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Research Report

Examining Climate Fragility and Building Resilience

A Multidimensional Analysis of Water, Land, Agrifood and Community Systems in the Bouregreg Basin, Morocco

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About The Agence de Bassin Hydraulique du Bouregreg et de la Chaouia

ABHBC (Bouregreg and Chaouia River Basin Agency) is a Moroccan public water management agency responsible for the development, planning and sustainable management of water resources and the hydraulic public domain in the Bouregreg and Chaouia river basin. It was established by decree in 2000 under Morocco's water law framework, has legal personality and financial autonomy, and works on integrated water resource planning, governance, flood risk management, pollution control, and related partnerships with stakeholders.

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Back cover photo: Lake Erroumi, Khemissat, Morocco (*Photo credit:* ABHBC Morocco)

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Acronyms and Abbreviations

ABHBC	Hydraulic Basin Agency – Bouregreg Chaouia
ANEF	National Agency of Water and Forest
AU	Urban Agency
CRTS	Centre Royal de Teledetection (Royal Centre of Remote Sensing)
CWANA	Central & West Asia and North Africa Initiative
DAH	Hydraulic Engineering Department
DPA	Provincial Department of Agriculture
DRA	Regional Department of Agriculture
DRPE	Water Research and Planning Directorate
F2R-CWANA	Fragility to Resilience – Central & West Asia and North Africa Initiative
GG	Green Generation Strategy
ICT	Information and communication technology
IPCC	Intergovernmental Panel on Climate Change
NbS	Nature-based solutions
OCP	Office Chérifien des Phosphates (Cherifian Office for Phosphates)
ONEE	National Office of Electricity and Water
ONCA	National Office of Agricultural Extension
PDAIRE	Integrated Water Resources Master Plan
PGPE	Water Shortage Management Plan
PMV	Plan Maroc Vert (Green Morocco Plan)
PPRI	Flood Risk Protection Plan
SMBA	Sidi Mohamed Ben Abdellah
SPEI	Standardized Precipitation and Evapotranspiration Index
WEF	Water-Energy-Food

Summary

The Bouregreg River basin spans an area of 10,597 km² in northwestern Morocco (ABHBC, 2022). This strategic watershed, home to various cities, towns and rural communities, is crucial for supplying drinking water to Morocco's administrative and economic capitals, Rabat and Casablanca. Therefore, the resilience and sustainable management of its natural resources are essential not only for the livelihood of its residents but also for the broader development of the region.

The Bouregreg Basin features diverse landscapes – ranging from fertile coastal plains to the rugged mountain ranges of the Middle Atlas – yet faces significant challenges due to its variable climate. With average annual rainfall fluctuating between over 750 mm in the northern mountains to under 350mm in the southern regions (ABHBC, 2022) the impact of climate change is becoming increasingly evident, contributing to pressures like inland desertification that threaten the area's water resources.

Water availability within the basin is intricately linked to rainfall patterns and the rates at which groundwater is replenished. However, both factors have become increasingly unpredictable due to climate change. A significant concern is the decline in river flows – specifically in the Bouregreg and Grou Rivers – caused by excessive water extraction for agriculture and urban use, compounded by successive dry years in Morocco. This groundwater depletion endangers ecosystems and threatens the livelihoods of rural communities that rely heavily on these vital resources.

Land ownership in the Bouregreg Basin consists mostly of privately owned lands, along with state-owned forest land and Habous (collective land). The analysis of land use over the last decades reveals that most of the Bouregreg watershed consists of uncultivated lands, including pasture and rainfed fallow lands. Erosion poses a significant threat to the basin, depleting essential soil nutrients and resulting in diminished fertility, loss of vegetation, and increased sedimentation in key water bodies, particularly the Sidi Mohamed Ben Abdellah (SMBA) dam.

Agriculture is the dominant economic activity in the Bouregreg Basin, especially for rural populations. While crops are predominantly rainfed, there is an increasing reliance on groundwater irrigation for fruit tree plantations in specific areas. The total agricultural area covers approximately 370,000 hectares (PDAIRE-ABHBC, 2019); however, irrigated land remains minimal and large-scale irrigation systems are absent.

Livestock farming is a vital component of the basin's economy, with sheep and goats serving as essential sources of income. The livestock population exceeds 3 million animals (PDAIRE-ABHBC, 2019), predominantly consisting of these animals. Extensive livestock farming primarily relies on natural fodder obtained from rangelands and stubbles. Additionally, equine farming, poultry raising and beekeeping contribute significantly to the region's agricultural economy.

Forests cover approximately 335,000 hectares (Laouina and Mahé, 2013) in the Bouregreg Basin, primarily consisting of deciduous trees—particularly cork oak and holm oak. However, these forests face significant degradation due to overexploitation, illegal logging, and wildfires. Unfortunately, reforestation efforts—largely involving eucalyptus and coniferous trees—have not been sufficient to actively counter deforestation.

In the Bouregreg Basin in Morocco, the management of water, agriculture, and land governance systems operates through a blend of regional and national frameworks. The Hydraulic Basin Agency – Bouregreg Chaouia (ABHBC) oversees the basin's water resources, regulating both distribution and quality. Agricultural practices are guided by policies aimed at enhancing productivity and sustainability, often supported by government initiatives and local cooperatives. Land governance is shaped by both national land policies and local management practices, striving to balance agricultural development with environmental conservation. Effective coordination among these systems, while essential, is often challenged by fragmented approaches and limited integration.

Industrial activity in the Bouregreg Basin is limited, contributing to only a fraction of Morocco's overall industrial output. The most notable industries include phosphate mining and the mineral waters sector. Despite this,

the basin attracts only 3% (HCP, 2017) of national industrial investments. In contrast, tourism - particularly ecotourism and cultural tourism – holds significant potential in the Bouregreg Basin, capitalizing on the region's natural beauty and proximity to major cities like Rabat and Casablanca. The area offers opportunities for outdoor sports, hunting and cultural experiences, aligned with national tourism development plans aimed at increasing visitor numbers and investments.

Approximately one million people live in the scattered rural communities of the Bouregreg Basin (Projections made by RESING/ research team based on RGPH 1994-2004-2014 data) (RGPH-HCP, 2023), many of whom depend on cultivating rainfed crops and raising livestock for their livelihoods. Analysis of population growth in the basin over recent decades reveals an overall positive trend; however, a slight decline has been observed in remote provinces. This decline is associated with rural exodus and reduced birth rates stemming from improvements in education, healthcare and living conditions. Economic conditions, geographical location and infrastructure also influence growth rates. According to the latest national census (2014), multidimensional poverty decreased significantly from 38% to 16%, indicating a promising trend in poverty reduction. The average annual decline of approximately 2.2% suggests continued progress in alleviating poverty.

Education is a critical factor affecting poverty levels, contributing approximately 50% to overall poverty, while inadequate access to water, electricity and sanitation, contributes an additional 28%. Despite recent improvements, sanitation remains a pressing issue, with many households lacking connections to a wastewater disposal network. In the Bouregreg Basin, education levels are generally low; over 50% of the population lacks formal education and only 2% have attained higher education (RGPH-HCP, 2014). Certain provinces exhibit particularly high rates of educational deprivation. Gender disparities are also pronounced, with a larger percentage of women lacking formal education compared to men. Improved social indicators, such as lower unemployment rates, are essential for poverty alleviation. Activity rates in the region, range from 45% to 52% (RGPH-HCP, 2014), but women's participation is notably lower than that of men. Unemployment rates are particularly high among women and vary across provinces.

This analysis examines the climate fragility of water, land and agrifood systems within the Bouregreg watershed, while also considering energy, biodiversity and community-based systems. The primary objective is to assess the characteristics and spatial-temporal distribution of fragility in these systems, within the context of current and projected climate scenarios. By employing an inclusive and scientific methodology, the analysis offers recommendations for collaborative resilience strategies and targeted investments for implementation.

The scientific approach developed to achieve this objective involved analyzing the status and future projections of the water, land and community systems in relation to identified hazards such as drought, erosion and floods. It assessed both the individual and combined fragility of these systems, which limit development, under projected climate change scenarios and socioeconomic pathways. Additionally, the approach focused on co-developing solutions to enhance resilience. The methodology employed advanced earth observation products, modeling and GIS analysis, complemented by a thorough participatory approach that included dialogues and focus group discussions. This enabled all stakeholders to examine the fragility of the systems within the Bouregreg watershed and identify their limitations and potential for development.

By integrating various modeling and GIS analyses with participatory approaches, the study assessed perceptions of hazards and inherent capacities. This analysis mapped the vulnerability and exposure of different systems to three hazards—floods, drought, and erosion—both individually and in combination. This effort led to the identification of several fragility hotspots.

The results showed that Bouregreg Basin faces growing challenges from droughts and floods. Severe droughts have lowered water levels, challenging agriculture and water systems, while floods, though vital for recharging aquifers, damage infrastructure and disrupt communities. Unregulated construction and poor water management worsen these issues. Pollution, outdated infrastructure and unsustainable farming, further degrade water quality and heighten shortages. Rapid urbanization and weak management increase pressure on water resources.

Climate change accelerates soil erosion due to heavy rains and droughts that weaken vegetation and soil stability. This leads to farmland loss, infrastructure damage, and social challenges. In the Bouregreg Basin, sediment buildup threatens water supply infrastructure, worsened by overgrazing and poor farming practices. Inadequate erosion control compounds these effects, impacting the environment and local communities.

Rising temperatures and frequent droughts intensify water scarcity, increasing the fragility of the region's agriculture. Forecasts predict significant temperature increases, boosting water demand and reducing arable land. This affects crop yields, soil fertility, and water availability, risking local food systems. Social factors like reliance on climate-sensitive farming and unequal resource access further weaken food security. Population growth adds more pressure on water and land.

Policies related to the “water-energy-agriculture-natural ecosystems nexus” in the Bouregreg Basin are fragmented and not effectively coordinated. Challenges include inconsistent policies, difficulties in implementation and a lack of integrated governance. The nexus approach is not well integrated into regional efforts, highlighting the need for better capacity building, research and innovation. Environmental education also needs to be more practical and widespread.

To enhance water system resilience, this analysis identified key measures like improving water resource monitoring. Currently, inadequate precipitation networks miss critical rainfall data, highlighting the need for more rain gauges and post-flood surveys to improve flood forecasting. Better groundwater management is also crucial, focusing on enhanced monitoring and regulation. Using surface water from the SMBA and Tiddas dams could help reduce pressure on aquifers.

Investing in small-scale water storage and natural retention methods can improve drought resilience. Enhancing flood forecasting, creating regional flood management committees, and raising awareness are vital for better flood response. Water conservation programs targeting farmers and other stakeholders are also essential. Policy reforms should focus on developing a comprehensive drought management plan, early warning systems and sustainable rainwater management to reduce erosion.

To strengthen land systems, priorities include ecosystem restoration, soil conservation and sustainable land practices. This involves planting native trees, implementing terracing and addressing human impacts like deforestation. Awareness programs and improved land management are also needed. Additionally, flood risk management should be enhanced through updated maps and prevention plans.

For resilient agrifood systems, the focus should be on efficient irrigation methods, water reuse and promoting drought-resistant crops. Community education, capacity building and monitoring irrigation efficiency are crucial. Implementing sustainable fertilizer and pesticide use will also minimize environmental impacts.

Research and innovation should prioritize drought-resistant crops, advanced water management and erosion control, supported by partnerships between Moroccan academic institutions, the private sector and international agencies. Investing in technological advancements like water accounting, weather forecasting and drought-tolerant seeds is essential. An integrated approach that combines water conservation, agricultural adaptation and community engagement is needed for sustainable water management.

Ongoing efforts are needed to improve land and agricultural productivity, conserve water and support community livelihoods in the Bouregreg Basin. Targeted interventions in identified “fragility hotspots” will help build resilience through better water management, land conservation and agricultural practices, backed by research, innovation and effective policies.

Bouregreg Basin Context

Physical Environment

Geographical Context

The Bouregreg watershed covers an area of 10,597 km², which is nearly 1.5% of the national territory (ABHBC, 2022). It is bounded to the northeast by the Wadi Sebou Basin, to the south by the Wadi Oum Erbia Basin, and to the southwest by the coastal Wadis of Wadi Cherrat, Wadi N'Fifikh and Wadi Malleh. The watershed opens up towards the west onto the Atlantic Ocean and occupies almost the entire Central Moroccan Plateau.

Climate

The Bouregreg watershed falls within the semi-arid Eastern Bioclimatic Stage, characterized by hot summers and mild, wet winters. The local climate in the area is also influenced by factors such as altitude and latitude, as well as its proximity to the Atlantic coast. The region experiences 90% of its annual precipitation rates between October and April. The Oulmes station, where the Bouregreg River originates, has an average annual rainfall of 760 mm. In contrast, Rabat typically records around 450 mm of rainfall, while the southern part of the basin receives a minimum of 350 mm. In contrast, the dry period generally lasts five months and is characterized by scarce rainfall that does not exceed 10% of the total annual rainfall. Average annual temperatures in the basin range from 15° to 18°C along the coast and from 15° to 17°C in the mountains, with maximum temperatures sometimes exceeding over 45°C.

Geomorphology

The study area is characterized by a varied landscape of mountains, plateaus, hills, alluvial plains and deltas. The mountains of the Bouregreg Basin are primarily made of sedimentary rocks, including sandstone, limestone and clay. Erosion has shaped the river valleys from these rocks, carving out stunning gorges and canyons. Additionally, the study area features numerous steep slopes and striking rock formations.

The alluvial plains of the Bouregreg Basin, located downstream of the mountains, are composed of sediment deposits transported by the rivers. Highly fertile, these plains are used for agriculture. The Bouregreg Wadi is also an important biodiversity hotspot, home to a wide variety of birds, fish and other animal species.

The Bouregreg Basin is divided into four major geomorphological units: (i) the eastern depression, (ii) the highland, (iii) the intermediate plateau and (iv) the lower plateau (Beaudet, 1969).

• The eastern depression

The eastern depression is situated between the highlands to the west and the western Middle Atlas to the east and features a northeast-to-southwest slope with moderate to low gradients. The near absence of vegetation in this area starkly contrasts with the towering reliefs on its eastern border. The outcrops in this region experience high levels of erosion, further limiting the presence of vegetation. Mountainous areas in the commune of Aguelmous are visible in Figure 1.



Figure 1. Mountainous areas in the commune of Aguelmous. *Source:* IWMI

- **The highland**

This geomorphological unit features varied topography and substrate. While steep slopes are prevalent, flat areas with moderate, rolling slopes also play an important role in this area's biophysical patterns. Schistose formations, characterized by their layered appearance and quartzite formations made from sandstone, dominate the region. Situated at elevations between 1,000 and 1,600 meters (Beaudet, 1969), the highland is distinguished by its sustained altitude and the deep entrenchment of its valleys, making it a unique geomorphological complex within the Bouregreg Wadi watershed. Figure 2 shows hilly landscapes in the commune of Moulay Bouazza in the Bouregreg Basin.



Figure 2. Hilly landscapes in the commune of Moulay Bouazza. *Source:* IWMI

- **The intermediate plateau**

The intermediate plateau consists of elevated areas ranging from 600 to 900 meters (Beaudet, 1969) in altitude, characterized by schisto-quartzite ridges separating the depressions of Tiddas (Figure 3) and Maâziz.



Figure 3. Valley relief in the commune of Tiddas. *Source:* IWMI

- **The lower plateau**

The lower plateau encompasses the coastal plateaus located at the base of the central plateau. The wadi has carved deeply into this unit, although the erosion becomes less pronounced as it approaches the coast, where the plateaus are lower. To the southwest of Tiflet, the Bouregreg Wadi widens around Souk Larbaâ des Shoul and the douar of Sidi Mohamed Ben Abdellah, creating undulating plains. As one approaches the coast, the lower Meseta plateaus transition into parallel strips of sandstone and limestone dunes alongside elongated, shallow depressions - typically less than 3.5% (Figure 4).



Figure 4. Rommani Plateau. *Source:* IWMI

Hydrographical network

The Bouregreg Wadi is one of the largest rivers in Morocco, originating from the Middle Atlas massif at an elevation of 1,627 meters near Jbel Mtourzgane and Grou (Figure 5). It flows westward into the Atlantic Ocean through the Meseta (Beaudet, 1969). The hydrographic network of the Bouregreg Basin is primarily comprised of two main rivers: the Bouregreg Wadi, which drains an area of 4,000 km² and the Grou Wadi, which covers an area of 3,600 km². Additionally, two tributaries of the Grou Wadi, the Korifla Wadi, draining 1,900 km² and the Akrech Wadi, with an area of 150 km², further contribute to the basin's water system (PDAIRE-ABHBC, 2019).

Since 1974, the SMBA dam, with a capacity of over one billion cubic meters partly filled by rainfall, has been harnessing the waters of this system. Located 18 km upstream from the estuary near Rabat, the SMBA dam provides drinking water to an estimated population of six million and caters to industrial needs in the area.

