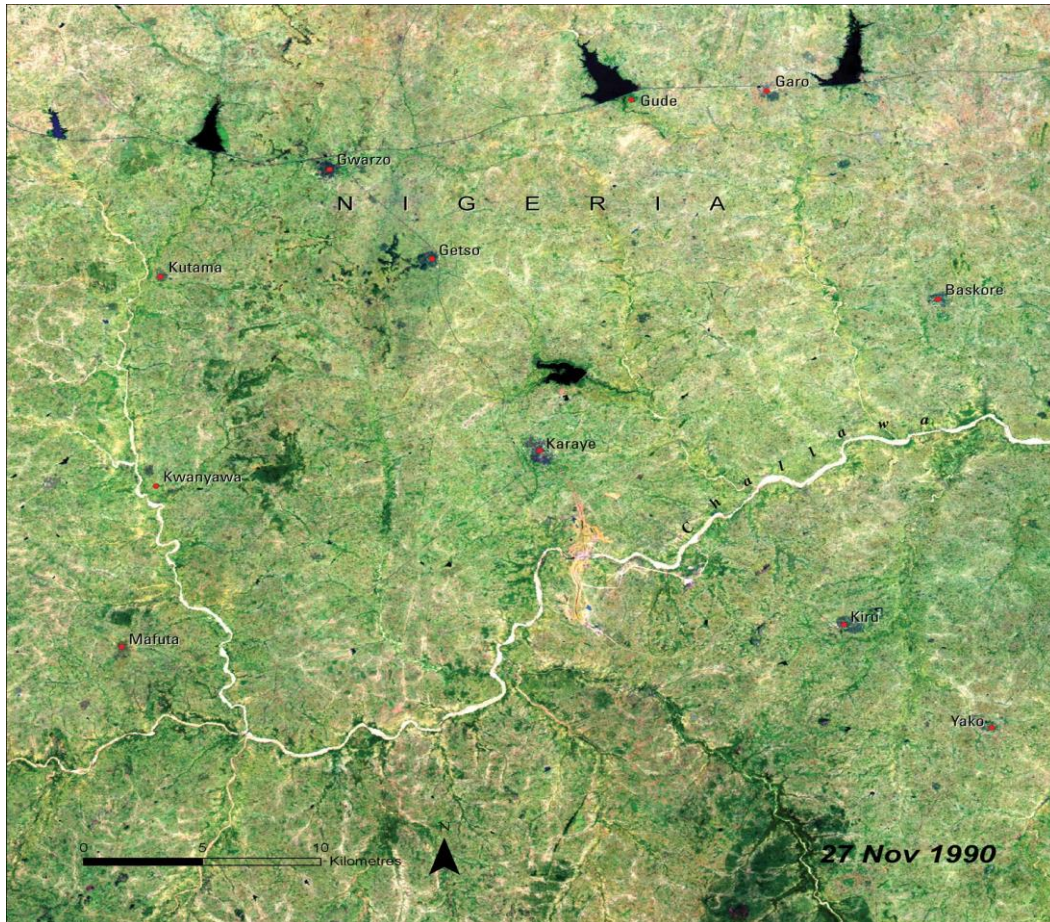
'The Challawa Dam in Kano State, Nigeria, was built to control flooding caused by seasonal and variable rainfall and to support irrigation. It also supplies water to Kano, Nigeria's third-largest city with a population of seven million. The Challawa River feeds into the Hadejia River, which then flows into the Hadejia-Nguru wetlands. Local rainfall peaks in August, with a subsequent dry season lasting from November to April. This rainfall pattern makes water levels in the Hadejia-Nguru wetlands highly seasonal.

The Challawa Dam has tamed highly seasonal downstream flooding at the expense of the Hadejia-Nguru wetlands. The combined effect of drought and the dam reduced the extent of seasonally flooded land from 300 000 hectares in the 1960s to between 70 000 and 100 000 hectares in recent years. Such severe reduction of the annual flooding extent has put the wetlands at risk and reduced the economic and environmental benefits they provide, including agriculture, cattle, fuelwood, fish, shallow aquifer recharge, and habitat for migratory and local bird species.

