Observatoire du Sahara et du Sahel
Sahara and Sahel Observatory

JOINT AND INTEGRATED WATER RESOURCES MANAGEMENT

Of the Iullemeden - Taoudeni/ Tanezrouft Aquifer Systems and the Niger River

Algeria, Benin, Burkina Faso, Mali, Mauritania, Niger, Nigeria

GICRESAIT | PROJECT
SUMMARY REPORT

April 2017

Facilité africaine de l'eau

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Of the Iullemeden - Taoudeni/ Tanezrouft Aquifer Systems and the Niger River

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List of acronyms & abbreviations

ABN : Niger Basin Authority

AfDB : African Development Bank

AGRHYMET : Centre Régional de Formation et d'Application en Agrométéorologie et Hydrologie Opérationnelle

ASTER : Advanced Spaceborne Thermal Emission and Reflection

AWF : African Water Facility

Ci : Continental intercalaire

CILSS : Permanent Interstate Committee for Drought Control in the Sahel

CT : Continental Terminal

ECOWAS : Economic Community of West African States

FFEM : Fonds Français pour l'Environnement Mondial, France

GEF : Global Environment Facility

GICRESAIT : Joint and Integrated Water Resources Management of the Iullemeden Taoudeni/ Tanezrouft Aquifer Systems and the Niger River

GIS : Geographic Information System

IAS : Iullemeden Aquifer System

IWRM : Integrated Water Resources Management Walls

LANDSAT : Land Satellite

MODFLOW : Modular finite-difference flow model

MODIS : Moderate Resolution Imaging Spectroradiometer

OMVS : Organisation de Mise en Valeur du Fleuve Sénégal

OSS : Sahara and Sahel Observatory

OMVS : Organisation de Mise en Valeur du Fleuve Sénégal

OSS : Observatoire du Sahara et du Sahel

RDBMS : Relational Database Management System

SEI : Stockholm Environment Institute

SRTM : Système Aquifère d'Iullemeden, de Taoudéni /Tanezrouft

SAT : Système Aquifère de Taoudéni/Tanezrouft

SEI : Stockholm Environment Institute

SMAS : Senegalo-Mauritanian Aquifer System

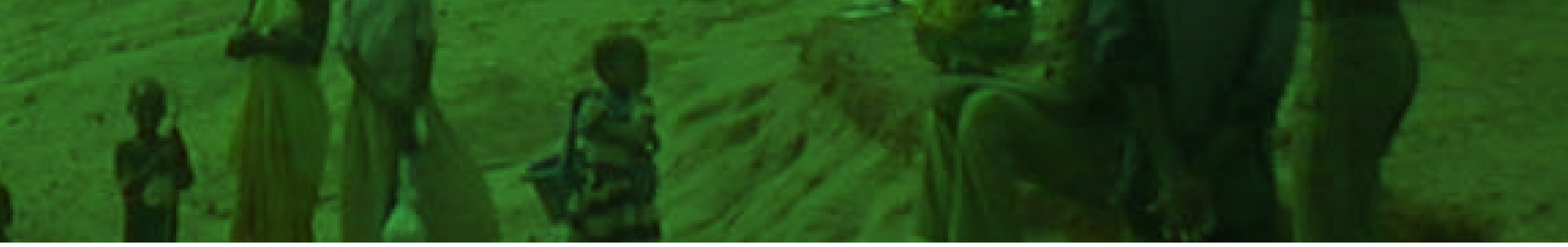
SRTM : Shuttle Radar Topographic Mission

TAS : Taoudeni/Tanezrouft Aquifer System

UNEP : United Nations Environment Programme

WRCC : Water Resources Coordination Centre of ECOWAS

PHOTOS CREDIT :
P17 : Wells for watering livestock **ABN**
P22 : Meeting of experts, Banizoumbou, Niger : **Sanoussi Rabe**
P23 : Partners round table and cover photo : **Lilia Benzid@oss**



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1 CONTEXT

West Africa is endowed with considerable water resources shared by several states, including hydrological river basins e.g. Niger River, Senegal River, and also transboundary aquifer systems, such as the Iullemeden Aquifer System (IAS), the Taoudeni/Tanezrouft Aquifer System (TAS) and the Senegalo-Mauritanian Aquifer System (SMAS). Unlike the attention given to the hydrological basins, for the last several decades, no special attention has been given to developing knowledge or joint management for the transboundary aquifers.

Although not well known, the aquiferous resources are increasingly threatened by growing water demand and continuous degradation of water quality due to pollution of many sorts and exploitation of deep and sometimes highly mineralized waters, in addition to non-concerted management.

Surface and ground waters are a strategic asset for the West Africa sub-region and play a decisive role in the economic and social development in the countries of the region.

Further studies should be conducted on the Iullemeden and Taoudeni/Tanezrouft Aquifer Systems (ITTAS) and how they function in order to support the development efforts of the ITTAS countries. Greater knowledge of the hydrological connection between the aquifer systems and the Niger River is a prerequisite to improving the management of the systems' surface and groundwater resources.

GICRESAIT Project *« Joint and Integrated Water Resources Management of the Iullemeden -Taoudeni/ Tanezrouft Aquifer Systems and the Niger River »*

The joint and integrated management of West Africa's water resources is a lever of development for the sub-region.

It has been taken up in the GICRESAIT project, which was funded by the AWF and FFEM (total amount 1,728,000 €), and implemented by OSS from 2010 to 2016, with the participation of seven countries (Algeria, Burkina Faso, Mali, Mauritania, Niger and Nigeria).

Project outputs :

- Significant increase in knowledge about the Iullemeden and Taoudeni/Tanezrouft water resources, which together form a single transboundary aquifer system
- Identification of areas with a major groundwater potential
- Creation of a regional database
- Study of themes such as hydrogeology, land cover, aquifer recharge, piezometry, vulnerability to climate change, water-table pollution
- **Facilitate the adoption of a Memorandum of Understanding and a road map for the creation of a Consultation Mechanism for the joint management of the ITTAS shared groundwater resources.**

PHYSICAL FRAMEWORK OF THE STUDY AREA

STUDY AREA OF THE GICRESAIT PROJECT

The project area of interest is located between longitudes 10° West and 10° East and latitudes 10° and 27° North (Fig. 1). It covers a total area of about 2,6 million de km2 (2 629 303 km^2) shared by seven (7) countries, namely Algeria (450.925 km^2, 17%), Benin (57.338 km^2, 2%), Burkina Faso (130.174 km^2, 5%), Mali (1.089.407 km^2, 41%), Mauritania (256.374 km2, 10%), Niger (524.813 km^2, 20%) and Nigeria (120.272 km^2, 5%).

The Iullemeden and Taoudeni / Tanezrouft Aquifer System is Africa's second largest aquifer system after the Nubian Sandstone Aquifer System (2,7 million km^2) shared by Egypt, Libya, Sudan and Chad.