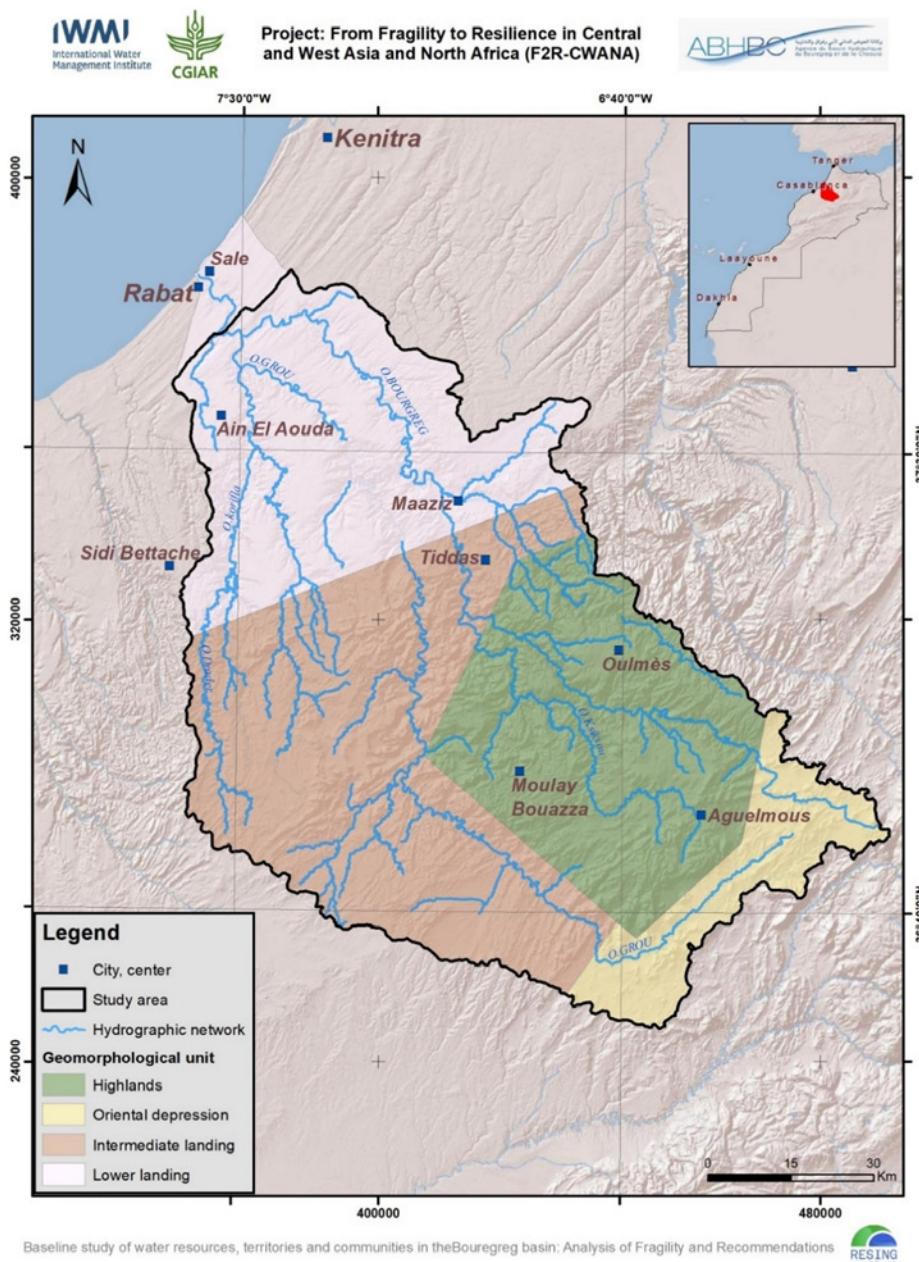
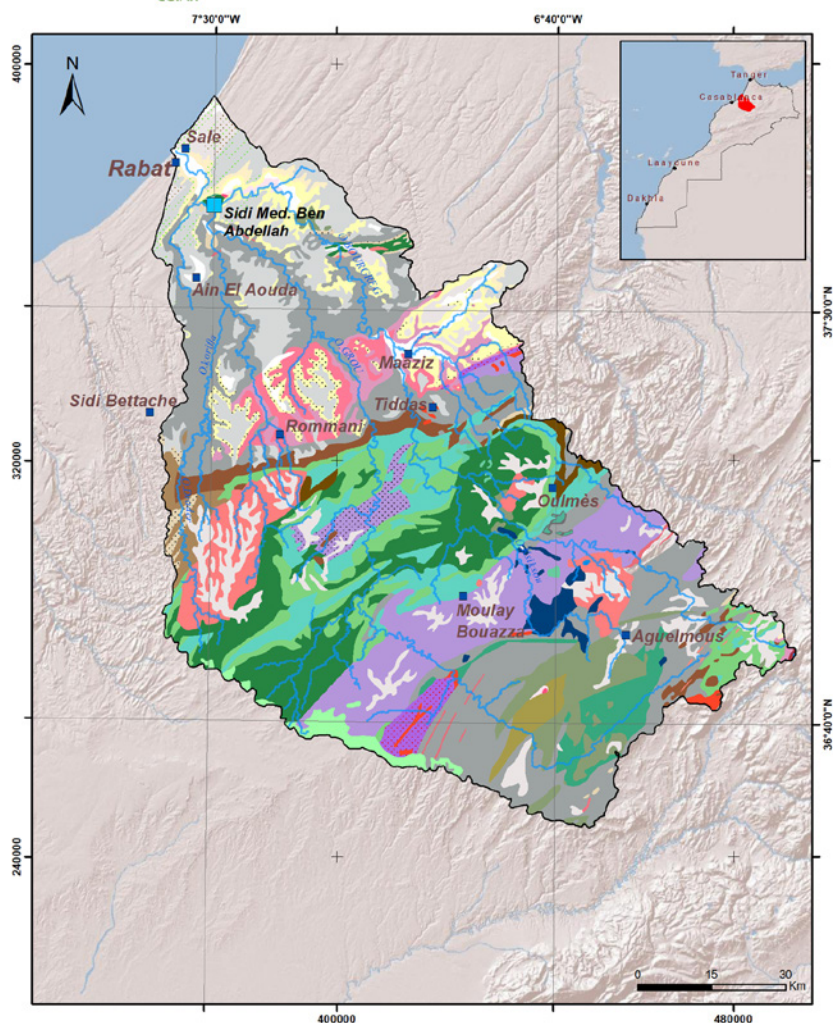


Figure 5. The four geomorphological units and hydrographic network of the Bouregreg watershed.
Source: IWM

Geology

The Bouregreg watershed is primarily composed of geological formations originating from sedimentary processes that date back to the Paleozoic era. This area features several granitic batholiths and large outcrops of metamorphic rocks. It is part of the Moroccan Central Plateau, a large Hercynian massif that extends 150 kilometers from east to west between the Middle Atlas to the Lower Chaouia and 100 km from north to south, stretching from the Gharb and Zemmour lowlands to the Phosphate Plateau. This region underwent significant geological changes, including folding, intrusion of igneous rocks and metamorphism during a period known as the Hercynian orogeny. Erosion later shaped the landscape during the Permian and Triassic periods. Subsequently, parts of the watershed were covered by deposits from the secondary period, including Triassic saliferous red clays and highly altered basalt (Beaudet, 1969). These formations from the early secondary period are found in a large structural feature known as a synclinorium at the level of Rommani and Mâaziz.

Figure 6 illustrates the geological composition of the basin.



WP4 : Etat des lieux des ressources hydriques, des territoires et des communautés dans le bassin de Bouregreg :
Analyse de fragilité et recommandations.

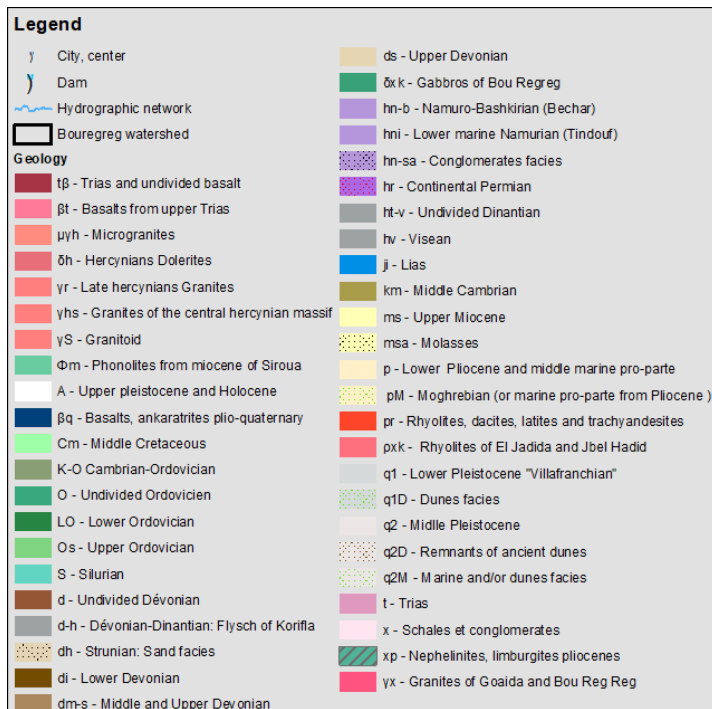


Figure 6. Geology of the Bouregreg watershed. *Source:* IWMI

Natural Environment and Soil Properties

Natural Environment

The study area is recognized as a biodiversity hotspot regarding ecosystem diversity. The basin is characterized by dominant species such as the cork oak and the holm oak in the sub-humid and semi-arid regions, while in the arid zone, these species are supplanted by thuja and oleaster. Additionally, this basin is home to two Sites of Biological and Ecological Interest (SIBE): the El Harcha forest and the Ment Plateau. However, the wetlands, which once supported a rich array of original and endemic flora, are now facing significant biodiversity loss due to destructive agricultural practices. This degradation is primarily driven by the overexploitation of natural resources, including the excessive usage of land use rights, illegal logging, wildfires and overgrazing by livestock.

The study area is rich in land resources, particularly in Mâamoura and Ben Slimane, as well as in the central massif of Oulmes and Moulay Bouâza. In the Rabat-Salé-Kénitra region, the forest domain spans 181,498 hectares (Table 1), highlighting its significance for forest resources. In addition, the Beni Mellal-Khénifra region also presents considerable potential for forestry development. Overall, the province has a substantial forestry base critical to the study area.

Table 1. Area of tree and shrubland formations in the study area

Region	Province	Area of tree formations (Ha)	Area of shrubland (Ha)	Total area (Ha)
Beni Mellal-Khénifra	Khouribga	676	19 651	20 327
	Khénifra	69 158	45 306	114 464
Rabat-Salé-Kénitra	Khémisset	94 285	87 213	181 498
	Study area	164 119	152 170	316 289

Source: Satellite images provided by the Centre Royal de Teledetection (CRTS) on April 2023

Pedology/Soil Characteristics

The Bouregreg watershed exhibits a remarkable diversity of geological substrates, relief, climate, and uneven vegetation cover, contributing to the heterogeneity of the soil textural profiles in this area.

From a pedological perspective, three main types of soil are prevalent in the Bouregreg Basin:

- **Poorly Developed Erosion Soils:** These soils are found along the Bouregreg River and its recent alluvial and colluvial tributaries. They primarily consist of red clays and are located in depressions and alluvial terraces. This soil type is dominant on sloping land with degraded vegetation cover.
- **Developed Soils:** This category includes brown forest soils and red or brown fersialitic soils*.

Brown forest soils: They are mainly found in sub-humid zones of the catchment area, developing on primary formations of schist and quartzite:

*Fersialitic soils are red and brown soils characteristic of the Mediterranean region, rich in free iron oxide. They develop on MioPlioQuaternary calcarenites found in the coastal meseta and the outwash from the Zaër and Zemmour low plateau. Additionally, they occur in mountainous areas on granitic and sandstone-schistose soils and in cork oak or holm oak forests. The red soils of the coastal plateaus have been shaped during wetter phases of the quaternary phases and developed along coastal strip complexes parallel to the current coastline.

It is also important to note the presence of vertisols or terres tirssified¹ soils, found within red clay and basalt formations. These soils are characterized by their high clay content and advanced evolution, including smectite's neoformation. The texture is typically claying loam.

Ghanem (1983) identifies three distinct types of vertisols in the watershed based on the nature of the parent rock:

- Shots or vertisols on dolerite basalt and triassic red clays in the Maâziz depression;
- Vertisols on Miocene Calcareous Molasse;
- Shots or vertisols on pliocene limestone.

Energy Resources

A summary of the general energy context in the Bouregreg Basin is presented below.

	Solar energy² (MASEN, 2025)	• Over 3,000 hours of sunshine annually • Temperatures vary from 25 to 34°C • Annual average overall horizontal irradiation: 1,873 kWh/m² (northeast) to 1,958 kWh/m² (southwest) • Area suitable for solar projects: approximately 2,500 km² (nearly 25% of the Bouregreg Basin)
	Wind power	• Wind speed varies from 2.68 m/s (northeast) to 3.16 m/s (southwest) (IRESEN geo-mapping, 2025) • Steeper slopes from the Atlantic coast inland may challenge wind energy harnessing • Substantial forest cover acts as a windbreak, potentially reducing overall wind energy potential
Renewable Energies	Biomass³ (Ministère de l'Énergie, des Mines et de l'Environnement, 2021)	• Rabat-Salé-Kénitra and Beni Mellal-Khénifra rank as the third and sixth regions of Morocco for biomass technical energy potential, representing over 24% of the national potential • Khémisset has a biomass potential of 990,452 MWh/year • Khénifra has a potential of 434,402 MWh/year • Khouribga has a potential of 230,647 MWh/year • Significant potential for organic household waste reclamation exists in the provinces of Rabat, Salé, and Skhirate-Témara
	Hydropower (Ministère de l'Énergie, des Mines et de l'Environnement, 2021)	• Eight sites with a combined potential power of 20 MW have been identified The SMBA dam primarily serves as a water storing and supply structure and is not equipped with hydroelectric stations
	Thermal Energy	• No potential for hydrocarbon deposits has been identified in the study area • Absence of ongoing prospecting or exploration operations for hydrocarbons

¹ "Tirssified soils" refers to thick soils characterized by a high proportion of clay, especially swelling clay. These soils typically contain significant amounts of nutrients and possess a strong ability to retain water, making them beneficial for agriculture and vegetation.

Socio-economic Context

Administrative Context

The Bouregreg Basin administratively spans 59 communes across 3 regions:

- The region of Béni Mellal-Khénifra spans 4,657 km² and covers 16% of the region's total land area
- The Casablanca-Settat region spans 144 km², or 1% of the total area
- The region of Rabat-Salé-Kénitra, with an area of 4,623 km², covers 26% of the region.

According to the 2014 General Census of Population and Housing (RGPH-HCP, 2014), the basin is home to 2,741,043 inhabitants and comprises 650,505 households.

Table 2 outlines the surface areas and the number of territorial communes included in this study, categorized by region and province.

Table 2. Distribution of the study area by region and province

Region	Prefecture/ Province (in km ²)	Total area of the province covered by the study (in km ²)	Area of the province covered by the study (in %)	Area of the communes in the province	Total number of communes covered by the study in the province	Number of communes by the study (as %)	Communes covered
Béni Mellal-	Khénifra	6,552	3,239	49%	38	13	34%
Khénifra	Khouribga	4,447	1,418	32%	31	12	39%
Casablanca- Settat	Benslimane	2,531	144	6%	19	2	11%
Rabat-Salé-	Khémisset	7,768	4,267	55%	35	27	77%
Kénitra	Skhirate-Témara	1,093	356	33%	10	5	50%

Source: Author's creation

Socio-demographic Characteristics

Table 3 illustrates the demographic trends of the populations in the study area. The analysis reveals a strong growth during the intercensal periods 1994-2004 and 2004-2014. However, in the latter period, the communes within the province of Khouribga experienced a moderate depopulation of approximately 2.4%. This decline can be attributed to several factors, including migratory movements and demographic changes characterized by a decrease in birth per family. This decline in birth rates is influenced by advancements in education, improved healthcare and sanitation and overall quality of life. The growth rate in the communes of the study area responds to various factors, including economic conditions, geographical location and the level of infrastructure development.