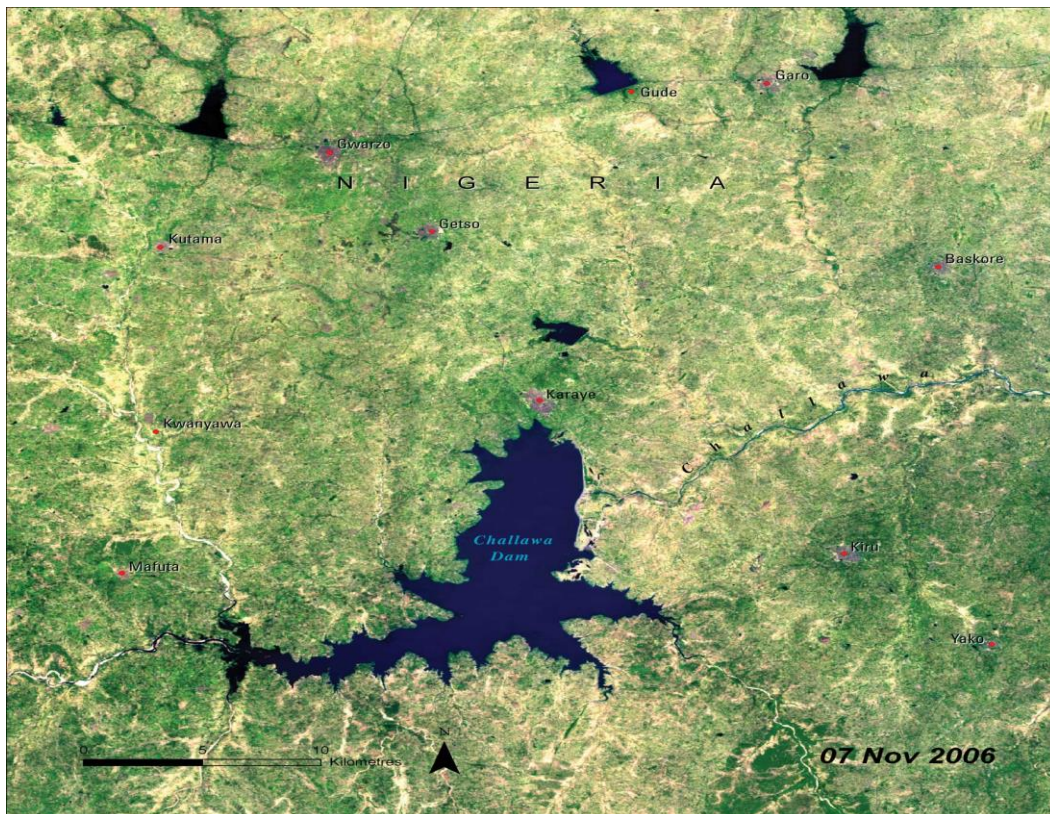
The economic impact of the Challawa Dam (and the Tiga Dam further upstream) has also been negative, eventually incurring millions of dollars more in losses than were yielded in benefits. In addition, while flood control was among the intended benefits of the dam, heavy rains often cause serious flooding above the dam.'  
(<http://na.unep.net/atlas/webatlas.php?id=162>)



1990



2006



## 15.10. Invasive Plants: Lake Chivero, Zimbabwe

[http://na.unep.net/AfricaAtlas/AfricaAtlas/site\\_images.php](http://na.unep.net/AfricaAtlas/AfricaAtlas/site_images.php)

'In 1952, the Manyame River was dammed 40 km southwest of Harare, creating Lake Chivero. The Lake was intended primarily as a water supply for Harare, but it is also a source of water for irrigation and industry and serves as a local fishery.

One year after Lake Chivero was created, water hyacinth, an invasive wetland plant, made its first appearance, as a result of the influx of nutrients from nearby agricultural lands and municipal and industrial wastes from Harare. In 1955/1956, the first serious water hyacinth outbreak occurred and was successfully treated with chemical herbicides. The next outbreak in 1971/1972 covered approximately 25 per cent of the lake. Attempts to end a third outbreak in 1986 used mechanical and chemical controls until public concern about the chemicals brought an end to their use. By 1989, water hyacinth covered 20 per cent of the lake's surface (1989 image, yellow arrows); by 1990, it covered 35 per cent. Weevils that feed on water hyacinth were released as a biological control; mechanical and new chemical controls continued.