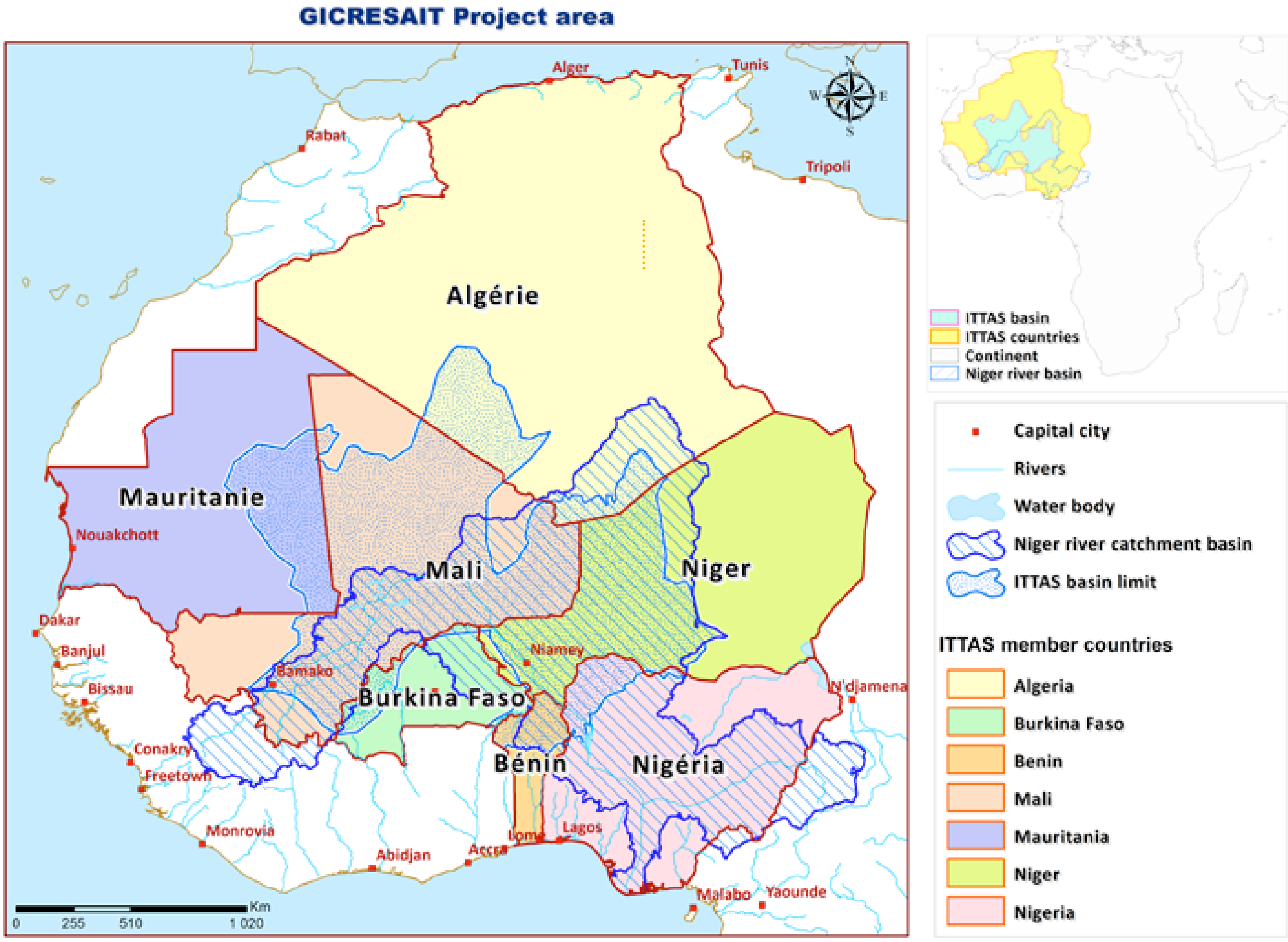


Figure 1 : GICRESAIT project area

CLIMATE & GEOGRAPHICAL FRAMEWORK

Geography

The project area is characterized by large plateaus and vast plains covered by sand dunes in the northern part. The elevation of the region is between 500 m in the north (Tanezrouft in Algeria) and 600 m (or higher) in Dogon region (Plateau of Bandiagara in Mali), to about 150 m in the Niger River valley downstream of the confluence with the Sokoto River in Nigeria.

Geomorphology

Highlights of the geomorphology the region :

- The Niger River valley which crosses the entire region from the west to the east and ensures a strong geographical and economic link in the most densely populated part ;
- The Inner Delta of the Niger River in Mali ;
- The Dallols fossil valleys in Niger (Bosso, Maouri, Tarka), and in Mali (Tilemsi) ;
- Extremely vast plains and low plateaus (Taoudeni, Tanezrouft, Tamesna, Gondo, Dhar of Nema...).

Climate

The region is divided into four climatic zones based on rainfall levels :

- The Sudanian zone with a Guinean climate and more than 1200 mm of rainfall per year ;
- The Sudan Sahelian zone with a tropical climate and 700 and 1200 mm of rainfall per year ;
- The Sahelian zone with a Sahelian climate and 700 to 200 mm of rainfall per year ;
- The sub-Saharan zone with a sub-desert climate climate and 200 to under 50 mm of rainfall per year.

During the last 50 years, West Africa has experienced a sharp decrease in rainfall, and suffered a drought period in 1968-1972 (Le Barbé et al. 1997, Nicholson 2001, Abdou et al. 2008). The significant reduction in precipitation is extremely clear in the Sahelian region, where severe rainfall deficits were recorded in 1972-73, 1982-84 and 1997. The 200 km southward shift of the isohyets is evidence of this trend.

The analysis of the Sahel Rain Index (SRI), based on data collected from 600 stations monitored by the AGRHYMET highlights three distinct periods (Fig. 2).

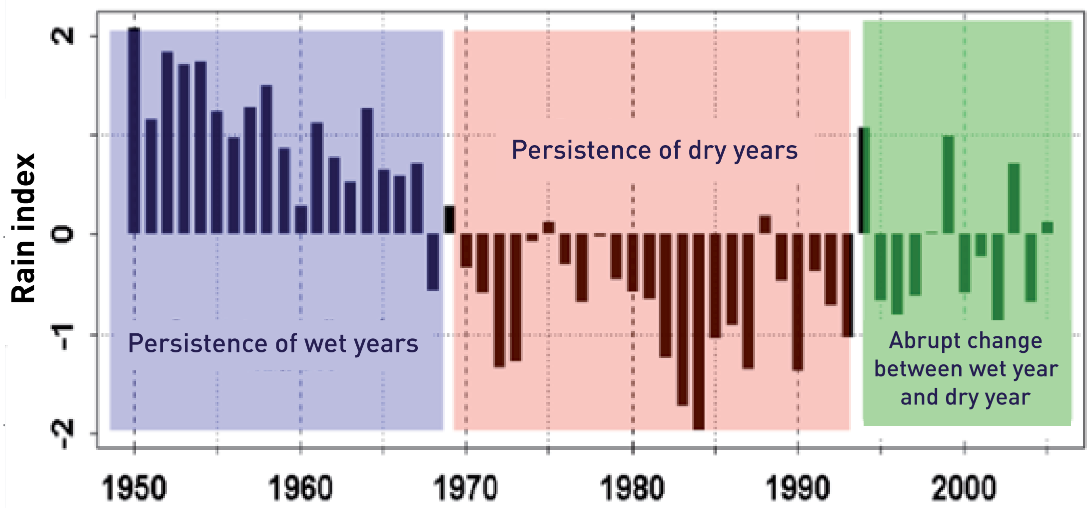


Figure 2 :
Sahel Rain
Index (SRI) (period 1950-2006)
(Source : AGRHYMET)

There is some doubt that the change in rainfall patterns that occurred during the past decades will continue. In fact, since the mid-1990s, **rainfall conditions have improved**, particularly in the Continental Sahel region, as evidenced by the isohyet shift in the opposite direction, during the last 15 years **(Fig. 3)**. The map shows that :

- Isohyets 50 and 150 mm during the 1981 - 2010 normal period in the Saharan and Sahel-Saharan areas of Mali, Niger and Algeria (by extrapolation) shifted slightly northwards compared to the 1961 – 1990 normal period.
- All the isohyets of the two normal periods are either equivalent to the 1981 - 2010 normal period or slightly below the 1961 - 1990 normal period.

There is practically no difference between the isohyets of the 1961–1990 period and those of the 1981 – 2010 period.

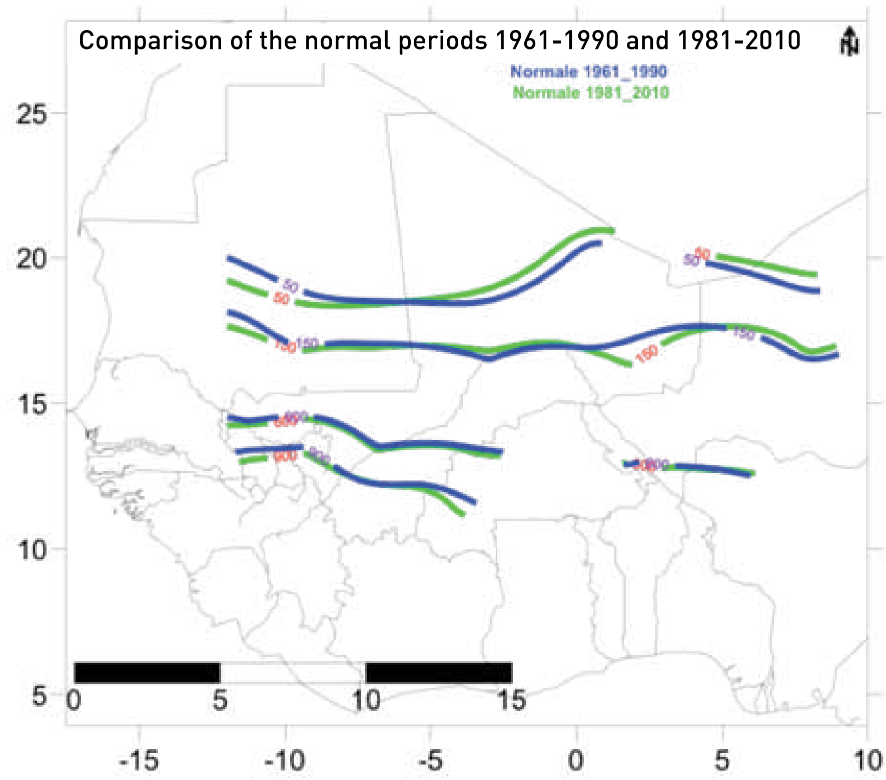


Figure 3 : : Comparison of isohyets for the 1961-1990 normal period and the 1981-2010 normal period
(Source : AGRHYMET)