Table 3. Demographic trends in the study area

Région	Province	Population			Average annual growth rate (%) 1994-04	Average annual growth rate (%) 2004-14	Projection	
		1994	2004	2014			2025	2030
Béni Mellal-	Khouribga	97,651	97,293	76,782	-0,04	-2,37	59,177	52,571
Khénifra	Khénifra	182,086	183,826	182,028	0,10	-0,10	180,071	179,188
Casablanca-Settat	Benslimane	14,850	11,565	11,782	-2,50	0,19	12,025	12,138
Rabat-Salé-Kénitra	Khémisset	347,325	388,096	436,550	1,11	1,18	496,865	526,970
	Skhirate-Témara	78,248	110,068	134,459	3,41	2,00	167,576	185,215
Total		720,160	790,848	841,601	0,94	0,62	915,714	956,081

Source: RGPH-HCP, 1994-2004-2014

Poverty and Vulnerability

According to statistics from the High Commission for Planning (HCP), the analysis of multidimensional poverty from 2004 to 2014 indicates a significant reduction in poverty levels in the study area. The average multidimensional poverty rate decreased from 38% in 2004 to 16% in 2014, reflecting an average annual decline of approximately 2.2% (RGPH data), (RGPH-HCP, 2025; RGPH-HCP, 2014). This downward trend suggests a substantial decrease in poverty rates may continue in the coming decades (see Figure 7 below).

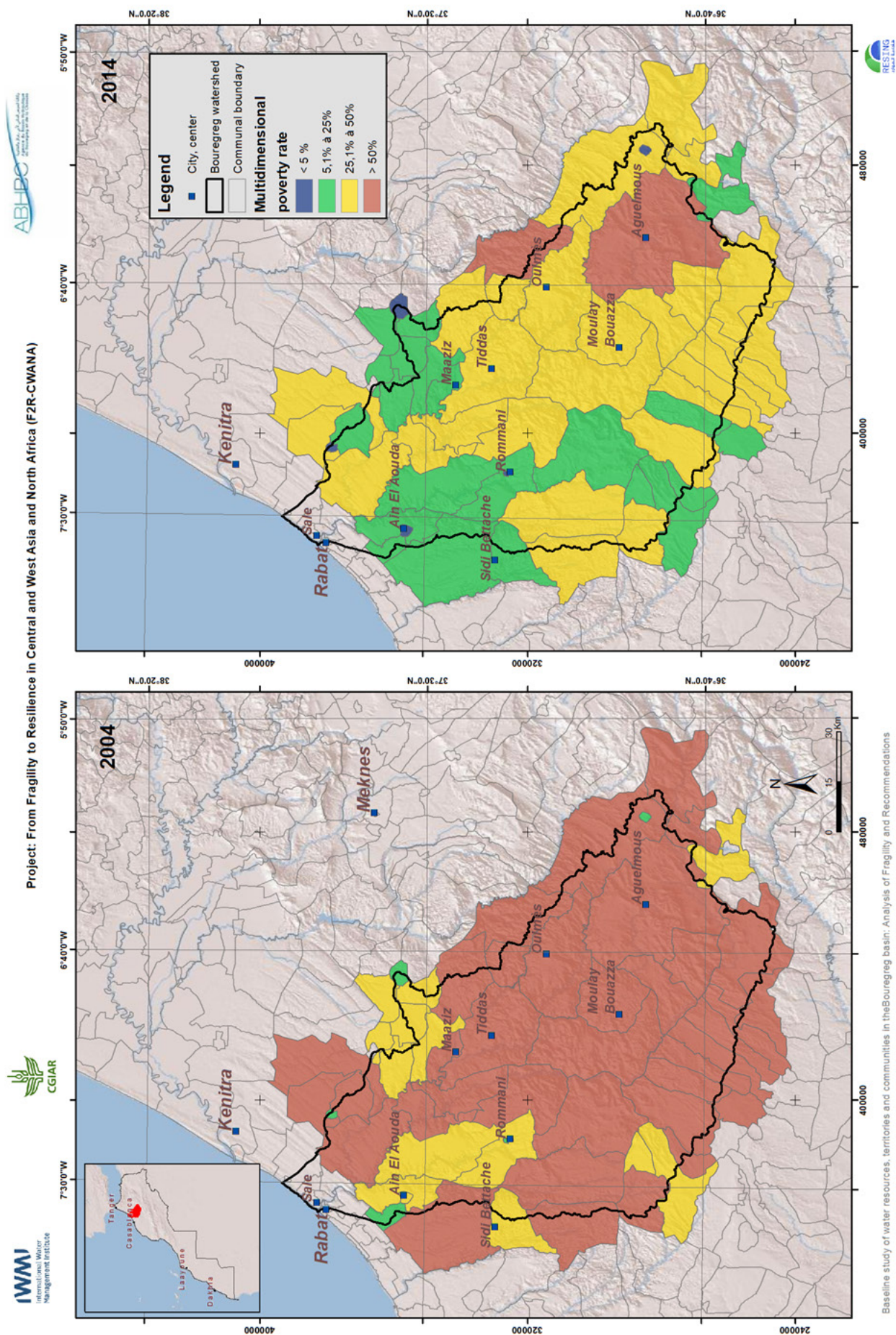


Figure 7. Multidimensional poverty over the decade 2004-2014. Source: (adapted from RGPH Data)

The analysis of poverty by sources of deprivation, underscores the crucial role of education in the poverty levels of the communes within the study area. As illustrated in the multidimensional poverty graph below (Figure 8), education accounts for about 50% of poverty on average, while inadequate access to water, electricity and sanitation contributes an additional 28%. This situation significantly affects the living conditions of the population.

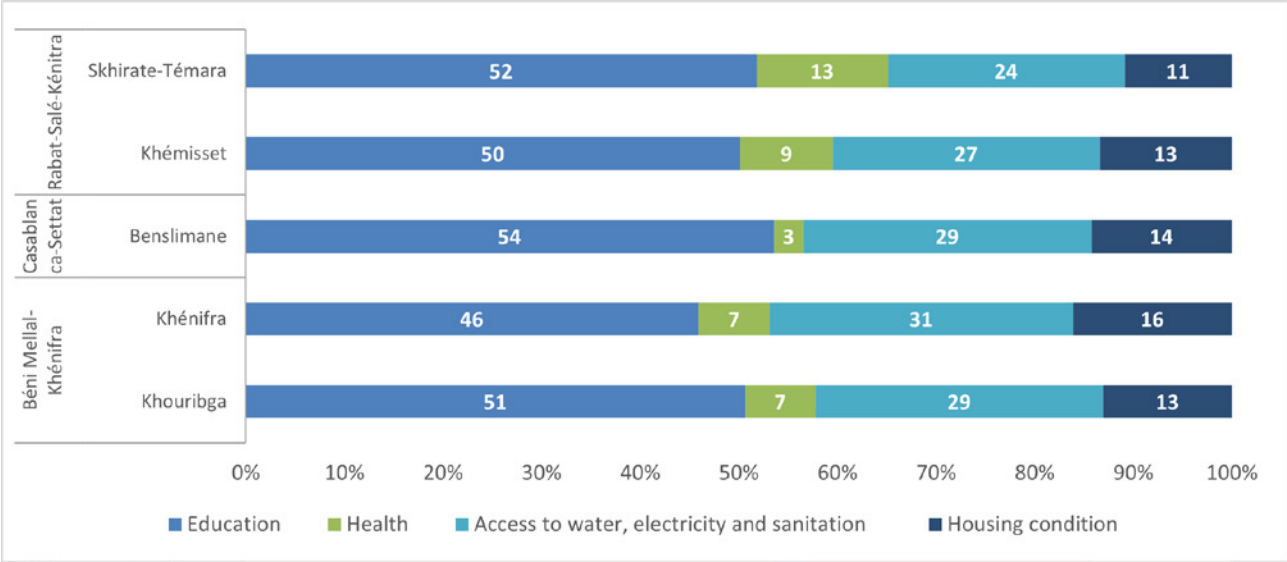


Figure 8. Breakdown of multidimensional poverty by source of deprivation
Source: RGPH-HCP, 2014

a. Access to Sanitation Services

Only 20% of households in the study area are connected to the wastewater disposal network. While this figure is considerably higher than the national average of 2.9%, it still indicates a pressing need for significant improvements in sanitation services. According to the RGPH-HCP Census (2014), households not connected to the sewer system rely on alternative methods, such as septic tanks—varying in quality—latrines (23%) or discharge waste directly into the environment (56%).

b. Solid Waste Disposal

In the area under study, a significant number of households (51%) dispose of their waste in open fields. This situation indicates a lack of organization and management in household waste collection within these municipalities. At the provincial level, areas such as Khouribga, Khénifra, Benslimane, and Khémisset are particularly affected by this challenge (RGPH-HCP, 2014).

c. Education

Figure 8 shows that over 50% of the population in the study area lacks formal education. 2% of individuals have attained a higher level of education, and 26% have completed primary education. The proportion of people who have never attended school is notably higher in the provinces of Khouribga, Khénifra, Benslimane, and Khémisset than in other provinces in the study area. Nationally, this percentage stands at 36.9%, with a 51% disparity between genders. In fact, data reveals that the percentage of women without formal education is substantially higher than that of men, at 46% compared to 30%. This trend is consistent across various levels of education (RGPH-HCP, 2014).

d. Employment

The improvement of specific social indicators, particularly the reduction in the unemployment rate, is a crucial factor in alleviating poverty. According to HCP data, the employment rates of the populations in the study area range from 45% to 52%. When examining gender distribution, it becomes evident that the activity rate of women in the study area is, on average, six times lower than that of men (RGPH-HCP, 2014; RGPH-HCP, 2025)

Regarding the unemployment rate, nearly 36% of women in the study area are unemployed, compared to 40% and 32% in the provinces of Benslimane and Skhirate-Temara, respectively. Additionally, the average unemployment rate in the province of Khouribga is significantly lower than in Khénifra and Benslimane (RGPH-HCP, 2014).

Land Ownership Situation

The analysis of land legal status conducted in this study reveals that the categorization of land in the Bouregreg Basin is defined by ownership and intended use. Land types in the basin include melk (privately owned), state-owned land (both private and public), forest land or habous (collective land).

Melk land is individually owned, distinguishing it from collective land owned by tribes or habous land, which is managed and owned by the Ministry of Habous and Islamic Affairs².

Each category has specific regulations that can restrict property rights to varying degrees (Land in Morocco: a fundamental lever for sustainable development and social inclusion, opinion of the Economic, Social and Environmental Council 2020). Within the study area, melk land is the predominant form of land ownership. For example, in the province of Khémisset, 94% of agricultural land falls under melk, followed by state-owned land at approximately 4% and collective land at about 2%. Habous land represents a minimally low proportion, accounting for less than 0.2%.

Economic Context

The analysis of the economic activities within the Bouregreg Basin draws on a range of available documents, including the Master Plan for the Integrated Development of Water Resources (PDAIRE), the Regional Land Use Planning Scheme (SRAT), the Regional Development Plan (PDR), regional monographs, statistical yearbooks from Morocco, as well as data provided by relevant ministerial departments at the provincial level. This comprehensive analysis encompasses the entire basin, focusing on the upstream area of the SMBA dam and on the provinces of Khémisset, Khénifra, and Khouribga. Table 4 summarizes the main economic sectors and their contributions to the national economy.

² Habous lands refer to parcels of land historically donated by private owners in Morocco as charitable contributions for specific purposes, such as orphan houses and mosques. In recent times, the Ministry of Habous and Islamic Affairs has managed these lands.

Table 4. Main economic sectors in the Bouregreg Basin

Agriculture (HCP, 2017)	• Agriculture is the primary economic activity in the Bouregreg Basin, particularly for rural populations • The agricultural sector is primarily rainfed (Bour), but there is an increasing reliance on private irrigation from groundwater for fruit tree plantations, particularly between the Tidass and Rommani plateaus • Livestock plays a vital role in the agricultural landscape of the study area • The total agricultural area in the basin is approximately 370,000 hectares • The area of irrigated land under small and medium-sized irrigation perimeters is minimal, and no large-scale irrigation perimeters currently exist
Livestock (PDAIRE-ABHBC, 2019)	• Livestock plays a crucial role in the study area, providing significant income for farmer-herders • In Zemmours and Zayane communities, sheep and goats are highly valued as sources of cash (El Mal). They are essential for maintaining family finances throughout the year, particularly during periods of favorable rainfall • Livestock breeding in the region is primarily extensive, with a strong emphasis on small ruminants, particularly sheep and goats • The total livestock population in the Bouregreg Basin exceeds 3 million animals, including 2,460,000 sheep, 360,000 goats, and 320,000 head of cattle • Equines, especially mules and horses, are commonly found in the provinces of Khémisset and Khénifra • Animal production predominantly relies on naturally occurring fodder sources, such as rangeland, stubble and fallow land, rather than cultivated fodder crops • Poultry farming and beekeeping are also important agricultural activities in the basin, particularly in the provinces of Khémisset and Khénifra
Forests (Département de l'Agriculture, DRA de Béni Mellal-Khénifra, Maroc, 2020)	• The provinces and prefectures within the Bouregreg Basin (Rabat, Salé, Khémisset, Khénifra, and Khouribga) encompass a total of 335,000 hectares of forest, with 90% of the forests found in Khémisset and Khénifra • Forested areas account for 29% of the Rabat-Salé-Kenitra region and 16% of the ABHBC zone of action • The predominant tree species are deciduous, particularly cork oak and holm oak, with occasional coniferous species such as cedar and oleaster • The subsoil is mainly covered with asphodel (a drought-resistant flower species) and doum palms, and there are notable large clearings along with agricultural encroachment into forested areas • Cork oak forests in the Bouregreg Basin, an extension of the Mâamoura forest, show signs of overexploitation due to excessive cork harvesting • Reforestation efforts involving eucalyptus and coniferous trees (such as pines) are proven insufficient in alleviating deforestation • Forest degradation is evident, driven by misuse of land rights, illegal logging for urban development and charcoal production, wildfires, and overgrazing by livestock
Industry (HCP, 2017)	• With the exception of the phosphate sector in the southern part of Khourigba Province, industrial activity in the Bouregreg Basin is minimal, primarily consisting of agro-food, textile and leather-related industries. The basin accounts for only 7% of national industrial units and contributes a mere 2.5% to national industrial production and exports • It attracts just 3% of Morocco's industrial investments, with even lower percentages in the upstream area of the SMBA dam • The Oulmes Mineral Waters Company is a key player in the region, utilizing the thermal springs of Lalla Haya (Aguennoun Wadi, Tarmilat Plateau and Oulmes circle) to produce Oulmes sparkling mineral water

Tourism (PDAIRE-ABHBC, 2019)	• Ecotourism, outdoor sports, and activities such as hiking, hunting, fishing, and rural tourism are prominent in the study area, particularly in the provinces of Khémisset and Khénifra • The cultural heritage of the Zairs, Zemmours and Zayans communities, along with Moussems and cultural festivals, offers significant potential for the development of cultural tourism • The Bouregreg Basin's proximity to Rabat-Salé and Casablanca, enhances its attractiveness for tourism development • The potential for cultural tourism aligns well with the objectives outlines in the new tourism development roadmap for 2023-2026, which aims to attract 17 million tourists and secure investments exceeding 6 billion DH
Mines and quarries (PDAIRE-ABHBC, 2019)	• Khénifra is renowned for the exploitation of diverse mineral deposits, including barite, lead, zinc, fluorite, iron, antimony, silver, copper and manganese, primarily managed by CMT (Campagne Minière de Tiouissit) • There are 259 active quarries in the Beni Mellal-Khénifra region, which produce construction materials as well as raw materials for pottery, bricks and marble • Khénifra and Khouribga provinces host over 192 quarry operations, making a significant contribution to the region's mineral extraction activities • In the Rabat-Salé-Kénitra region, Khémisset province alone accounts for more than 55% of the total quarries, underscoring its critical role in mineral resource extraction • There are 150 quarries in the action areas of the Chaouia Hydraulic Basin Agency (ABHCB), further emphasizing the region's substantial involvement in quarry operations

Methodology

Context Analysis

The regions of Central and West Asia, as well as North Africa (CWANA), are facing unsustainable pressure on natural resources due to rapidly growing populations and rising prosperity levels. The increasing demand for water, land, food, and energy – combined with climate change, intersectoral competition and urbanization – is exacerbating long-standing water scarcity problems in the region (World Bank, 2018). Economic disparities further encourage short-term approaches to production and consumption, undermining long-term sustainability. The limitations and shortages of natural resources could lead to social and political instability, geopolitical conflicts and irreversible environmental damage.

According to the World Bank (2018), fragility is now a prominent reality in several CWANA countries. This fragility encompasses multiple dimensions, including armed conflict, migration, economic and political instability, the erosion of the social contract and increased pressure on natural resources.

According to the World Economic Forum (WEF, 2015), the region is most unprepared for several significant risks. The most critical risk is the water crisis, followed by severe social instability, state collapse and conflict between states. These risks are closely connected to fragile situations. The WEF survey highlights the seriousness of these challenges, emphasizing that water crises and fragility pose existential threats to the well-being and prosperity of millions in the region.

The water crisis in CWANA may exacerbate this fragility. In recent decades, countries in the region have faced significant challenges in managing their water resources and providing adequate water services for irrigation, domestic and industrial purposes. The interconnected nature of water, land, food, energy, biodiversity and climate, emphasizes the importance of minimizing trade-offs, exploring synergies and

suggesting actions to influence behaviors related to the nexus. This involves engaging, empowering and implementing strategies at the community level to encourage local actors who rely on primary resources to adopt more sustainable patterns of consumption.