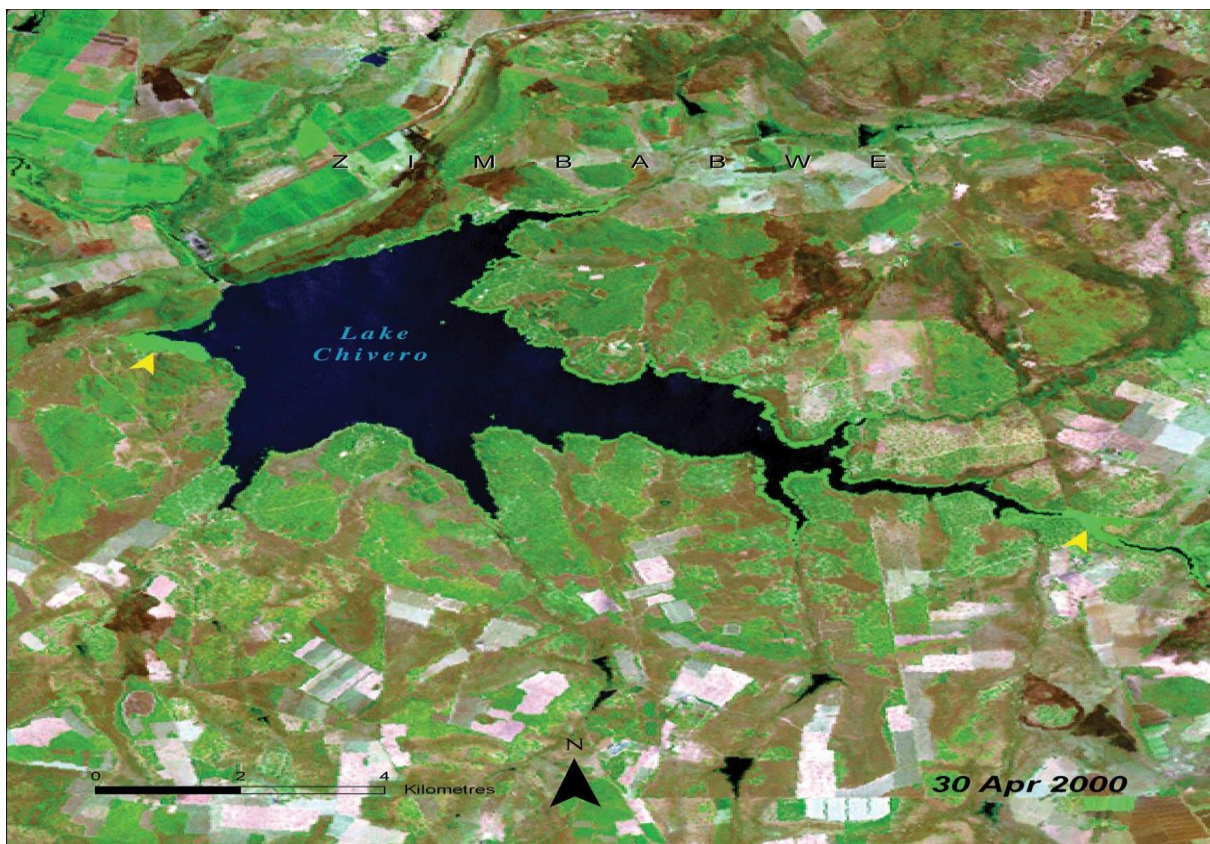
By 1997, it appeared that water hyacinth had been brought under control (2000 image, yellow arrows). By 2005, however, the invasive plants had returned again, reportedly covering as much as 40 per cent of the lake. In addition to water hyacinth, this most recent infestation includes massive amounts of another invasive plant, spaghetti weed (*Hydrocotyle ranunculoides*). (<http://unepatlas.blogspot.com/search?q=chivero>)