“ Exceptional Rains of 2012 ”

In August-September 2012, torrential rains hit West Africa, notably Burkina Faso, Niger and Senegal

- **From North Cameron to Senegal :** heavy rains were recorded on 18 August 2012 (156 mm in less than 2 hours in Dakar on 25 August 2012).
- **In Burkina Faso (provinces of Soum, Oudalan and Yagha) :** Total rainfall of 100 to 160 mm in 1 to 5 days (twice in a month for certain localities) were registered in all the provinces of the national part of the Niger Basin in Burkina Faso.
- **In Burkina Faso (provinces of Seno and Yagha),** monthly rainfall between 200 and 320 mm in the month of August and between 150 and 200 mm in September 2012.
- **In Burkina Faso : overall rainfall in September 2012 exceeded 750 mm in certain localities while the average annual rainfall seldom reaches 600 mm in the region.**
- **In Burkina Faso (provinces of Soum, Oudalan and Yagha) :** rains of 100 to 160 mm in 1 to 5 days (twice in a month for certain localities) were recorded in all the provinces of the Burkinabe part of the Niger Basin.
- **At the Niamey hydrometric station :** More than half of the station's rainfall was recorded in the month of August, specifically during the first 20 days of the month (327 mm against an average rainfall figure of 160 mm in Niamey). It should also be mentioned that 18 August 2012 was an especially rainy day, with 119 mm of rainfall recorded in the Niamey-Airport station.

GEOLOGY & HYDROGEOLOGY 3

The geological map of the Iullemeden-Taoudeni/Tanezrouft Aquifer System covers major aquifers of sedimentary formations extending from the Paleozoic era to the Quaternary period. These formations rest on a fractured crystalline bedrock which may contain discontinuous aquifers **(Fig. 4).**

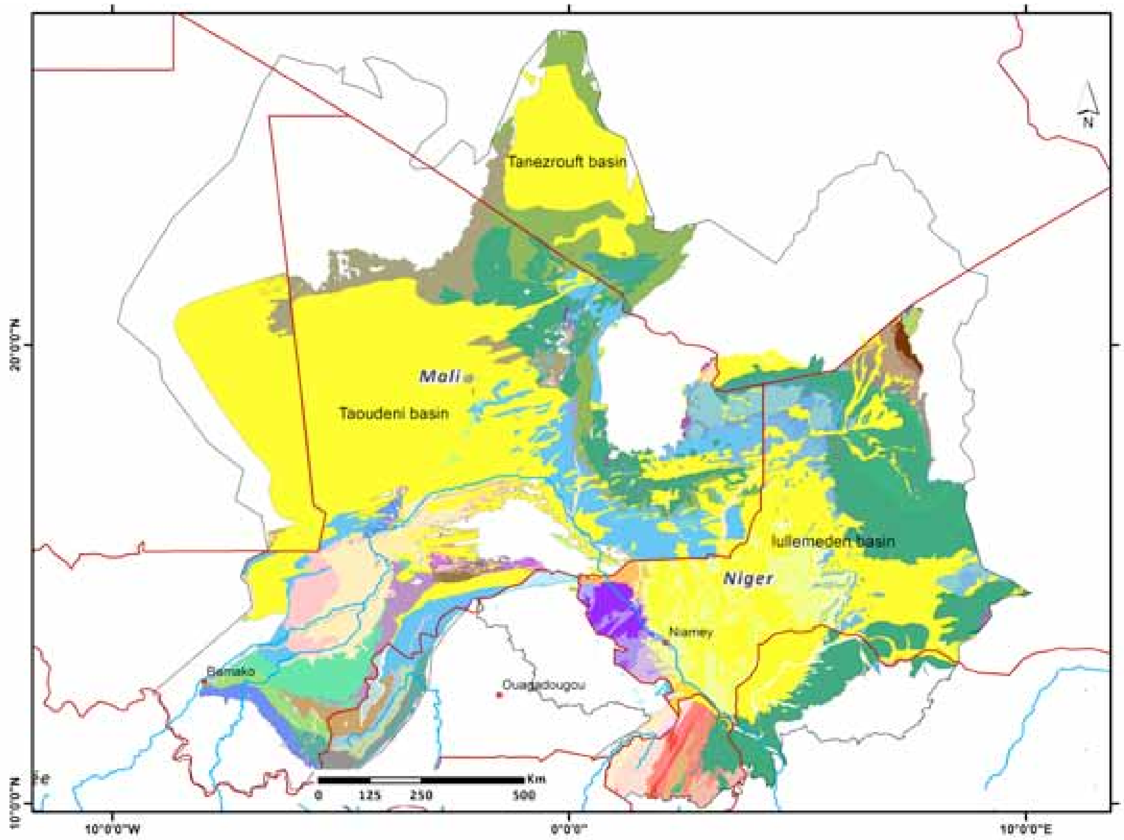


Figure 4 : Geological map of the study area at the scale of 1/1.500.000, 2013.

3.1. TWO SUPERIMPOSED AQUIFERS

These are the two superimposed layers of the Continental Intercalary (CI) and the Continental Terminal (CT) with the latter on top. These two acquiferous formations are found in the **Iullemeden and Taoudeni/Tanezrouft** basins, which are criss-crossed by the Niger River.

The Iullemeden Aquifer System is a vast and deep basin of a synclinal and relatively simple form. At this level, the two big aquifers of the Continental intercalary (CI) and Continental Terminal (CT) were studied separately.

In the Taoudeni-Tanezrouft Aquifer System the geometric structure is complex given its tectonic history which has brought about the marked variability of its sedimentary cover.

At this level, the CI and CT aquifers are not clearly separated and are frequently found in continuation with very varied porous or cracked underlying formations.

3.2. AREAS WITH HIGH WATER POTENTIAL

The hydrogeological studies ndicated the presence of areas with high groundwater potential (Fig. 5), mainly as a result of :

- A connection with surface waters which ensures the regular feeding of the basins even in times when climate variation caused water deficits. These resources include :
  - The Inner Delta of the Niger River in Mali,
  - The Dallos downstream sector in Niger and Nigeria,
  - The Mouhoun basin upstream the Gondo plain in Burkina Faso,
  - The Gao Graben in Mali and Niger.
- The thickness and high permeability of the aquifers formations, which may lead to high flow rates in the water catchment areas, including :
  - The Tahoua sector in Niger,
  - The Dhar de Nema south sector in Mauritania,
  - The Nara Graben in Mali.

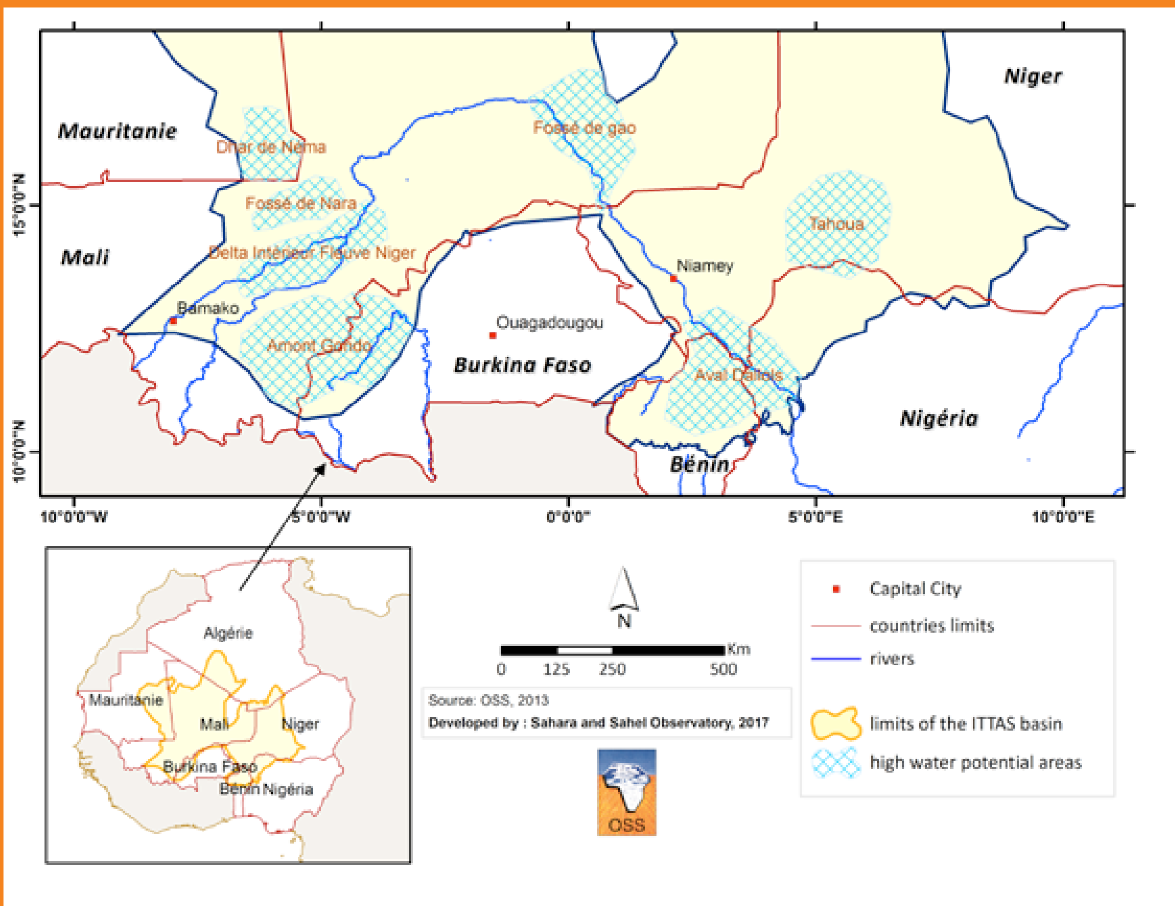


Figure 5 : Sectors with high groundwater potential, 2013.