The primary objective of the current study, as well as the broader Fragility to Resilience – Central & West Asia and North Africa (F2R-CWANA) initiative, is to promote action by offering evidence-based policies and innovative solutions, exploring synergies and enabling the transition from fragility to a more resilient future in targeted basins and watersheds.

The CGIAR System Organization’s (CGIAR) F2R-CWANA initiative aims to respond to the climate, nutrition and agrifood challenges most affecting the CWANA region by applying, scaling and supporting effective, resilience-focused solutions, reducing fragility and conflict, and empowering all stakeholders for change, while minimizing and mitigating any trade-offs. Work package 4 of F2R-CWANA: “Integrated Food, Land, Water and Energy Systems for Climate Resilient Landscapes,” under which this analysis has been developed, aims to identify the limits to growth and improve the long-term potential for sustainable livelihoods. This will be achieved by strengthening inclusive policies and governance for management across the food-land-water-energy nexus.

Objectives of the Current Analysis

This analysis examines the climate fragility of water, land and agrifood systems within the Bouregreg watershed, with additional consideration of energy, biodiversity and community systems. The primary objective is to assess the characteristics and spatial-temporal distribution of fragility in these systems under climate-related hazards in current and projected future scenarios. Utilizing an inclusive and scientific methodology, the analysis provides recommendations for collaboratively identified resilience strategies and targeted investments for implementation.

Work Packages and Study Activities

Figure 9 showcases the structure of the study, outlining the three work packages (WPs) along with the corresponding tasks assigned to each component:

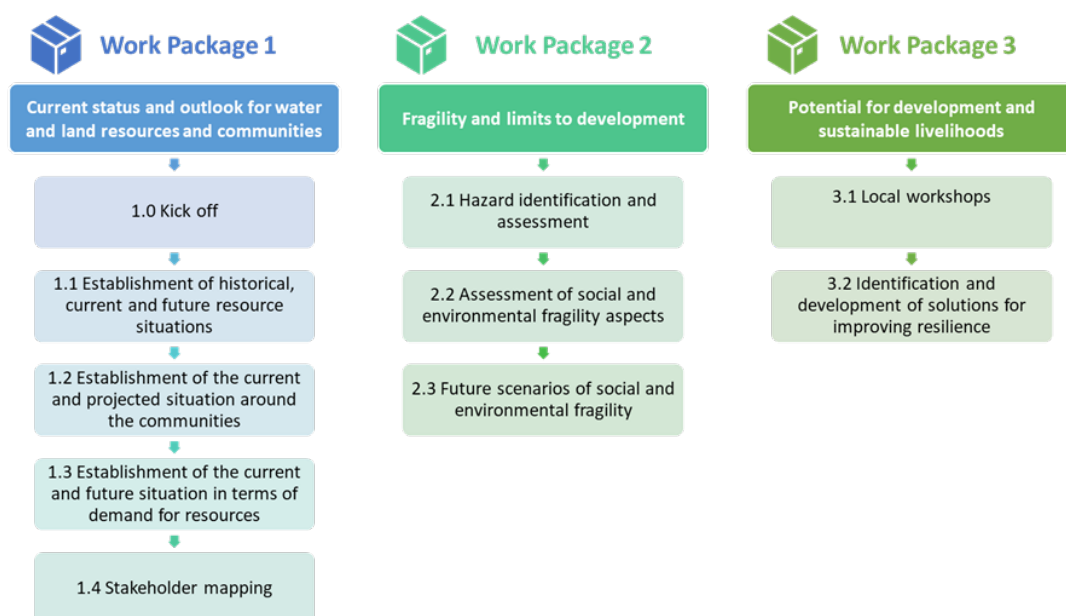


Figure 9. Breakdown of the study Work Packages

Source: Author’s creation

Core Elements of the Global Approach

A climate or water risk is defined by the interaction between three components, as presented in Figure 10 (IPCC, 2014):

- **Climatic hazard:** The specific climate-related phenomena that may pose risks.
- **Exposure:** The degree to which populations, environments and activities within a territory are subjected to this hazard.
- **Vulnerability:** The susceptibility of these populations, environments and activities to the impacts of climatic hazards.



Figure 10. Risk diagram illustrating the three components: hazard, exposure and vulnerability

Source: Modified from IPCC, 2014

Risk arises from the interaction between a potential hazard and the vulnerability of the exposed environment.

The overall methodology used to analyze the three components of risk - hazard, exposure and vulnerability - is illustrated in Figure 11.

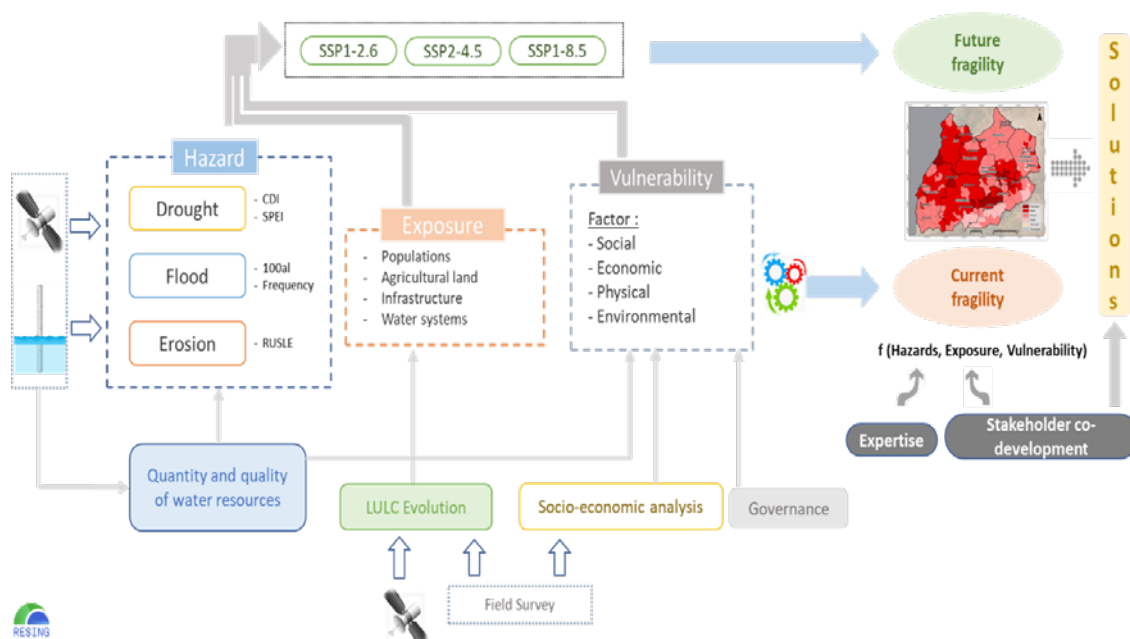


Figure 11. Overall framework for analyzing fragility in the Bouregreg Basin

Source: IWMI

The composite fragility of each commune in the Bouregreg Basin was assessed by aggregating impact-specific risks. However, the distribution of potential fragility differs across the basin due to varying spatial patterns of hazards and exposed elements. For instance, riverine floods are concentrated near major riverbeds, whereas drought can affect the entire basin to different extents.

Figure 12 below provides a schematic representation of the methodology used to evaluate fragility to hazards in the Bouregreg Basin region.

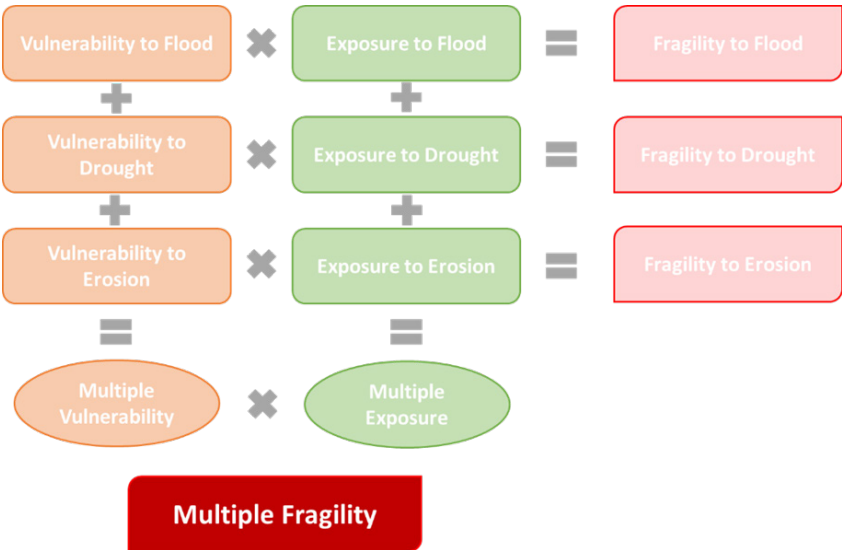


Figure 12. Methodology employed to evaluate fragility
Source: Author’s creation

A "fragility-matrix" approach combines vulnerability and exposure scores to conduct a comprehensive risk assessment. Initially designed for evaluating probability and severity, this method has been adapted to incorporate combinations of vulnerability and exposure. Risk categories – very low to very high – are assigned based on predetermined thresholds. According to the IPCC’s Fifth Assessment Report, a lack of exposure or vulnerability signifies the absence of risk.

The resulting categories of exposure and vulnerability are combined using a defined risk matrix, as detailed in Figure 13.

EXPOSURE	Very High	Moderate	High	High	Very high	Very high
	High	Low	Moderate	Moderate	High	Very high
	Moderate	Low	Moderate	Moderate	Moderate	High
	Low	Very low	Low	Moderate	Moderate	High
	Very Low	Very low	Very low	Low	Low	Moderate
		Very Low	Low	Moderate	High	Very High
		VULNERABILITY				

Figure 13. Risk matrix integrating exposure and vulnerability categories
Source: Author’s creation

Participatory Process

The Global Approach

This study placed special emphasis on the participatory process. An operational and effective framework for dialogue and collaboration was established to support Moroccan regional and local institutions, as well as local communities and their representatives, in analyzing the fragility of these systems within the Bouregreg watershed and identifying its limitations and development potential.

This multi-stakeholder (Figure 14) multi-level consultation process was conducted concurrently with the modeling and estimations, enabling the integration of localized elements and contextual parameters into the studies while gradually validating the results of the technical analyses.

Two processes were carried out in parallel, with converging and interdependent objectives, utilizing various types of participatory workshops:

- **Regional working group:** Consisting of representatives from various national and regional institutions, as well as local community members, the main objective of the regional working group was to establish common references, foster a shared understanding of the challenges facing the region and facilitate exchanges regarding the limitations and development potential of the Bouregreg watershed. This dialogue was enhanced by both the outcomes of local discussions and the technical and scientific expertise provided by the consulting team.

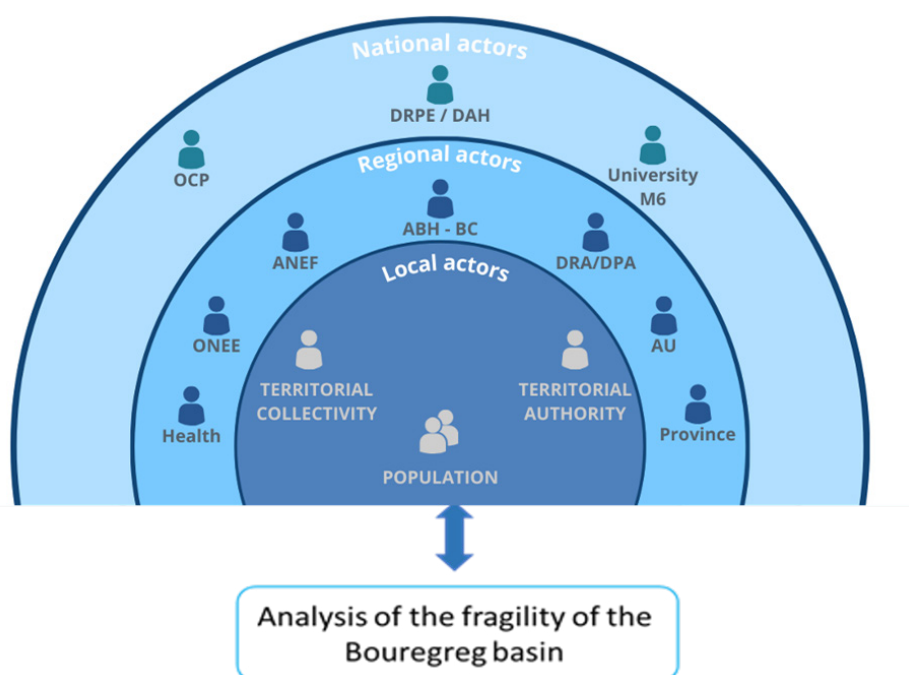


Figure 14. Actors involved in the participatory study process. *Source:* IWMI

- **Local stakeholders:** In each of the identified hotspots, local stakeholders became engaged in the process. Their participation not only validated the work but also contributed valuable insights for the regional working group's discussions on the most commonly experienced hazards, the impacts observed and the needs that must be addressed to mitigate these impacts.

Overview of the participatory process

The diagram below (Figure 15) illustrates the key stages of the multi-stakeholder, multi-scale participatory process implemented as part of the project.

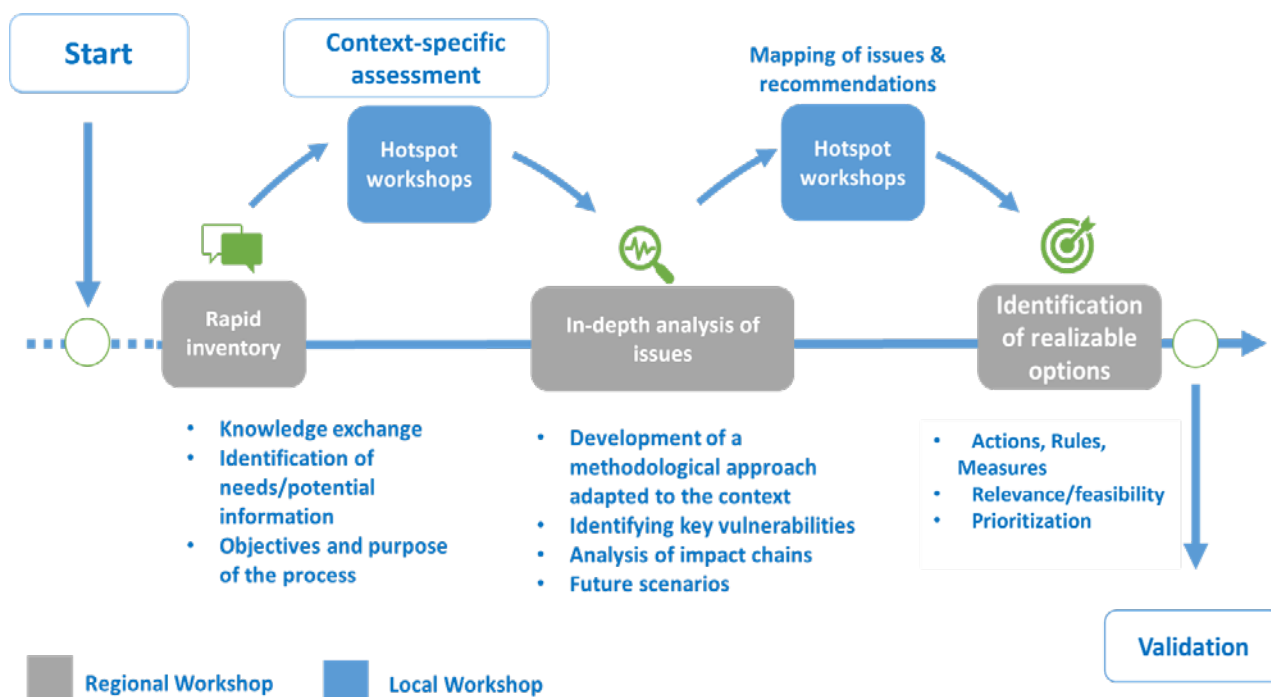


Figure 15. Stages of the multi-stakeholder, multi-scale participatory process implemented as part of the project. *Source:* IWMI

Regional Workshop for Rapid Inventory

The primary goal of the first workshop was to conduct a rapid assessment of the situation, enabling participants to collaboratively build a collective understanding that included all categories of stakeholders and their knowledge of hazards and impacts within the watershed. The workshop also aimed to explore specific issues related to the target groups, identify measures to address these challenges, examine existing studies on relevant topics in the area and pinpoint information gaps that need to be addressed.

The initial tool employed during the workshop was participatory mapping. Participants used colored sticky notes to document the impacts of identified hazards on the overall ecosystem, including the environment, economy, society, housing and infrastructure. This exercise also informed the consultant's team planning for field visits and surveys as part of the study.