1989



2000





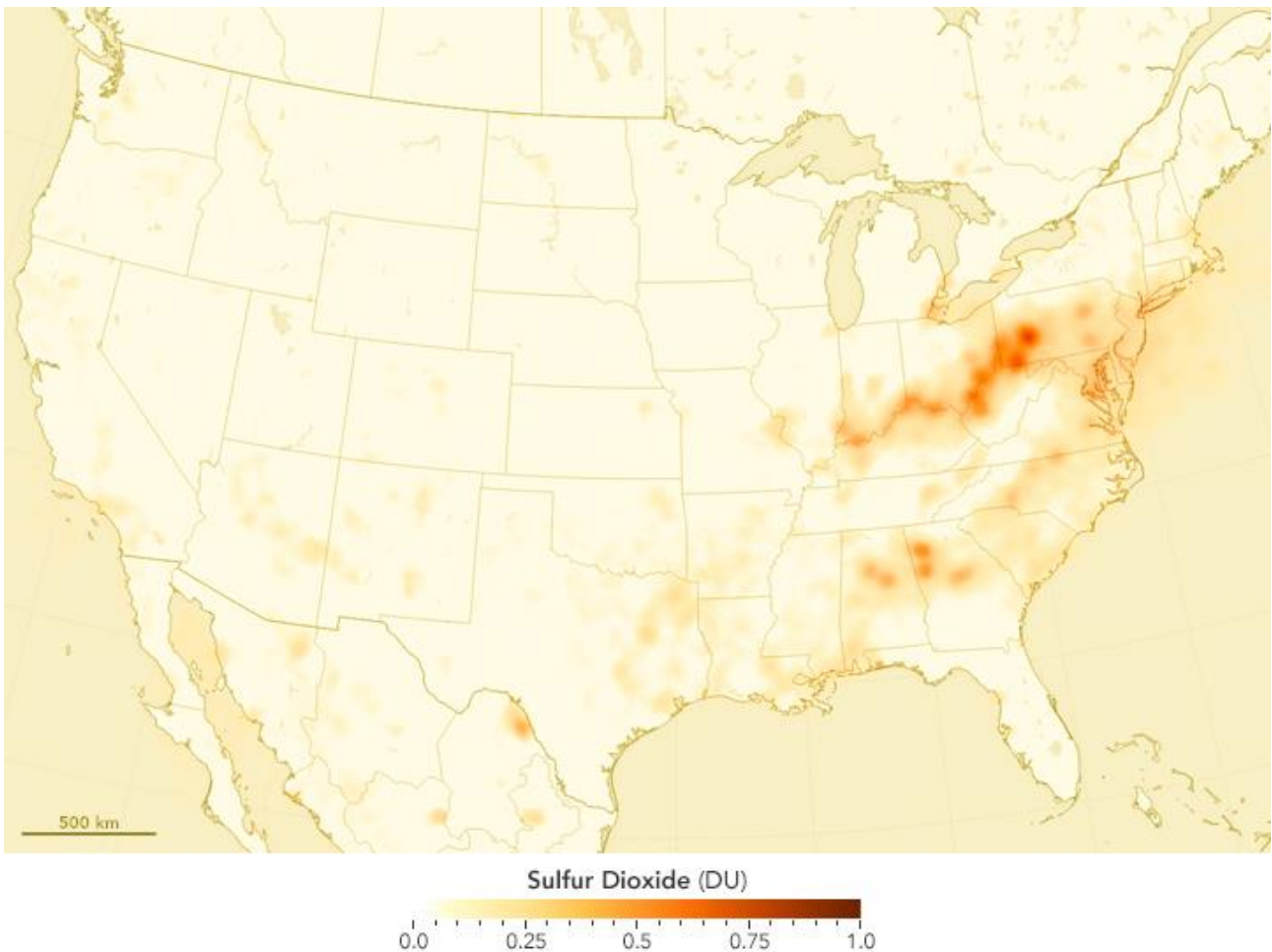
### 15.11. Sulphur Dioxide Down over the United States

<http://earthobservatory.nasa.gov/IOTD/view.php?id=87182>

The good news for people living in the eastern United States is that levels of sulphur dioxide dropped by about 80 per cent between 2005 and 2014, according to a new analysis of satellite data. The maps below depict multi-year averages of sulphur dioxide concentrations over the eastern United States. The upper map shows the average for 2005–2007 in Dobson Units (DU); the lower map shows the average for 2011–2014. Most of the sulphur dioxide hot spots are associated with coal-fired power plants or other industrial facilities that burn coal with high sulphur content. Smelters, which are used to concentrate metals found in ore, also produce the gas.