DATABASE 4

The main objective is to create a simple and user-friendly tool to enable the database managers (OSS and partner countries) to consult and capitalize the data collected from the water points.

Regional database

By the end of the year 2016, the database included :

- **Information on about 123.000 water points (including the chronological series of the piezometric levels available) ;**
- **Rainfall data :**

  monthly precipitation levels at 50 stations from 1960 to 2011 ;
- **Hydrological data :**

  quarterly average ratings and monthly average flows from 1960 to 2012 for 5 stations on the Niger River.

Definition of altitudes based on DEM

For some of the water points in the database, data on their altitude are not available or are uncertain.

A special tool has been developed based on a Digital Elevation Model (DEM) to make up for this lack of information.

The DEM altitudes for water points uses a single file and can therefore be used to design geo-referenced piezometric sections and maps.

5 REMOTE SENSING

5.1. REMOTE SENSING APPLICATION : DATABASE

An evaluation of available geospatial data on the zone was conducted. The final selection of data and images was carried out in a way that ensured an overall and undisturbed representation of the ITAS zone. The sensors selected for the data analysis are the following :

- **MODIS for land cover mapping** at the scale of 1/2.000.000, for the total intervention area ;
- GlobCover data (ESA GlobCover Project) ;
- **LANDSAT for land cover mapping** at the scale of 1/200.000, for a south-north transect as a pilot zone.

5.2. DIGITAL ELEVATION MODELS (DEMs) PROCESSING

SRTM Version 4.1 data were chosen to provide a homogenous, continuous topography of the entire intervention area (Fig. 6).

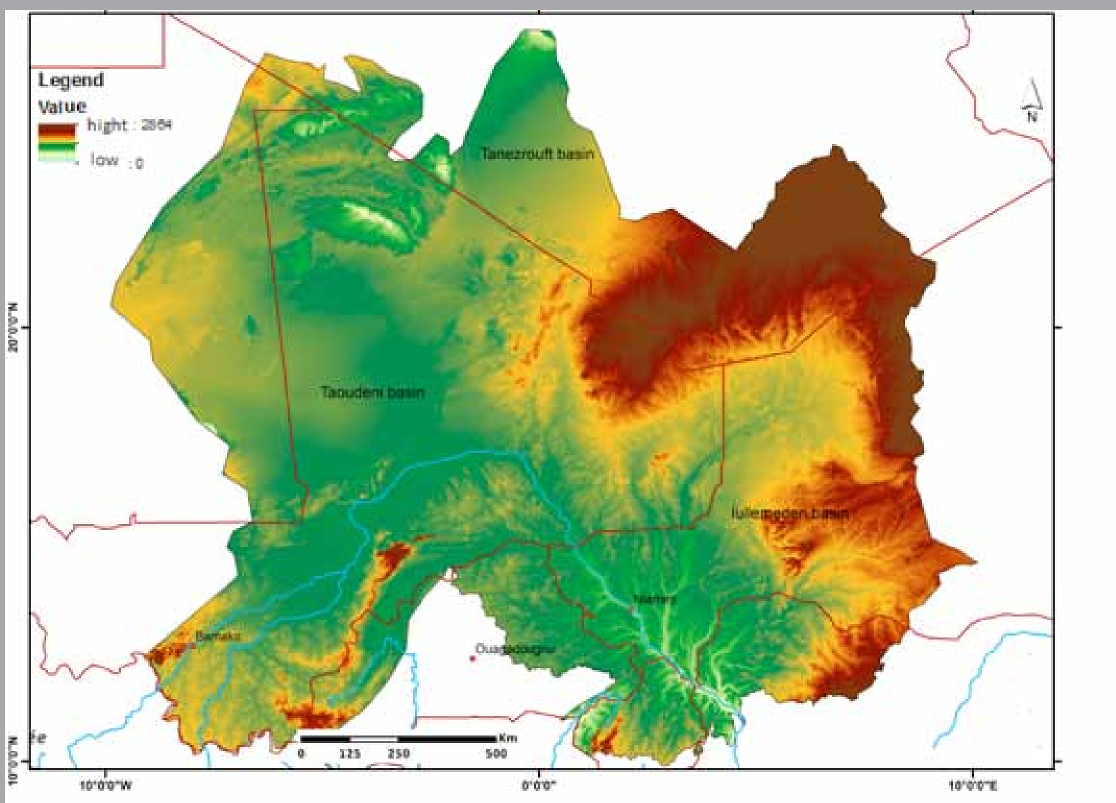


Figure 6 : Elevation map of the 2013 intervention area based on the SRTM DEM

Maps of slopes, exposures and the basin drainage system were produced using the corrected DEM **(Fig. 7, 8 and 9)**.

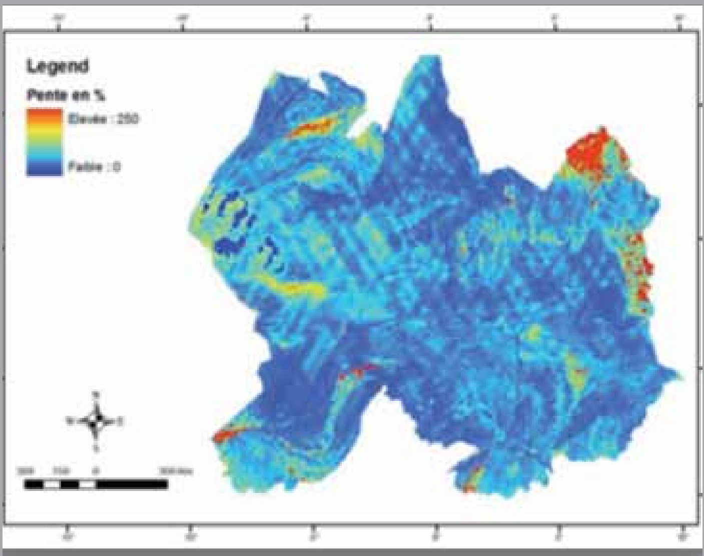


Figure 7 :
Slopes map of the area of intervention derived from the **DEM SRTM**

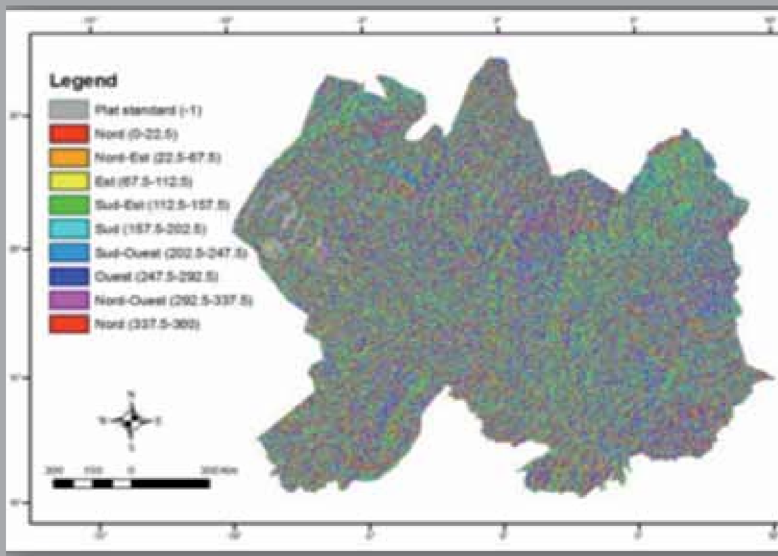


Figure 8 :
Exposures map of the area of intervention derived from the **SRTM DEM**