After the plenary mapping exercise, participants formed three sub-groups, each focusing on drought, flooding, or erosion (Figure 16). Within these groups, they engaged in discussions addressing the following questions:

- Who is most affected?
- What measures and operational procedures are currently in place or underway to address these issues?
- What studies exist on the subject and within the area?
- What additional information, if any, is required?

This work established an initial information base to guide the consultant team in the document collection process and to identify unexamined aspects that could be incorporated into the scope of the current study.



Figure 16. First meeting of the regional working group. *Source:* RESING

Local Workshops for Context-Specific Assessment

Following the initial regional workshop, the consultant team conducted field visits and organized introductory meetings with local stakeholders. Two distinct tools were employed to facilitate dialogue: questionnaires designed to survey eight communes in the area and a custom card game (Figure 17) to foster interaction with the local community.

The questionnaires were primarily focused on gathering insights into how local authorities assess risks within their communes and the degree of exposure to these risks.

Key aspects covered in the questionnaire included:

- Hazards encountered in the commune, along with their frequency, intensity and impact
- Historical occurrences of hazards
- Identification of risk zones
- Level of vulnerability
- Factors contributing to vulnerability factors
- Existing protection and prevention measures
- Community preparedness
- The role of citizens in managing risks and hazards
- Involvement of other departments and stakeholders

The goal of the card game was to gather the local population's assessment of their own vulnerability to climate change in an engaging and enjoyable way.



Figure 17. Card game used during field visits with various stakeholders – including traders, farmers and children – to assess fragility related to climate change. *Source:* RESING

Regional Workshop for In-Depth Issue Analysis and Participatory Prospective Simulation

The second meeting with the regional group spanned three days (Figure 18). These “Enabling and Co-Production Days” aimed to build upon the results of the first workshop, enriched by the context-specific assessment conducted by the consultant’s team at the local level. The objective was to thoroughly analyze the impacts of climate change in the Bouregreg Basin, including understanding the interconnectedness of vulnerability factors and their implications for the region’s present and future.

The main stages of the project were as follows:

- i. The collaborative development of a cause-and-effect model to examine the relationships and causal connections between hazards, resources and populations within the Bouregreg Basin. To understand these complex interactions, the consultant team asked the following questions: What is the problem? What are its effects on the biophysical environment? Who is affected by these effects on the biophysical environment? In what way is this specific stakeholder affected?
- ii. An in-depth analysis of the stakeholders affected by each hazard, based on their level of involvement and their capacity for action (strong/weak) in addressing the hazard.
- iii. An examination of the impact chains associated with climate change, with a focus on identifying vulnerability factors and their interdependence.
- iv. A weighting (or prioritization) of the identified vulnerability factors for each, through a voting process which includes defining the vulnerability indicators selected for technical studies and calculating the overall weight assigned to each hazard based on cumulative votes.
- v. The co-development of prospective scenarios regarding future changes in vulnerability factors, drawing on the expertise and knowledge of participants in the study area. These scenarios were developed considering three climate change pathways outlined in the IPCC’s 6th Assessment Report (AR6): SSP 5-8.5, SSP 1-2.6, SSP 2-4.5.



Figure 18. Highlights from three days of empowerment and co-production during the second meeting of the regional working group. *Source:* IWMI

Local Workshops for Problem Mapping and Solution Identification

The second series of local workshops aimed to compare and contextualize the assessments carried out by the regional working group and the consultant team at the commune level. Additionally, these workshops gathered proposals for recommendations that are particularly actionable for the local population and institutions.

Communities selected for the workshops were based on the results of fragility analyses, prioritizing areas identified as hotspots. The communities visited and involved in this series of local workshops were:

- Aguelmous
- Ezzhiliga
- Maaziz

Using satellite imagery as shown in the Figure 19 below, local community representatives and civil society members documented the various impacts observed in their area and subsequently proposed operational recommendations to address these issues.

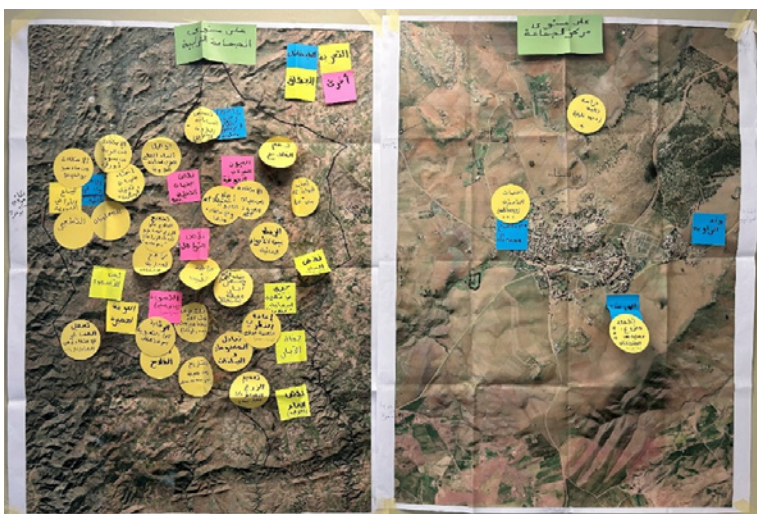


Figure 19. Hotspots workshops. *Source:* RESING

Regional Workshop to Identify and Develop Solutions to Improve Resilience

The third and final meeting of the regional working group concentrated on identifying and formulating solutions to enhance the resilience of the Bouregreg Basin.

The workshop began with a presentation of the preliminary findings from technical analyses assessing current and future fragility. This was followed by sub-group work aimed at analyzing and validating these preliminary results.

To refine the diagnosis and outline strategic directions for strengthening the Bouregreg Basin's resilience to climate change, participants explored the various dimensions of potential solutions, including governance, capacity building, technical and technological interventions (Figure 20).

For each dimension and hazard, participants conducted a SWOT analysis to assess the existing system's strengths and weaknesses, as well as the opportunities and threats it faces.

After conducting SWOT analyses for each of the climate change hazards (flooding, drought and erosion), participants developed operational recommendations aimed at enhancing resilience. The work was organized by solution category: governance, capacity building and technical/technological solutions. The identified solutions were then prioritized based on the scale of impact/effort to evaluate their relevance and feasibility.

At the end of the workshop, the proposed solutions were compared with those generated from the local hotspot workshops conducted in three communes, with the goal of integrating and consolidating the recommendations.



Figure 20. Third meeting of the regional working group. *Source:* IWMI

Assessment of Water and Land Resources

Land Use

In this study, the characterization and mapping of land use in the Bouregreg Basin were developed based on the following sources:

- Vegetation maps from previous studies and projects, primarily those produced by the provincial water and forestry departments
- The land use map generated from the study “Elaboration of the Drought Management Plan at the Communal Level in the Action Zone of the Bouregreg and Chaouia Hydraulic Basin Agency”
- Land use maps derived from scientific research, particularly studies focusing on erosive processes, soil vulnerability and agricultural practices
- Land use maps obtained from the WAPOR and ESRI platforms
- Sentinel-2 satellite imagery with a resolution of 10 meters, captured in July 2015 and August 2022, which enabled the differentiation of various land use themes

The following land use themes have been identified and depicted on the maps:

- **Vegetation cover:** this includes irrigated agricultural land that lines the banks of some rivers in the Bouregreg Basin and extends to new agricultural developments within the area. It is characterized by forests that dominate both the mountainous regions and the lower downstream areas of the basin
- **Water bodies:** represented solely by the Sidi Mohamed ben Abdellah (SMBA) dam, located in the lower section of the basin
- **Built-up areas:** primarily consisting of the main urban centers in the basin, such as M'irt and Maaziz
- **Uncultivated areas,** including pasture and rainfed land. Uncultivated areas constitute the primary landscape in the study area. They are widespread, with interruptions from other land uses. Rainfed areas, where cereal farming occurs, are the most dominant. The development of pastureland in these areas and rainfed agriculture heavily rely on climatic conditions, specifically annual rainfall.

The analysis of land use maps from 2015 and 2022 reveals that most of the Bouregreg watershed consists of uncultivated land, heightening the risks of erosion due to various factors. The remaining areas are allocated to urban areas, forests and irrigated agricultural land.

These changes in land use classes can be summarized as follows:

Vegetation Cover Degradation

Statistical data captured by satellite imagery indicates a significant decline in vegetation cover by 10% between 2015 and 2022. This degradation can primarily be attributed to the following factors:

- **Rainfall Deficit:** A lack of sufficient rainfall has adversely affected forest ecosystems, particularly in shrubland areas
- **Deforestation:** The conversion of wooded areas into agricultural land, pasture or urban developments has led to a loss of forest cover
- **Forest Exploitation:** The illegal harvesting of timber for various purposes has further depleted forest resources
- **Overgrazing:** Excessive grazing of livestock and prolonged grazing periods in certain areas have resulted in the overexploitation of plant resources and exacerbated erosion.

Diminishing Irrigated Zones

The cultivated areas, scattered within the irrigated zones, are primarily located in the central and downstream regions of the Bouregreg Basin. A statistical analysis of remote sensing data reveals a 20% decline in cultivated areas between 2015 and 2022, which can be largely attributed to the annual rainfall deficit observed over the last three years (Figure 21).

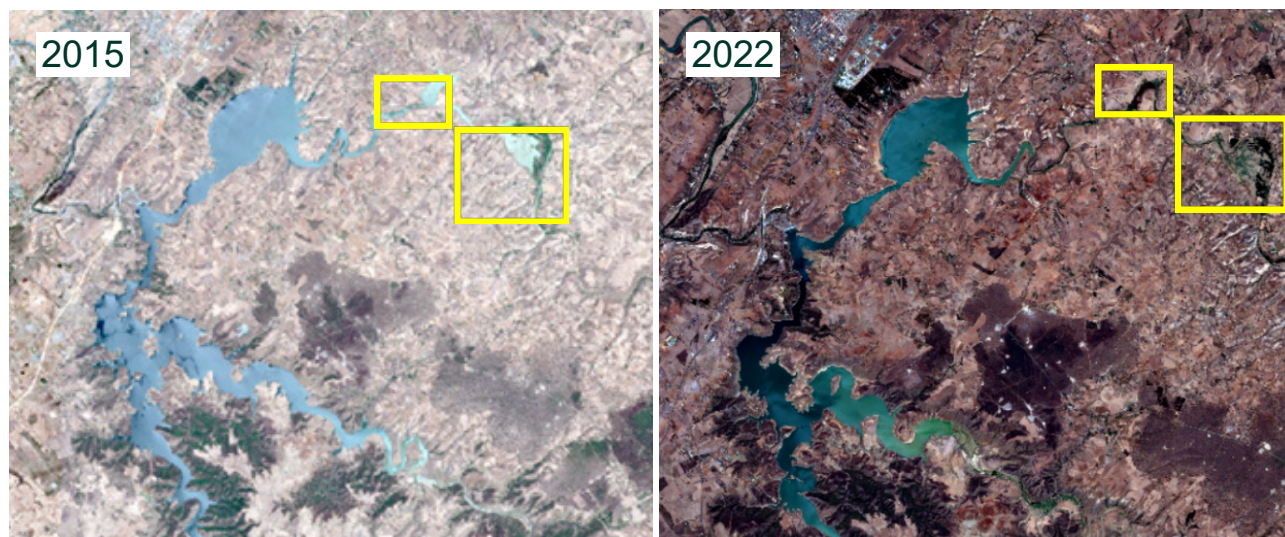


Figure 21. Size of the Sidi Mohamed Ben Abdellah dam in 2015 and 2022. *Source:* Author's creation

Fallow and Grazing Land

A comparison of the land use maps from 2015 and 2022 (Figure 22) reveals that a significant portion of the Bouregreg Basin is occupied by fallow land and rangeland. In 2022, this land category accounted for 74% of the basin's total area, up from just 71% in 2015.

This increase of approximately 3% may be due to deforestation and expansion of fallow land, among other factors.

Water Bodies

The Bouregreg Basin experienced a 42% reduction in water bodies, as illustrated by the above satellite images and the land use maps.

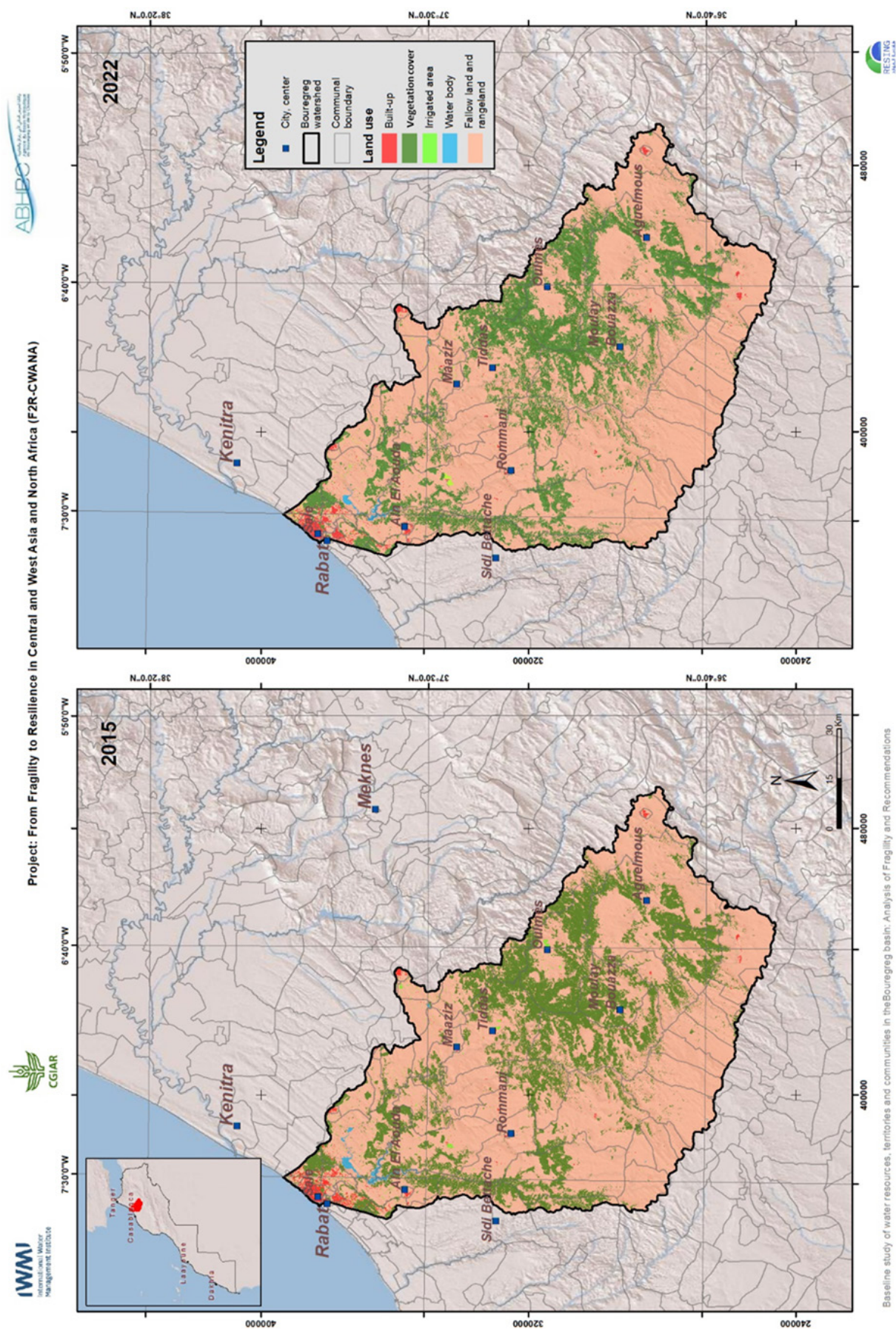


Figure 22. Land use maps of the Bouregreg Basin in 2015 and 2022. Source: IWMI

Water Resources

The analysis of the collected data, combined with climatic, hydrological and hydrogeological information, has allowed us to assess the status of water resources in the Bouregreg Basin.

Surface Water Assessment

The Bouregreg watershed encompasses an area of 10,597 km² and consists of two primary rivers: the Bouregreg River, which dominates a sub-watershed of 4,199 km² and the Grou River, with a sub-watershed of 5,617 km². These rivers converge at the SMBA dam, located 18 km from the Atlantic Ocean (PDAIRE-ABHBC, 2019).

The surface water measurement network in the Bouregreg Basin includes 13 rain gauge stations, of which nine are dedicated hydrometric stations.

In addition, the piezometric network consists of 30 piezometers monitoring the Sehoui water table and 20 piezometers for the Tanoubart water table. (RGPH-HCP, 2025; RGPH-HCP, 2014).

The water quality monitoring network within the Bouregreg Basin features several sampling stations along the Bouregreg Wadi and its tributaries. This network comprises ten hydrological stations and nine sampling points on the wadis and their confluences.

Precipitation and surface water analysis

The analysis of annual precipitation trends (Figure 23) indicates several exceptionally wet periods, including 1978/1979, 1995/1996, 1996/1997, 2009/2010 and 2010/2011. In contrast, the 1980s and late 1990s experienced significantly low rainfall, resulting in widespread drought throughout the study area.