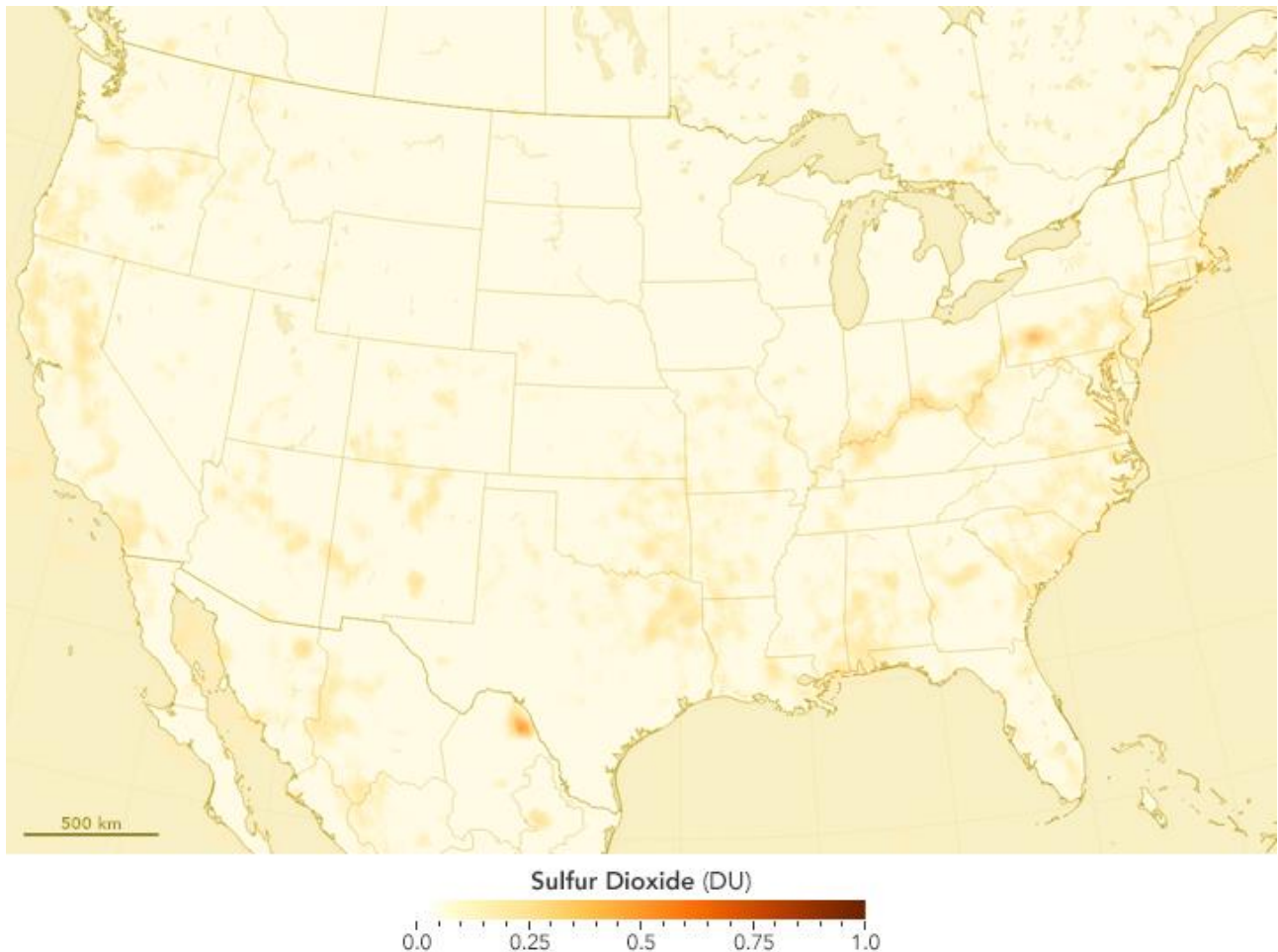
The observations were made by the Ozone Monitoring Instrument (OMI), a sensor on the Aura satellite. OMI has been monitoring sulphur dioxide and other air pollutants since 2004.

2005-2007





2011-2014



NASA Earth Observatory. 2005. Dust Storm off West Africa. Available at: <http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=15520>. Accessed on: 4 March 2016.

NASA Earth Observatory. 2008. Urbanization of Ouagadougou, Burkina Faso. Available at: <http://earthobservatory.nasa.gov/IOTD/view.php?id=8870>. [Accessed 3 March 2016].

NASA. Earth observatory. 2015. Shrinking Aral Sea. Available at: ([http://earthobservatory.nasa.gov/Features/WorldOfChange/aral\\_sea.php](http://earthobservatory.nasa.gov/Features/WorldOfChange/aral_sea.php)). [Accessed 30 April 2016].

NASA. Earth observatory. s.a. How Will Global Warming Change Earth? Available at: (<http://earthobservatory.nasa.gov/Features/GlobalWarming/page6.php>). [Accessed 30 March 2016]

NASA. Earth observatory. 2015. Sulfur Dioxide Down over the United States Available at: (<http://earthobservatory.nasa.gov/IOTD/view.php?id=87182>). [Accessed 30 March 2016].

United Nations Environment Programme. 2008. Africa: atlas of our changing environment. United Nations Environment Programme, Division Early Warning and Assessment. Nairobi, Kenya.