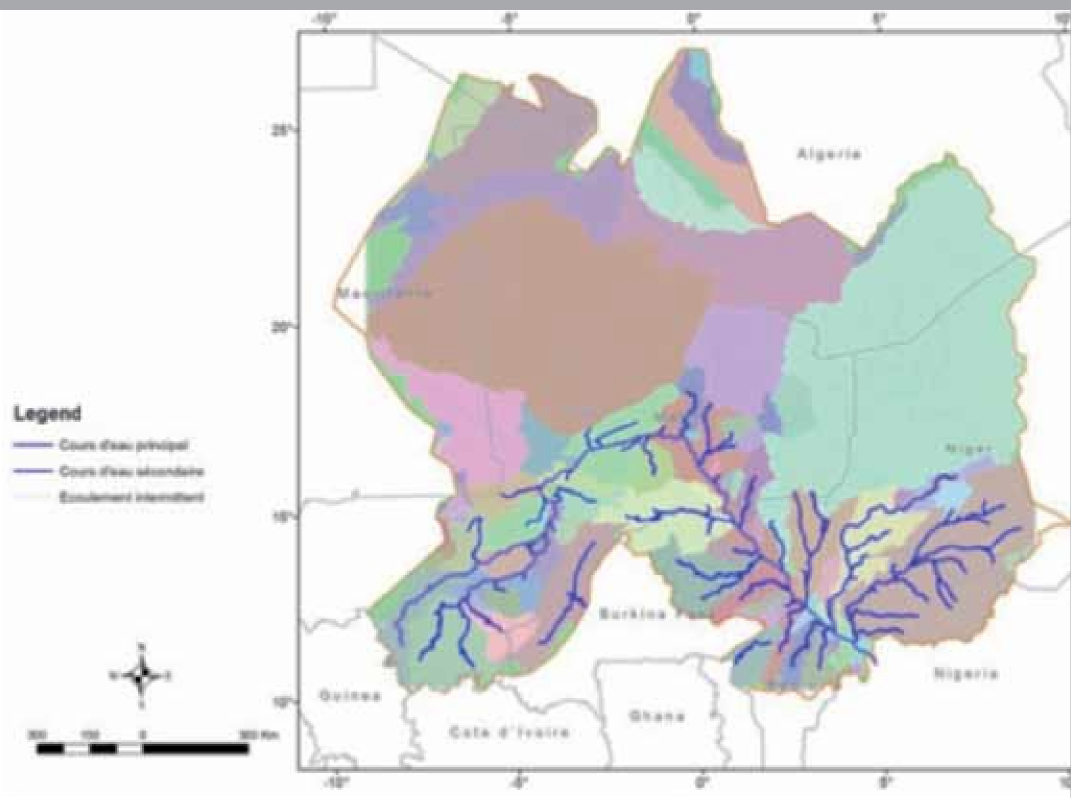


Figure 9 :
Map of drainage network and catchment basins of the area of intervention derived from the **SRTM DEM**

5.3. DEFINITION OF LAND COVER IN THE PILOT ZONE

Land cover mapping of the pilot zone were produced at the scale of 1/200,000 in order to compare the maximum number of isohyets at three different dates (January, April and September 2011). Nineteen LANDSAT scenes were used to cover the pilot zone on the three selected dates.

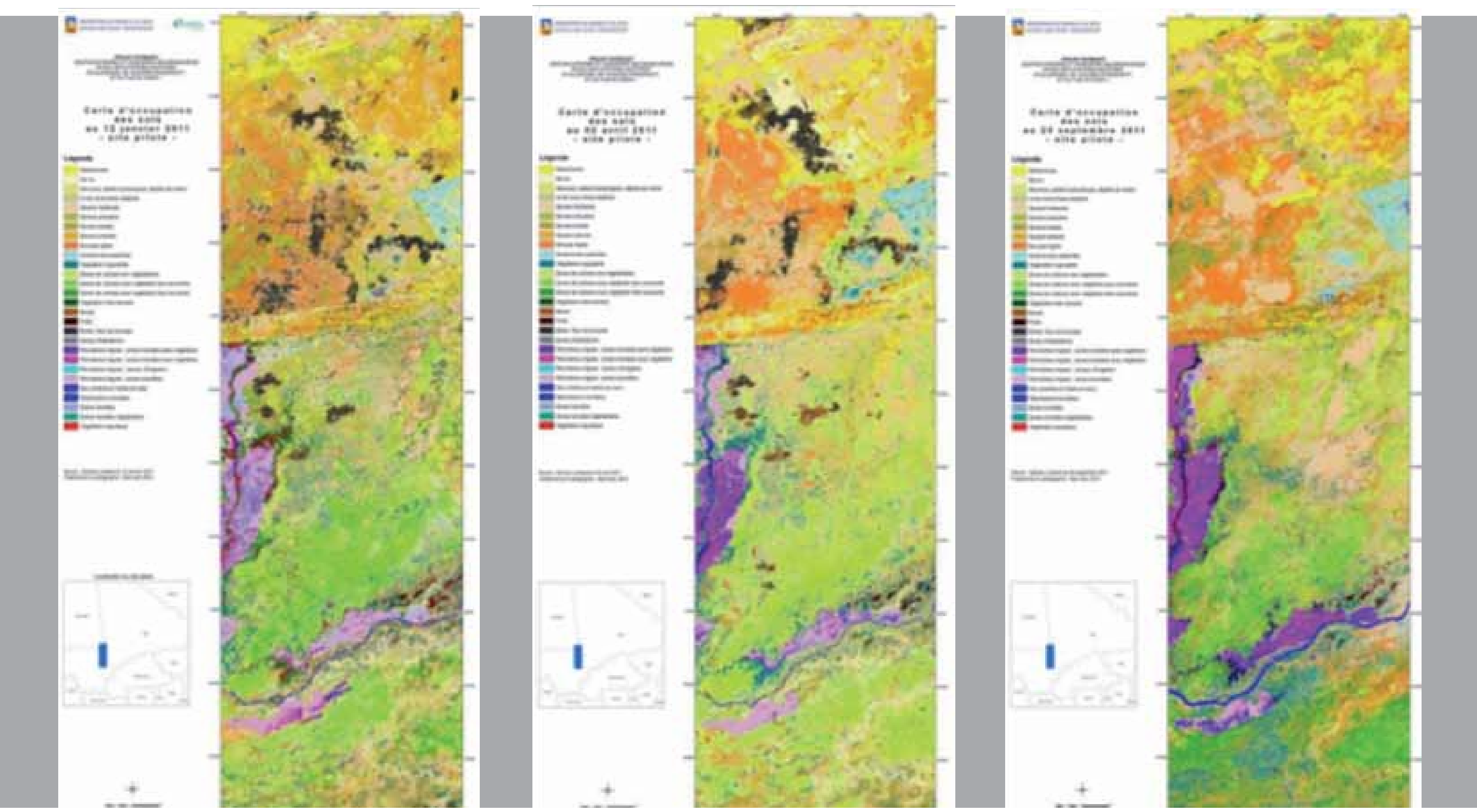
Following data preprocessing (radiometric corrections), three mosaics were developed to cover the pilot zone at different dates (12 January 2011, 2 April 2011 and 25 September 2011). Each mosaic includes three LANDSAT scenes selected for the same date in order to avoid the effects of atmospheric disturbance.

Three land cover maps were created for each date (January, April and September) (**Fig. 10**).

The land cover dynamic represented in this study is seasonal and clearly shows the change in land cover between the rainy season and the dry season.

The land cover map for April highlights the transitional stage between the rainy and the dry season. The contrast between these seasons is all the more important as we move southwards in the pilot zone, which further confirms the effects of climate on this dynamic.

The seasons also have a notable effect on the development of the irrigated perimeters.



January 2011 **April 2011** **September 2011**

***Figure 10* :** Land cover maps of the pilot zone 1/200.000

A natural dependence of land cover on season can be observed, even for the irrigated perimeters, thus providing an important indicator of the resources use. The land cover maps may play the role of indicators that allow us to deduce or estimate the perimeters with the most important recharge rates.