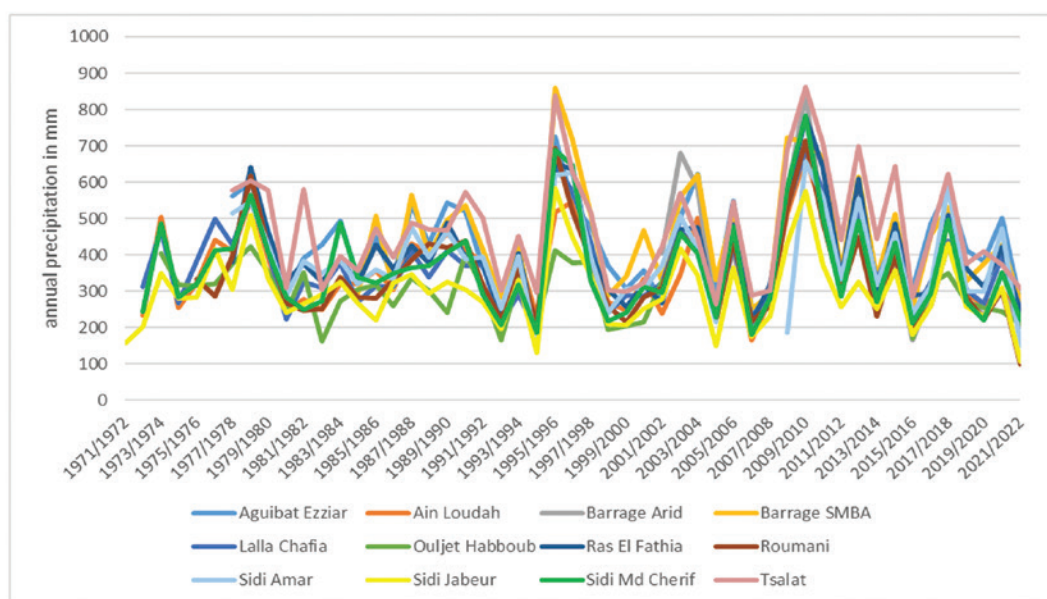


Figure 23. Changes in average annual precipitation 1970-2022. Source: IWMI (Data ABHBC)

Average annual flows at the monitoring stations (Figure 24) range from 0.05 to 40.3 m³/s, with the Ouljet Habboub station recording the highest flows, often exceeding 4 m³/s. Maximum flow values were observed in 2009 at several stations, while the lowest flows occurred in 2004. Overall, average flows typically fall between 0.4 and 2.4 m³/s, with median values ranging from 0.3 and 1.4 m³/s (ABHBC, 2022).

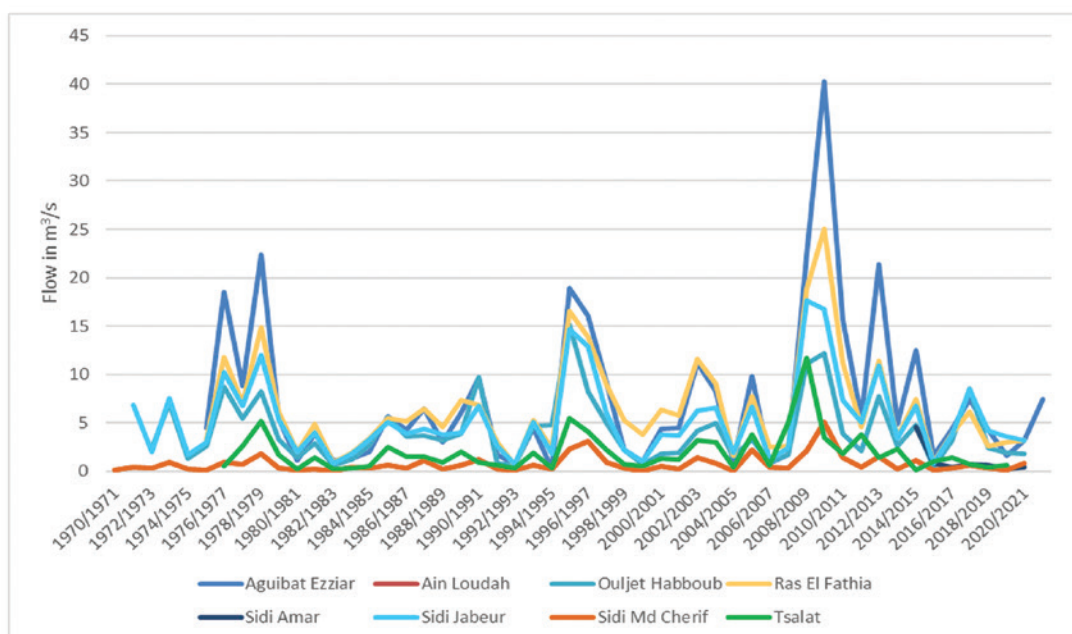


Figure 24. Changes in average annual flows 1970-2022. *Source:* IWMI (Data ABHBC)

Surface water quality (2022 status)

The parameters assessed for surface water quality include conductivity, BDO5, sodium (Na⁺), chloride (Cl⁻), nitrates, phosphorus and total coliforms. The Lalla Chafia station on the Bouregreg Wadi shows a high conductivity level of 6,000 $\mu\text{S}/\text{cm}$. In contrast, the Rass El Fathia station, located upstream of the SMBA dam, exhibits the lowest conductivity during the dry season at 422 $\mu\text{S}/\text{cm}$. During the wet season, the Ouljat Habboub station shows a 475 $\mu\text{S}/\text{cm}$ conductivity. BDO5 values vary significantly between seasons and locations, with the highest measurement recorded at the Tanoubert Wadi (ABHBC, 2022). Total phosphorus levels fluctuate throughout the year, reaching peak concentrations at Tanoubert Wadi during the wet season. Nitrate levels also display seasonal and spatial variations, with elevated concentrations observed in the Akrach Wadi during wet periods. Additionally, both total and fecal coliforms show high readings at specific points.

Surface water mobilization

The study area is currently supported by one large dam (SMBA), which meets the drinking water needs of Rabat-Salé, Mohammedia, northern Casablanca and surrounding communities. In addition to this primary dam, there are seven small dams of local significance, with the recently commissioned large Tiddas dam.

Planned dams for the area include Khanoussa and Sidi Omar in the Khémisset province, as well as Sidi Amer in the Khénifra province, with a combined capacity of 117.7 Mm³ (ABHBC, 2022).

Sebou and Bouregreg Basin interconnection project

The water transfer project between the Sebou and Bouregreg Basins, launched in 2023 with a budget of 6 billion DH, aims to interconnect the two basins to offset the Bouregreg Basin's water deficit with the Sebou Basin's water surplus. This project will increase the drinking water supply to Rabat and communities along the coast between Rabat and Casablanca. As part of the National Drinking Water Supply and Irrigation Program (PNAEPI) for 2020-2027, the project connects the Garde Sebou and Sidi Mohamed Ben Abdellah dams. Key infrastructure components include a water intake system, 66.5 km of steel pipelines, two pumping stations and a regulation facility with a 5,000 m³ reservoir (Fédération Nationale du Bâtiment et des Travaux Publics, 2024).

Groundwater Assessment

The Bouregreg watershed is characterized by a lack of geological bedrock that can support substantial water tables. Three distinct hydrogeological units have been identified within the study area: the Témara, Sehoui and Tanoubart aquifers. This complex geological configuration presents challenges for effective water resource management in the region, highlighting the need for an integrated approach to address these hydrogeological issues effectively.

Témara aquifer

The Témara aquifer serves as a crucial source of drinking water for the town of Témara and is also utilized for irrigation purposes. However, overexploitation has resulted in a significant decline in water levels. The aquifer is primarily recharged through rainfall infiltration, with an annual recharge of approximately 16 Mm³. In contrast, abstractions for agricultural and drinking water purposes total 16.5 Mm³ per year, contributing to outflows from the aquifer. Water quality in the Témara aquifer is generally poor to very poor, primarily due to elevated nitrate concentrations (PDAIRE-ABHBC, 2019).

Sehoui aquifer

The Sehoui aquifer, which spans an area of 200 km² and is an extension of the Maamora forest, has limited potential for local development. It has annual outflows of approximately 10 Mm³, mainly used for agriculture and drinking water. The aquifer's low transmissivity, attributed to the predominance of marly rock, leads to fluctuating piezometric levels which have declined since 2010. The aquifer is replenished by rainfall infiltration at a rate of 10 Mm³ per year; however, its water quality is compromised by the presence of nitrates (PDAIRE-ABHBC, 2019).

Tanoubart aquifer

The Tanoubart aquifer, located in the Mâaziz region, is fed by the Tanoubart Wadi and serves as a key development lever for the area. It spans approximately 15 km² and comprises Quaternary and Miocene rocks, primarily alluvium and sand. Groundwater recharge is influenced by the hydrological cycle of the wadi, with annual infiltrations estimated at 2.7 Mm³ and irrigation return flows of 0.4 Mm³. Annual outflows estimated at 2.6 Mm³, are mainly used for agriculture and irrigation. In terms of water quality, electrical conductivity varies and the presence of salinity and nitrates results in average to poor water quality, based on analyses conducted in 2022 (PDAIRE-ABHBC, 2019).

Future Evolution of Natural Resources

Impact of Climate Change on Surface Waters

Considering the impacts of climate change on surface water resources, average basin inflows are projected to decrease from 654 Mm³ per year to 523 Mm³ per year. This decline accounts for a 10% reduction in rainfall, translating to an estimated 20% reduction in runoff (PDAIRE-ABHBC, 2019).

Future Water Requirements

The drinking water needs of urban and rural areas in the Bouregreg Basin have been assessed using ONEE-Eau criteria, considering all communes and projecting needs up to 2050. Variable growth rates were incorporated, applying a rate of 1% for communes experiencing negative growth. The total population, estimated at 829,284 in 2014 (RGPH-HCP, 2014), is projected to reach approximately 1,438,840 by 2050, with an average annual increase of 16,932.

As of 2023, urban drinking water requirements (Office National de l'Électricité et de l'Eau Potable, 2014)) were recorded at 404 l/s, which is expected to rise to 470 l/s by 2050 due to rapid growth, particularly in the commune of Ain El Aouda. Meanwhile, water consumption in rural areas was 10,687 m³/d in 2023 and is

anticipated to increase to around 24,955 m³/d by 2050. This translates to average production requirements of 163 l/s in 2023, growing to 380 l/s in 2050.

Irrigation expansion projects associated with the new dam developments in the Bouregreg Basin will cover a total area of 20,300 hectares, necessitating an additional water requirement of 131.3 Mm³ per year, which equates to an allocation of 6,400 m³/ha/year (Ministère de l'Agriculture et de la Pêche Maritime – Direction de l'Irrigation et de l'Aménagement de l'Espace Agricole-DIAEA, 2013).

Assuming a 10% increase in irrigation water demand, the future water requirements for irrigation water within irrigation perimeters are projected to rise from 71.9 Mm³ per year without climate change, to 79.1 Mm³ per year when accounting for climate change impacts.

Wastewater Potential in the Bouregreg Basin

The wastewater potential in 2020 (RGPH-HCP, 2014) in the Bouregreg Basin is approximately 9.7 Mm³, projected to increase to around 18 Mm³ per year by 2050, reflecting an annual growth of about 0.27 Mm³.

This potential stresses the importance of promoting the reuse of treated wastewater for irrigation, especially in light of increasing pressure on conventional water resources amid growing concerns about drought and water scarcity, which are likely to worsen in the future due to climate change.

The anticipated rise in wastewater volume of 18 Mm³ by 2050 (Projections made by RESING) presents significant opportunities for both agriculture and industry through alternative water use strategies:

- o Agriculture: Treated wastewater can be repurposed for irrigation, reducing dependence on freshwater sources. When properly treated, this recycled water provides a reliable and sustainable option for crop irrigation. Farmers can mitigate the effects of water shortages, enhance crop yields and ensure food security by utilizing treated wastewater.
- o Irrigation of Urban Green Spaces: Treated wastewater can also be used to irrigate parks, public gardens, sports fields and other urban green areas in cities and communities such as Maaziz, Roumani, Oulmès, and Zehiliga.

Basin Resource Management and Governance

Governance of Natural Resources in Morocco

Governance of Water Resources

Water Law 36-15, which revises Law 10-95 – Morocco's initial organic water law from 1996 – establishes the present legal framework for national water policy, aligning with the principles set forth in the 2011 constitution. This law represents a significant legislative reform that addresses dysfunctions arising from past practices such as intensive resource exploitation and pollution. These factors collectively characterize the state of water resources at national, regional and local levels.

The law also prioritizes resilience to the impacts of climate change to safeguard water resources against extreme weather events, such as droughts, water scarcity, floods and hail. This focus on climate resilience is particularly relevant to the water resource situation in the Bouregreg Basin.

Water resource planning in Morocco is based on a participatory approach that integrates the National Water Plan (PNE) with the guidelines established in Law 36-15 on water, the Master Plans for Integrated Water

Resource Development (PDAIRE), and the Local Water Management Plans outlined in this legislation. Chapter VII (Articles 90 to 95) of Law 36-15 identifies the following key water planning documents:

- National Water Plan (PNE)
- Master Plan for Integrated Water Resources Development (PDAIRE)
- Local Water Management Plans (PLGE)
- Participatory Management Plans (PGE)

Additionally, the Water Law specifies the bodies responsible for water management at the river basin level. Chapter VI (Articles 78 to 89) defines the entities overseeing water administration as follows:

- Superior Council for Water and Climate (CSEC)
- Water Basin Council (CBH)
- Provincial Water Commissions (CPE)
- Water Committees
- Technical Committee of the Hydraulic Basin Council
- Flood monitoring and management committees

In addition to these bodies, water basin agencies are administered by a board of directors chaired by the minister responsible for the water department, with meetings held twice a year.

Agricultural Policy: From Green Morocco Plan to Green Generation Strategy

The agricultural plans for the Rabat-Salé-Kenitra, Béni Mellal-Khénifra and Casablanca-Settat regions, developed in 2008-2009 as part of the Green Morocco Plan strategy, deployed 120 projects for Pillar I – related to modern, high value-added agriculture – and 150 projects for Pillar II on solidarity-based agriculture. The total investment amounted to approximately 40 billion (b) DH, consisting of 18b DH in state contributions and 22b DH in private investment (Ministère de l'Agriculture, de la Pêche Maritime, du Développement Rural et des Eaux et Forêts, 2020).

The Rabat-Salé-Kénitra Regional Agricultural Plan (PAR) required an investment of 15b DH, with 52% originating from public funds and 48% from private sources. This investment contributed to enhancing productivity in the agricultural sector and generated about ten million working days between 2009 and 2019. Meanwhile, the Béni Mellal-Khenifra RAP identified 110 projects (48 under Pillar I and 62 under Pillar II) with a total investment of 13.5B DH.

The regional iterations of the new agricultural strategy, Green Generation 2020-2030, focuses on the following key areas of intervention:

- Encouraging the emergence of a new farming middle class
- Encouraging agricultural entrepreneurship among youth
- Deploying a new generation of professional agricultural organizations
- Establishing new agricultural advisory and support mechanisms
- Consolidating the agricultural production sectors
- Developing and managing rangelands and 'transhumance' practices

Energy Policy: Challenges and Opportunities

Morocco's energy policy aims to transition to sustainable sources but faces several challenges. The target for renewable electricity production set for 2020 at 42% has not been achieved, despite investments of \$550 million in various projects (International Trade Administration, 2025). Dependence on coal and energy imports, which account for 65% of total energy consumption, presents a significant challenge. Nevertheless, progress is being made with introducing natural gas and promoting renewable energies through Law 13-09,

which offers financial incentives. Morocco is also working towards liberalizing the electricity grid to encourage private production, particularly of solar energy.

However, long-term contracts with energy companies will limit the country's ability to reduce its reliance on coal until 2044. Morocco is exploring biomass to diversify its energy sources, particularly in the Bouregreg Basin, with ambitious integration targets of 25 TWh/year (Ministry of Energy Transition and Sustainable Development, 2021). Despite having general legal frameworks, specific guidelines for biomass utilization are lacking.

Overall, Morocco's energy policy is progressing through investment in renewable energy and sector liberalization. However, challenges persist, particularly the dependence on coal and imports, which affect the Bouregreg Basin and the nation as a whole.

Governance of Biodiversity and Natural Systems

The governance of biodiversity and natural systems in Morocco is established through a comprehensive legal framework encompassing various aspects, including water systems, fauna, flora, forestry and environmental protection. This framework includes national legislation aimed at forest conservation, establishing national parks and protected areas, management of pastoral transhumance, species protection, water and waste, and environmental impact assessments. Furthermore, Morocco has ratified several international conventions and agreements that pertain to biodiversity conservation and protection, demonstrating its commitment to global environmental stewardship.

This governance framework has important implications for the overall governance of the Bouregreg Basin in Morocco. Like other regions in the country, the Bouregreg Basin is governed by national laws and international agreements related to biodiversity conservation and natural resource management. The various laws and conventions provide a legal basis and guidelines for managing biodiversity and natural systems within the basin. For instance, the laws concerning water management (Law n° 36-15) and waste management (Law n°28-00) are crucial in addressing water pollution and waste disposal issues and safeguarding the basin's ecosystems and biodiversity.

Furthermore, this governance framework's national strategies and programs directly affect the Bouregreg Basin. Initiatives such as the National Action Plan for Conservation and Use of Biodiversity, the National Forestry Program and the National Action Program to Combat Desertification, are instrumental in fostering the sustainable management of natural resources and ecosystems in the basin. These strategies focus on objectives such as soil protection, water regulation, biodiversity conservation and socio-economic development, aligning with efforts to preserve the Bouregreg Basin while protecting local communities.

Key Interconnections Between Water, Energy, Agriculture and Climate Change

The ecosystems described above are intrinsically interconnected, with strong interdependencies between these systems and their resources. Identifying these critical interactions, conflicting demands and potential synergies between water, energy, agriculture and ecosystems is essential for achieving long-term climate adaptation. In the Bouregreg Basin, growing pressure on natural resources is a key driver and focus. The demand for food, water and energy continues to escalate while the resources necessary for their production are limited and, in many cases, dwindling.

The Bouregreg Basin features numerous interactions and dependencies within the water-energy-agriculture-natural ecosystems nexus. These interconnections extend beyond the basin's boundaries, particularly given their role in supplying drinking water to Rabat and Casablanca. The current project to transfer water from the Sebou Basin to the SMBA dam will further complicate these interactions. The following paragraphs explore the current physical relationships among the various sectors of the nexus.

The Bouregreg Basin faces a series of interconnected challenges that affect its ecosystem, water and energy systems. Sedimentation from soil erosion, exacerbated by deforestation, alters the capacity of dams such as the

SMBA. Additionally, using wood as fuel in rural areas contributes to deforestation, negatively affecting soil quality and water run-off. Nearly 18% of Morocco's national energy supply comes from fuelwood, adding considerable pressure on forest resources.

Water plays a vital role in both hydroelectric power generation and agriculture. Fluctuating water levels directly affect electricity production in the basin's dams (Tiddas, Boukhmiss and potentially at SMBA if a hydroelectric station is established) and water availability directly impacts agriculture.

Energy is crucial for irrigation, livestock farming, and water extraction, transport and distribution. However, energy access is closely tied to water availability and management.

Climate change is directly affecting rainfall patterns in the basin, with subsequent impacts on:

- Surface water inflows from the Bouregreg Wadi and its various tributaries
- Rainfed and irrigated agriculture, which relies on water diverted from rivers and groundwater
- Water inflows to the SMBA dam, which directly influence:
 - The drinking water supplies for the coastal axis from Salé to Casablanca
 - The potential for future hydroelectricity production at the dam

Moreover, the increasing frequency and severity of extreme weather events such as droughts, heat waves, cyclones, hail, flash floods and floods are significant characteristics of the impacts of climate change.

In summary, the relationships between energy, water and natural ecosystems in the basin are complex and interdependent. Preserving these resources requires a holistic approach that accounts for the interactions among these elements to ensure the basin's sustainable development.

In the Bouregreg Basin and similarly to the other basins in the country, programs, projects and initiatives linked to the "water-energy-agriculture-natural ecosystems nexus" have not consistently adhered to policy coherence and territorial integration principles. Instead, they tend to employ a linear approach, treating each sectoral plan in isolation without meaningful coordination.

The following key inconsistencies have been identified:

- Fragmentation of policies:** there is a lack of cohesive policies within the "water-energy-agriculture-natural ecosystems nexus" sectors, along with inadequate cross-sectoral coordination mechanisms
- Implementation challenges:** difficulties have arisen in effectively implementing the current legislative and regulatory framework on the ground
- Lack of integrated governance:** there is a notable absence of collaborative governance, particularly in the areas of planning, programming and monitoring and evaluation
- No nexus approach:** this approach is not adequately integrated into the dynamics of regionalization and devolution efforts
- Weak capacity in training and innovations:** training, research and development, innovation, and public awareness are currently underdeveloped
- Insufficient environmental education:** environmental and sustainable development education is insufficiently integrated into the school curriculum and practical activities

Bouregreg Basin: Stakeholders and Water Governance Bodies

Various stakeholders intervene before, during and after hazards occur, acting within their designated responsibilities. However, in some instances, roles and intervention areas are not well delineated, which leads to overlaps or gaps in the emergency response.

An analysis of stakeholders based on their susceptibility to climate change hazards and their capacity for action (strong or weak) reveals significant involvement across different population segments. While farmers can combat erosion on a plot-by-plot basis through effective agricultural practices, the overall capacity of most other groups to cope with climate change challenges remains low. Conversely, central and external government departments generally possess strong capacities in areas pertinent to their mandates. The private sector's concern regarding climate change appears to be moderate, although some players may have considerable capacity for action.

At the basin level, two committees have been established to monitor and manage drought and flood hazards: the Provincial Water Commission and the Vigilance Committee. Additionally, joint committees are formed for specific projects, comprising, (i) the executive body (such as the watershed agency scope for floods), (ii) committee members who provide feedback and propose suggestions and (iii) a monitoring committee responsible for overseeing and evaluating the projects. Notably, there is currently no dedicated committee at the basin level focused specifically on erosion management, though this issue is addressed by the National Council for Combating Desertification (CND).

Financially, various state actors – including central services, external agencies and local authorities – contribute to service provision and infrastructure development in accordance with their budget mandates for the provision of services. Financial oversight is carried out by agencies such as the Inspectorate General of Finance, the Inspectorate of Public Administrations and civil society. To date, there is no unified fund at the basin level specifically targeting the various climate change hazards. However, at the national level, the "*Fonds de Lutte contre les effets des Catastrophes Naturelles*" (CAS-FLCN) was established under the Finance Act for the 2009 budget year, with the Minister of Interior serving as the authorizing officer. This fund is dedicated to preventing and addressing the impacts of natural disasters nationwide.

One of the main challenges facing stakeholders, is the lack of clarity regarding their specific roles and responsibilities concerning particular hazards such as drought, erosion and flooding. This ambiguity can lead to multiple entities overlapping in their efforts, resulting in wasted resources and operational confusion.

Overlapping jurisdictions can lead to inefficient resource utilization, while gaps in mission coverage may result in poorly managed areas and neglected communities. For example, several organizations may respond to the same need in a flood-prone region without coordinating their efforts. However, if these entities collaborate, they can address different complementary aspects of the problem, thereby enhancing the effectiveness of their interventions.

Bouregreg Basin: Water Governance Instruments and Tools

According to the provisions of law 36-15, any exploitation or use of the public hydraulic domain – whether for irrigation, industry, drinking water supply or hydroelectric power production – requires the payment of a fee per the conditions specified in this law. Several financial instruments have been implemented to establish effective and efficient governance of water management in the Bouregreg Basin. These instruments include pricing for drinking water and irrigation and sanitation, charges for water abstraction, discharge fees in the public hydraulic domain, and various incentives to promote water-saving techniques. The Hydraulic Basin Agency – Bouregreg Chaouia (ABHBC)'s financial resources primarily consist of state subsidies and charges associated with the use of water and wastewater resources and the public hydraulic domain.

Information and communication technology (ICT) tools currently used in Morocco's water sector have significantly improved access to data. These new technologies facilitate the measurement of hydrological parameters, enhancing the governance of water resources within the ABHBC's zone of intervention. Some of the ICT tools currently employed in the management of water resources in this area include:

- A Geographic Information System (GIS) established by ABHBC
- A monitoring and surveillance system implemented by the agency which permits regular tracking of water quality and quantity in water bodies

- A water quality information system
- A flood forecasting and warning system
- Flood risk prevention plans
- Remote sensing technologies
- A dematerialized electronic platform to manage the public hydraulic domain, known as the "Portal for Water Users"
- Hydrological modeling systems

In the Bouregreg Basin, promoting renewable water resources is essential for raising awareness among the public and stakeholders about sustainable water management. ABHBC employs various communication tools to facilitate this objective. However, the promotion and communication efforts related to water resources must be continuously integrated into a comprehensive strategy for sustainable water management in Morocco. Public education and awareness-raising are essential components in fostering participation and commitment from all sectors of society in the preservation of this vital resource.

Actions and Strategies to Strengthen Governance

Understanding the interconnections between water, energy, agriculture and natural ecosystems presents opportunities to enhance resource efficiency and foster cooperation and policy coherence across these sectors. The nexus approach can promote interdisciplinary and mutually beneficial actions, addressing the population's future needs, particularly those without adequate access to drinking water and energy. The urgency to adopt the nexus approach arises from the challenges of water scarcity, increasing food demand, rising energy consumption and the degradation of natural ecosystems.

In the Bouregreg Basin, the water sector has the potential to play a pivotal role in establishing a new balance between "development" and "environmental preservation" within the nexus framework, through the following strategies:

- At a national level, the Royal Institute for Strategic Studies (IRES) report from 2020, which examines water issues in Morocco through the nexus approach amid climate change, has highlighted several crucial actions:
 - Ensure the alignment of sectoral public policies with each other and with the National Strategy for the Environment and Sustainable Development (SNEDD) objectives.
 - Overhaul and adapt the legislative and regulatory framework governing nexus sectors by speeding up the implementation of related laws and regulations (including decrees, orders, monitoring, and the involvement of local authorities.). This should also include developing a comprehensive strategy to adapt legislative and regulatory texts in nexus sectors, while ensuring their simplicity, applicability and feasibility.
 - Reduce the number of stakeholders and overlapping responsibilities within the nexus sectors.
 - Integrate and align planning and development policies for infrastructure.
 - Include local territories in the nexus dynamic and reinforce participatory approaches by localizing the country's international commitments to combat climate change.
 - Accelerate the commitment from the state, local authorities and the private sector, towards the transition to a green economy.
 - Set up robust systems for monitoring and evaluating progress.
 - Consolidate and strengthen resource allocation for implementing nexus programs, projects and actions.
 - Promote research, development, innovation and public awareness-raising initiatives.
 - Create frameworks and protocols to strengthen communication and collaboration among stakeholders involved in nexus sectors.
- At the Bouregreg Basin level, strengthening water governance must be grounded in a nexus approach, leveraging the tools and frameworks established under Law 36-15.

The basin has several unique characteristics that should serve as foundational elements for any effective effort to enhance water governance:

- The surface water resources are primarily directed to other areas, playing a critical role in ensuring drinking water supply security
- Underground water resources are limited and not well understood, with the exception of the Tanoubart aquifer, which is located in fractured geological formations
- The basin is a pivotal component of Morocco's major North-South water transfer project
- It has recently seen the construction of several new water storage facilities, collectively capable of holding over 500 Mm³ (PDAIRE-ABHBC, 2019)

In light of Morocco's ongoing water scarcity and the recurring drought years caused by climate change, there is a compelling need to shift the paradigm and adapt economic development strategies to match available water resources rather than the opposite.

Therefore, it is crucial to move away from the previous rationale that drove the construction of new dams to generate additional demand for every resource mobilized. A thorough assessment of the growth of irrigated areas downstream from Boukhmis and Tiddas is crucial, particularly addressing:

- o Factors related to climate change and its effects on water inputs
- o When selecting crop varieties for these regions, priority should be given to their water requirements per hectare and their contribution to local and global food security. Maximizing agricultural water usage and enhancing water productivity is vital during the establishment of these areas. Appropriate irrigation techniques must be adopted, and systems put in place to monitor and control water extraction, using either scientific irrigation management or regulatory approaches. Additionally, the water pricing in these areas should accurately reflect its true value in light of scarcity, in accordance with Morocco's recent development recommendations model.
- o Scheduling the commissioning of these irrigated perimeters with the activation of the dams
- Clearly outline and establish trade-offs between irrigation water supplies, drinking water provision and hydroelectric energy production.
- Promote participatory management and ensure active engagement from users in managing these areas.
- Prioritize the sustainable management of strategic groundwater resources by utilizing surface water for drinking water supply and irrigation.
- Implement participatory and integrated management strategies for the Dayet Roumi wetland to enhance its ecological health and functionality.
- Promote the contributions of the two new dams towards generating green hydroelectric energy.
- Accelerate the establishment of a hydroelectric energy production station at the SMBA dam
- Enhance the reuse of treated wastewater in the major urban centers of the basin, tapping into the significant annual wastewater production potential of over 6 Mm³. This approach will also help preserve the surface water resources of the Bouregreg River from pollution, which is currently at concerning levels.
- Conduct an inventory and strengthen the control of various polluting activities across the basin
- Implement measures to develop the upstream areas of the basin to reduce sedimentation rates in the SMBA, in the recently commissioned Tiddas dam (2023) and the Boukhmiss dam

To ensure the sustainable use and preservation of water resources, ABHBC has established a participatory water management contract (CGP) for the Berrechid aquifer to manage these vulnerable and strategic resources within the basin effectively.

Additionally, a Local Water Management Plan can be developed for the entire Bouregreg Basin and approved by the Bouregreg Basin Council. This plan will facilitate the implementation of the provisions outlined in the Agency's PDAIRE, validated in March 2023.

Regarding managing extreme weather events, the ABHBC will implement a Water Shortage Management Plan (PGPE) and the Flood Risk Protection Plan (PPRI) in consultation with various stakeholders and the relevant provincial commissions. These plans must be approved by the ABHBC's board of directors, following recommendations from the Basin Council (CB) and the Provincial Commission (CPE). The Agency has already launched the PPRI in several areas within the ABHBC's jurisdiction. Together, these plans will improve the early management of these extreme weather events and establish alert systems to mitigate their impacts.

The ABHBC is also tasked with accelerating the establishment of its water information system, which will facilitate data exchange and ensure consistency of information among various institutional actors and users. This system will collect and organize diverse human, physical and biological data relating to the basin in an interactive and accessible manner for all stakeholders and resource users. Access to shared and scientifically validated knowledge about the functioning of the hydraulic systems in the Bouregreg Basin is essential for adequate management.

Additionally, establishing annual water accounting at the basin level will provide the ABHBC and its partners with up-to-date information on supply and demand at the level of this basin, allowing for the tracking of water resources in real-time and ensuring compliance with the provisions outlined in various planning documents.

The implementation of these governance tools will enable the following:

- Establish a shared vision of the basin's future and development, with a particular emphasis on the role and responsibilities of the basin council
- Encourage development strategies that align with the nexus approach
- Create the necessary conditions for effective communication and collaboration between institutional actors and between these actors and resource users

In summary, clarity regarding the roles and responsibilities of stakeholders is essential for effectively managing hazards such as drought, erosion and flooding. Improved coordination and communication among all involved parties will enhance prevention, management and rehabilitation efforts, ultimately mitigating negative impacts on communities and the environment.

Synthesis of the Current and Future Hazard Situation

The study and evaluation of the dynamics of climatic hazards, particularly floods, drought and erosion, constitute a comprehensive and multidimensional research initiative; its goal is to elucidate the complex mechanisms and impacts associated with these environmental phenomena, which directly contribute to the fragility of the Bouregreg systems. This research employs a vast range of methodologies, including hydrological analyses, meteorological assessments and the examination of various indicators. This holistic approach aims to understand the intricate dynamics of climatic hazards and their effects on ecosystems, communities and broader socio-economic systems.

In assessing future hazard situations, we considered projected climate change scenarios, adjusting rainfall and evaporation data based on results from 24 models corresponding to specific time horizon scenarios relevant to the Bouregreg Chaouia agency's action zone, as presented in Tables 5 and 6.