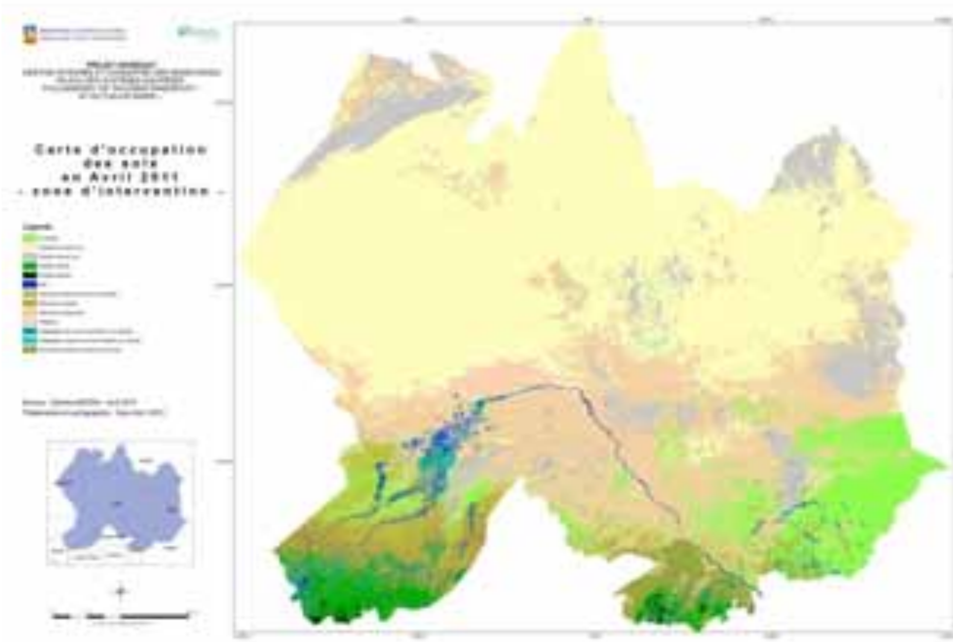
5.4. DEFINITION OF LAND COVER OF THE ENTIRE AQUIFER SYSTEM

MODIS images were used for mapping the entire area of intervention at two different dates : April 2011 during the dry season and September 2011 at the end of the rainy season (Fig. 11).

Image classifications were made on the two MODIS mosaics for the two selected dates.

Two land cover maps at the scale of 1/2,000,000 (at the basin level) were developed for each date :

April 2011



September 2011

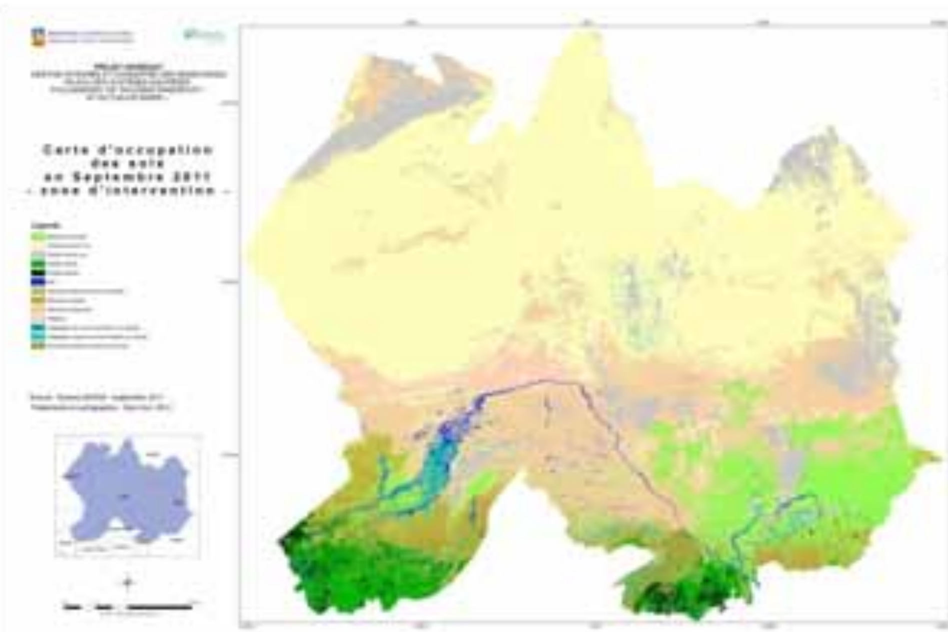


Figure 11 : Land cover maps for the ITTAS

6 MODELLING

6.1. MODELING THE IULLEMEDEN AND THE TAOUDENI/TANEZROUFT AQUIFER SYSTEMS ITTAS

The Iullemeden Aquifer System (IAS) and the Taoudeni/Tanezrouft Aquifer System (TAS) are in geological continuity with each other through the Gao Graben, which corresponds to a section of the Niger River valley in the region of Gao, Mali, between the Adrar des Ifora massif in the north and the Gourma massif in the south. Hydraulic exchanges between the two aquifers are very limited as the water flow directions are perpendicular to the Gao Graben axis.

Two mathematical models were used to model the Iullemeden Aquifer System and the Taoudeni/Tanezrouft Aquifer System. However, in order to guarantee the representation of their geological continuity, the western part of the IAS model was extended to overlap the eastern part of the TAS over a strip of 125,000 km^2 with identical hydrodynamic characteristics (Gao Graben).

Contribution of the mathematical simulation model of the ITTAS behavior under climate change

The mathematical model was developed to establish the water balance in the entire ITTAS, and more specifically to :

- Define the hydraulic relations between the ITTAS groundwater resources and runoff from the Niger River ;
- Simulate the behavior of groundwater resources under climate variation, especially when rainfall levels decline.

6.2. WATER BALANCE

The water balance, i.e. the quantity of water entering and exiting an aquifer system, has been calculated for the two aquifer systems.

The renewable water resources potential was estimated at **11 billion m^3** per year for the Taoudeni/Tanezrouft Aquifer System (Tabl. 2) and at **8 billion m^3** per year for the Iullemeden basin (Table 3).

Water abstraction from the aquifer systems (for all purposes combined) was estimated at 63 billion m^3 per year and 284 billion m^3 per year for the IAS.

Rainwater infiltration is by far the main source of the aquifers renewal (Fig.12) : more than 80% for the TAS and close 95% for the IAS.

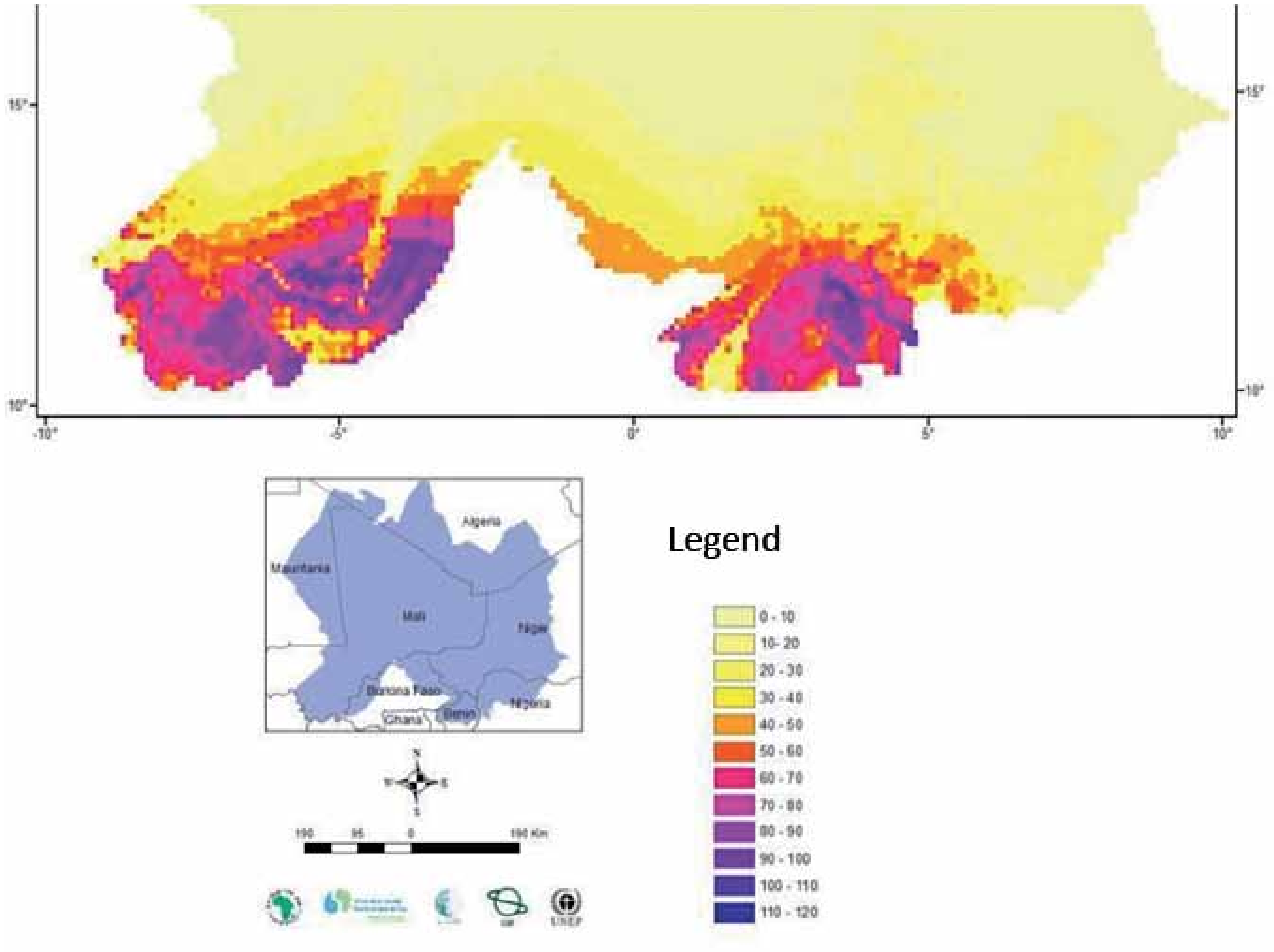


Figure 12 : Aquifer recharge in the wettest year of the 1960-2010 period

6.3. HYDRAULIC EXCHANGES BETWEEN THE NIGER RIVER AND THE AQUIFERS

Throughout its course the Niger River plays a major role in feeding the aquifer systems.

At the level of the Taoudeni/Tanezrouft Aquifer Systems, (TAS) the Niger River constitutes both an outlet (more than 280 million m^3/yr) and a drain (more than 1.5 billion m^3/yr). Only the upstream part of the Inner Delta drains water. Downstream in the Iullemeden basin, the Niger River receives about 3.3 billion m^3 of water per year.

6.4. REACTION OF GROUNDWATER RESOURCES TO CLIMATE VARIATIONS

The mathematical model can also be used to estimate the impact of aquifer recharge and factor in the increasing water demand caused by population growth.

Simulations show that the reduction in aquifer level due to severe droughts and population growth would only be a few meters more than in normal years, which can be considered negligible given the thickness of the aquifers in sedimentary land, (300 m on average).

Simulations have also demonstrated that the recharge induced by a single very rainy year can make up for for several consecutive years of drops in the water table due to low recharge.

The regional model could serve as a basis for developing local models, in particular for the zones with a recognized high water potential.

7 RESOURCE VULNERABILITY

Modeling contributes to better scientific knowledge of the functioning of the **ITTAS**, whilst a study and an evaluation of the vulnerability of these water resources to climate change and the impacts of human activities are essential in defining sustainable management approaches.

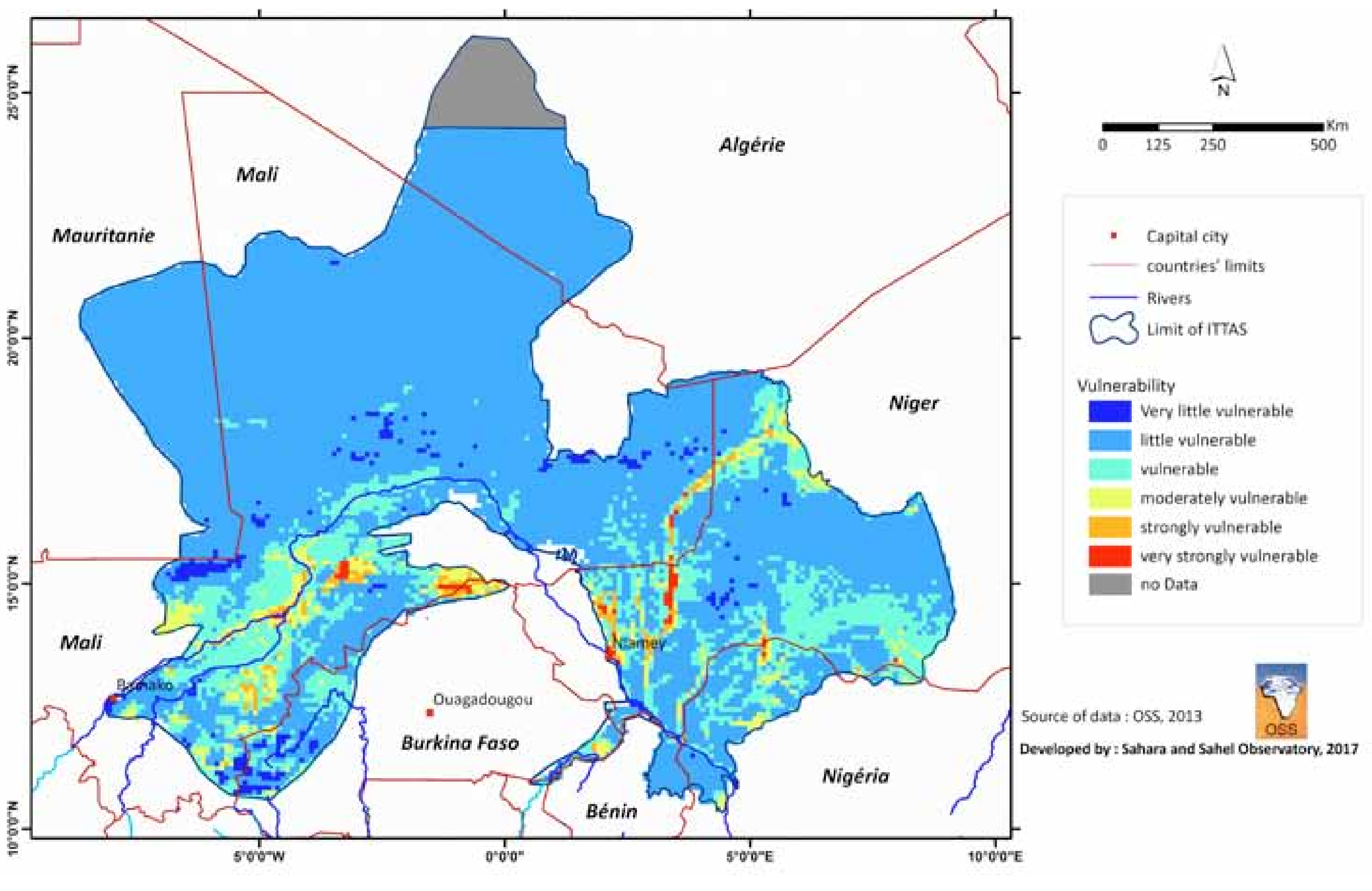
Hence, the focus was on two major themes that are priorities for the water managers :

- Aquifer levels drawn down by climate stress and increasing exploitation ;
- Chemical and bacteriological pollution from anthropogenic activity.

A risk information system was constructed using SIRIS, the System of Integration of Risk with Interaction of Scores, which included the "physical" constraints of the aquifer systems and their environment (recharge, permeability, water depth, free/confined waters) and anthropogenic pressure (populations, water demand, well density).

The studies prepared the way for the production of maps on the "vulnerable" **(Fig. 13)** and risk zones in the project area of intervention **(Fig. 14)**. These zones are considered as "priority sectors for management" .

Figure 13 : Groundwater vulnerability to climate change connected to lowering of piezometric level.



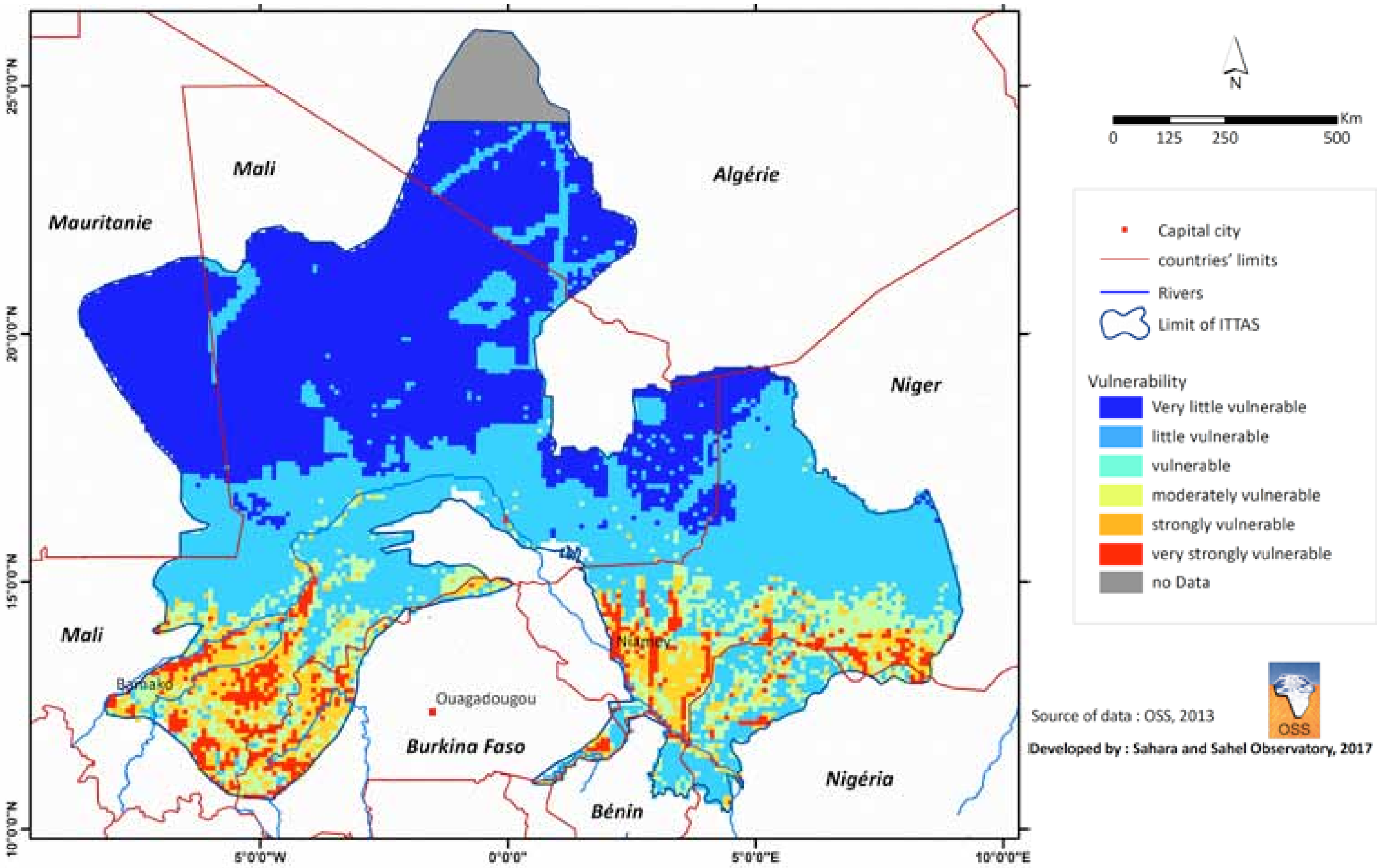


Figure 14 :
Risk of organic contamination of groundwaters

8 MONITORING-EVALUATION INDICATORS

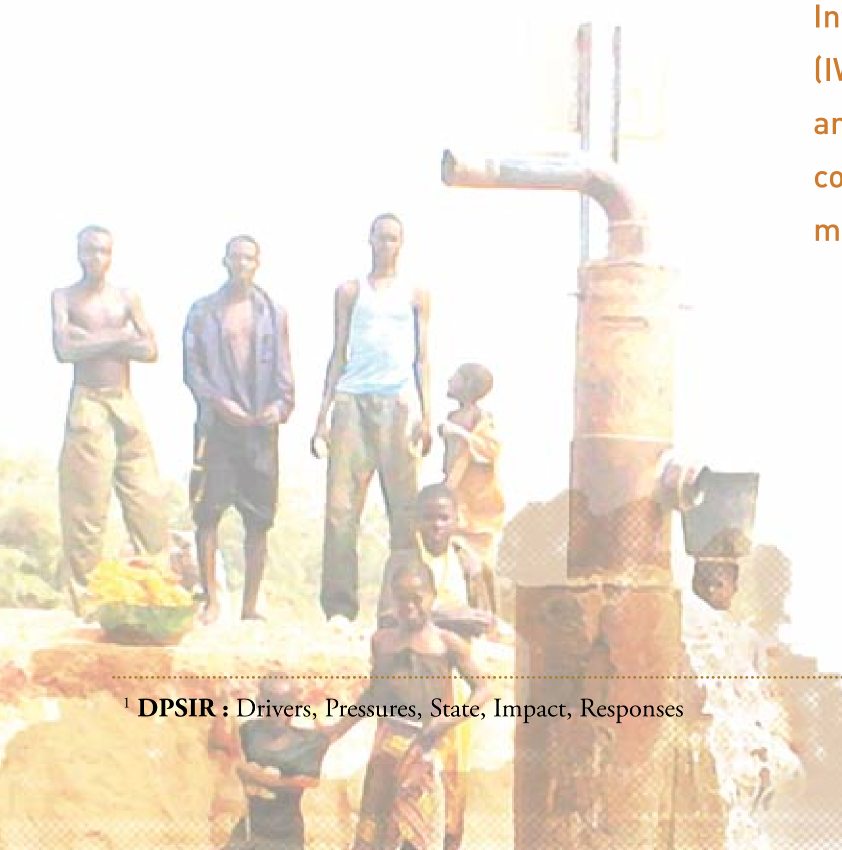
The monitoring-evaluation indicators should make it possible to :

- Better understand the social dynamics and development of the ITTAS ;
- Control the effects of these dynamics on the environment and aquifer systems ;
- Identify the actions needed for aquifers management and preservation.

The following DPSIR[1] indicators were used to monitor of the IWRM activities. Indicators of :

- **Driving Forces :** Population, agricultural perimeters, inventory of wells, boreholes and dams, industrial activities, livestock ;
- **Pressures :** pesticide quantities, volume of drinking water production in factories ;
- **State :** piezometric levels, surface and groundwater quality, air temperature, rainfall, watercourse flow rates ;
- **Impact :** piezometric levels and rainfall trends in the short and medium term, impacts of groundwater quality on water usages (drinking water provision, irrigation, watering), changes in agricultural yields, duration of water deficit in permanent water sources ;
- **Responses :** action program for protecting water catchment structures, reducing pollution reduction, ensured water access, and regulatory policies for water preservation.

These indicators should be developed as Integrated Water Resources Management (IWRM) in the ITTAS zones progresses and should become part of the monitoring component of the IWRM technical and methodology strategies.



[1] **DPSIR :** Drivers, Pressures, State, Impact, Responses

9 STRATEGY FOR JOINT AND INTEGRATED WATER RESOURCES MANAGEMENT

OBSERVATION

The Integrated Water Resources Management (IWRM) strategy for ITTAS should be based on reliable, up-to-date scientific and technical knowledge and on consultations with key national and regional actors.

The project has simulated groundwater exploitation up to 2050, based on the strongest past tendencies. Population growth (population doubles every 20 years, urban/rural differentiation) and access to drinking water were the main factors considered in the simulation.

A FIRST STEP TOWARDS JOINT MANAGEMENT

The first studies of the Iullemeden Aquifer System (2004-2009) led the Ministers in charge of water in Mali, Niger and Nigeria to adopt a Memorandum of Understanding for the creation of a Consultation Mechanism to manage the Iullemeden Aquifer System.

In 2013 the GICRESAIT project carried out a diagnostic study of the general legal and institutional framework of the three countries concerned.

The results of the study were presented at a meeting of Ministers in charge of ITTAS water resources, in Abuja in March 2014 and led to an agreement, in principle, on a protocol for the creation of a Consultation Mechanism, with its own legal status, for the integrated and joint management of the ITTAS water resources.

This Mechanism aims to :

- Promote integrated, joint management of the ITTAS water resources ;
- Strengthen solidarity and promote cooperation and information-sharing to facilitate and improve joint risk management ;
- Define rules to protect the environment and ecosystems against degradation and pollution ;
- Facilitate the sustainable development of the ITTAS resources.

2nd meeting of Ministers of the countries sharing the basins of Iullemeden-Taoudéni-Tanezrouft in Abuja

ON A REGIONAL MASTER PLAN FOR THE ALLOCATION OF SHARED RESOURCES

OSS proposed the creation of a regional master plan that includes the actions planned for the Niger River resources in the NBA's Sustainable Development Action Plan (SDAP).

This would entail :

- Making a regional diagnosis of the countries' current and future water needs (at timelines 2030 and 2040) for purposes such drinking, agriculture and industry, factoring in climate change adaptation ;
- Identifying agricultural, mining and industrial development potentials per country ;
- Planning for water allocation from zones with high water potential at timelines 2030 and 2040 and for the related investments ;
- Strengthening the role and action of the ITTAS Consultation Mechanism.

This should make it possible to :

- Gradually meet the populations' increasing demand for water ;
- Cultivate the basin's arable lands (estimated at more than 137 million hectares)
- Improve national food security (both quantity and quality) ;
- Set up a regional transboundary infrastructure to promote economic development ;
- Create jobs and increase farmers' income.

Expert meeting, Banizoumbou, Niger

GENERAL CONCLUSION

The GICRESAIT (2010–2016) project has fulfilled its goals. More than 70 technical officers from the ministries in charge of water resources have been trained to update the management tools (database, models) that policy-makers need for making decisions on meeting the populations' needs for water at the lowest cost, and, by the same token, meeting the Sustainable Development Goals by 2030.

Capacity building for staff and technical staff is necessary to contribute to the development of a regional master plan on allocating shared waters.

The GICRESAIT project is just one step since it scoped the regional transboundary basin level. Further work is needed for a better understanding of the high water potential sectors that have been identified by the project.

This would contribute to planning for more effective, low cost utilization of the region's resources for drinking water, agriculture, and industry.

GICRESAIT development Partners Roundtable, Tunis

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