Table 5. Mean annual precipitation changes based on 24 models across different warming scenarios and time horizons

Model	2021-2040		2041-2060		2061-2080	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
MPI-ESM-MR	-18,49	-20,49	-8	-23,3	-19,44	-38,44
MPI-ESM-LR	-8,14	-16,83	-12,03	-29,56	-6,33	-42,25
inmcm4	-17,66	-13,1	-19,83	-33,3	-23,85	-38,81
MRI-CGCM3	19,66	3,14	8,13	11,86	-3,81	-5,37
bcc-csm1-1	-9,24	-19,59	-5,03	-18,26	-15,39	-32,98
NorESM1-M	2,24	4,45	-6,86	-14,9	-2,11	-36,39
MIROC5	-3,05	-5,35	-11,26	-15	-25,25	-42,57
MIROC-ESM-CHEM	-13,89	-23,16	-23,31	-27,2	-33,07	-36,73
MIROC-ESM	-23,75	-17,88	-22,28	-33,01	-32,96	-49,4
IPSL-CM5A-MR	-30,94	-26,79	-29,83	-25,41	-21,14	-37,12
IPSL-CM5A-LR	-36,58	-24,19	-32,01	-27,93	-34,66	-53,38
GFDL-ESM2M	-21,25	-26,63	-27,79	-33,64	-30,24	-49,24
GFDL-ESM2G	-17,35	-17,84	-13,16	-29,1	-11,88	-30,56
GFDL-CM3	-47,62	-38,51	-48,94	-58,93	-48,72	-64,85
CanESM2	-7,71	-12,43	-20,85	-18,87	-26,04	-28,2
CSIRO-Mk3-6-0	-4,62	-13,89	-11,6	-11,71	-16,92	-22,88
CNRM-CM5	4,3	10,41	0,43	-17,58	-7,41	-9,42
CESM1-BGC	0,59	-20,8	-16,64	-20,81	-16,95	-30,59
CCSM4	-18,14	-24,24	-23,91	-28,19	-30,73	-35,47
BNU-ESM	-21,43	-18,68	-21,9	-23,75	-26,53	-33,06
ACCESS1-0	-20,29	-55,88	-28,42	-63,86	-27,78	-68,84
CCCma	-13,45	-12,94	-23,98	-20,68	-26,18	-25,55
KNMI	-19,82	-7,98	-16,56	-20,28	-11,78	-25,61
ALADIN	-7,87	-4,33	-8,14	-15,56	-9,59	-16,14
Mean	-14	-17	-18	-25	-21	-36

Source: ABHBC and DMN

Table 6. Future change in ETR (evapotranspiration) according to THORNTHWAITE on an annual scale (in%)

Model	2021-2040		2041-2060		2061-2080	
	RCP4.5	RCP8.5	RCP4.5	RCP4.5	RCP8.5	RCP4.5
MPI-ESM-MR	7,8	10,96	11,43	15,86	14,96	31,37
MPI-ESM-LR	5,89	8,78	6,55	15,85	12,7	26,53
inmcm4	2,83	2,74	4,55	10,48	8,44	17,38
MRI-CGCM3	3,59	6,56	8,09	9,99	11,00	20,04
bcc-csm1-1	6,47	9,09	10,44	14,66	12,17	27,23
NorESM1-M	7,36	9,05	11,83	14,64	14,15	23,70
MIROC5	9,85	9,98	12,93	18,11	16,60	28,77
MIROC-ESM-CHEM	12,29	15,08	17,65	27,93	23,99	44,34
MIROC-ESM	12,29	15,08	17,65	27,93	23,99	44,34
IPSL-CM5A-MR	8,49	10,33	12,23	19,25	16,69	15,89
IPSL-CM5A-LR	8,77	8,39	14,25	19,02	32,34	34,87
GFDL-ESM2M	9,13	10,24	10,34	16,39	13,82	25,85

Continued >>>

Table 6 Continued

Model	2021-2040		2041-2060		2061-2080	
	RCP4.5	RCP8.5	RCP4.5	RCP4.5	RCP8.5	RCP4.5
GFDL-ESM2G	5,17	8,46	10,52	14,03	10,57	22,89
GFDL-CM3	16,7	16,96	23,82	31,47	30,04	50,86
CanESM2	12,35	13 ,13	17,01	23,75	21,98	36,78
CSIRO-Mk3-6-0	8,9	8,81	15,75	16,67	19,06	28,09
CNRM-CM5	5,72	5,46	8,93	12,37	10 ,34	19,98
CESM1-BGC	6,13	10,09	8,78	13,23	13,46	21,02
CCSM4	7,41	8,18	11,89	13,23	11,76	22,32
BNU-ESM	10,48	10,45	14,15	15,21	16,59	30,60
ACCESS1-0	7,79	9,55	11,25	15,44	16,76	28,15
ALADIN	5,93	6,20	9,39	13,18	10,62	21,30
CCCma	11,61	14,58	16,72	25,25	24,01	39,43
KNMI	17,34	8,66	10,80	14,26	13,18	24,23
Mean (%)	8,8	9,7	12,4	17,4	16,9	28,6

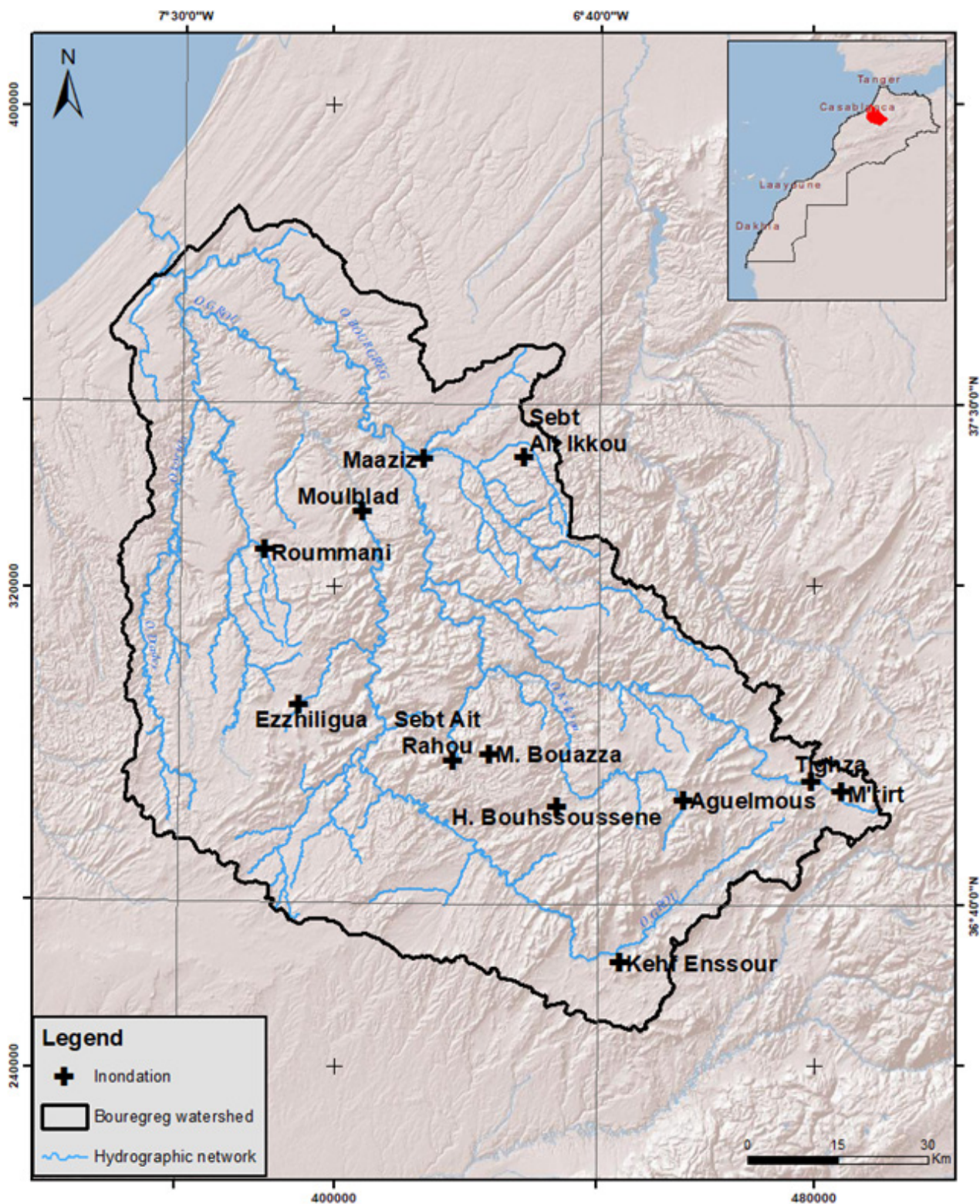
Source: ABHBC and DMN

Flood Analysis

Flooding is one of the most damaging hazards in the Bouregreg watershed and its frequency is likely to increase due to current and future climate change. To assess the impact of flooding at the basin level, two approaches were employed:

- **Hydraulic approach:** This traditional approach relies primarily on hydrological and hydraulic calculations.
- **Cartographic approach:** This method was utilized in areas where topographic data was insufficient to conduct a hydraulic approach. It primarily involved visual interpretation of satellite images and existing geographic information, as well as field visits to relevant sections of the watercourses. This approach enabled the quick assessment of flood hazards.

The map below (Figure 25) illustrates the flood-prone areas upstream of the SMBA dam, based on the findings from the PDAIRE-ABHBC, 2019.



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 25. Flood-prone sites in the Bouregreg Basin. *Source:* IWMI

Diagnostic

The main objective of the field visits was to evaluate the characteristics of the wadis and chaabas (small irrigation canals) that run through urban centers, assess the existing hydraulic structures, analyze the nature of the catchment areas, investigate damage from previous floods and determine the proximity of flood risk zones to populated areas. Figure 26 below shows examples of hydraulic infrastructure in the Bouregreg Basin.



Figure 26. Hydraulic infrastructure in the Bouregreg Basin. *Source: IWMI*

Modeling Results

After reviewing all the data, the hydrological studies were updated to reflect the specific features of the catchment areas. For the flood study, a multi-faceted approach was used that incorporated various methods and statistical treatments, which were analyzed and compared to determine their suitability based on the characteristics of the catchments:

- Statistical adjustment of maximum annual instantaneous flows
- Gradex method transposed via the Francou-Rodier method
- SCS method
- Rational method

This hydrological study considered the hydro-climatological specificities of the study areas. Based on the available topographic data, boundary conditions and analysis of stream roughness, hydraulic calculations were performed using 2D flow modeling for each stream.

Current state

Table 7 below summarizes the 100-year flood extent of the sites modeled.

Table 7. Hydraulic simulation results of the flood-prone site

Flood-prone sites	Flood extent (T100)	Flood-prone sites	Flood extent (T100)
Tighza		Ezzhiliga	
Bouhssoussen		Sebt Ait Ikkou	
Aguelmous		Sebt Ait Rahou	
Rommani		Maaziz	
Moulblad			

Source: Author's creation

Future state

Research into the impact of climate change on flooding in Morocco, is an increasingly vital area of investigation. Currently, there is a clear emphasis on the effects of climate change on heavy precipitation, but few studies cover the whole region. Existing research on maximum daily precipitation or intensities in Morocco presents conflicting results, indicating increases and decreases in extreme precipitation events.

Additionally, most studies focus on daily precipitation, neglecting potentially significant changes in sub-daily precipitation patterns. Exploring this aspect requires regional climate models capable of accurately representing convection, although these models may introduce uncertainties.

It is crucial to recognize that climate change's effects on flooding extend beyond heavy rainfall events. Factors such as soil moisture history and land use also play critical roles in watershed hydrology. Therefore, a comprehensive understanding of the influence of climate change on flooding must consider these parameters.

The analysis of the effects of climate change on flooding in Morocco is a dynamic and evolving field, characterized by limited data, conflicting findings and the significance of factors beyond extreme precipitation. To address these challenges, future research should prioritize understanding trends in various parameters that influence watershed hydrology during extreme precipitation events.

Drought Analysis

Changing rainfall patterns, driven by climate change, directly impact water resources and make their management increasingly complex. Morocco is among the countries most affected by these shifts, with a notable consequence being a rise in the frequency of both intra- and inter-annual droughts.

Drought refers to "a decrease in precipitation compared to levels deemed normal, which can impact the environment and human activities over a given time." However, this notion can vary depending on the perspective of different stakeholders, which include:

- water managers
- farmers
- hydroelectric power plants operators
- wildlife biologists
- others

This chapter outlines the activities undertaken and the methodology used to characterize the drought phenomenon in the Bouregreg Basin.

Standardized Precipitation and Evapotranspiration Index (SPEI)

Meteorological drought in the Bouregreg Basin has been assessed using the SPEI indicator for the period 1979-2022. This analysis is conducted at ten monitoring stations, using an intensity scale ranging from 1 to 48 months, with specific emphasis on SPEI-12 and SPEI-6, which characterizes hydrological drought over 12 and six months, respectively. The SPEI index is calculated by incorporating both precipitation and evapotranspiration data over 12 months, providing valuable insight into long-term hydrological conditions.

Table 8 below categorizes dryness and moisture levels according to SPEI values.

Table 8. SPEI categories

Category	SPEI
Extreme dryness	$\text{SPEI} \leq -2$
Severe dryness	$-2 < \text{SPEI} \leq -1.5$
Moderate dryness	$-1.5 < \text{SPEI} \leq -1$
Normal	$-1 < \text{SPEI} \leq 1$
Moderate humidity	$1 < \text{SPEI} \leq 1.5$
High humidity	$1.5 < \text{SPEI} \leq 2$
Extreme humidity	$\text{SPEI} > 2$

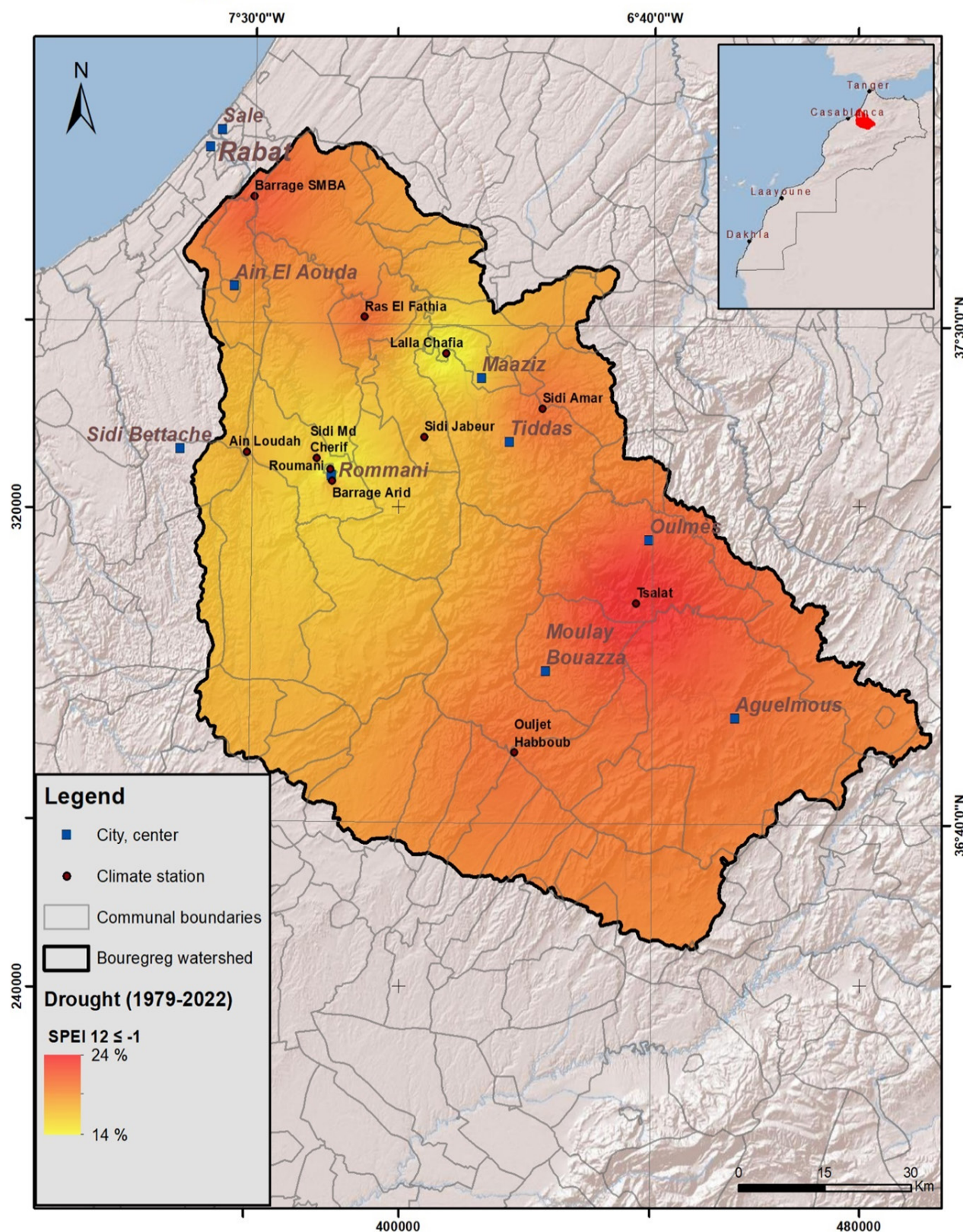
Source: Author's creation

a. SPEI 12:

Current state

The spatial analysis results reveal that the drought occurrence frequency in the basin, fluctuates between a minimum of 14% to a maximum of 24% from 1979 to 2022 (Figure 27), indicating that the region has experienced those variations over centuries. Notably, the highest frequencies of drought occurrence were recorded in the southeast and northern areas of the basin.

The analysis of the SPEI's temporal evolution over a 12-month period (SPEI-12) indicates that the Bouregreg region experienced its most severe drought episodes in 2017, 2019, and 2022 (Figure 28).



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 27. Spatial distribution of the August drought index (SPEI-12 ≤ -1) over the period 1979-2022.

Source: IWMI

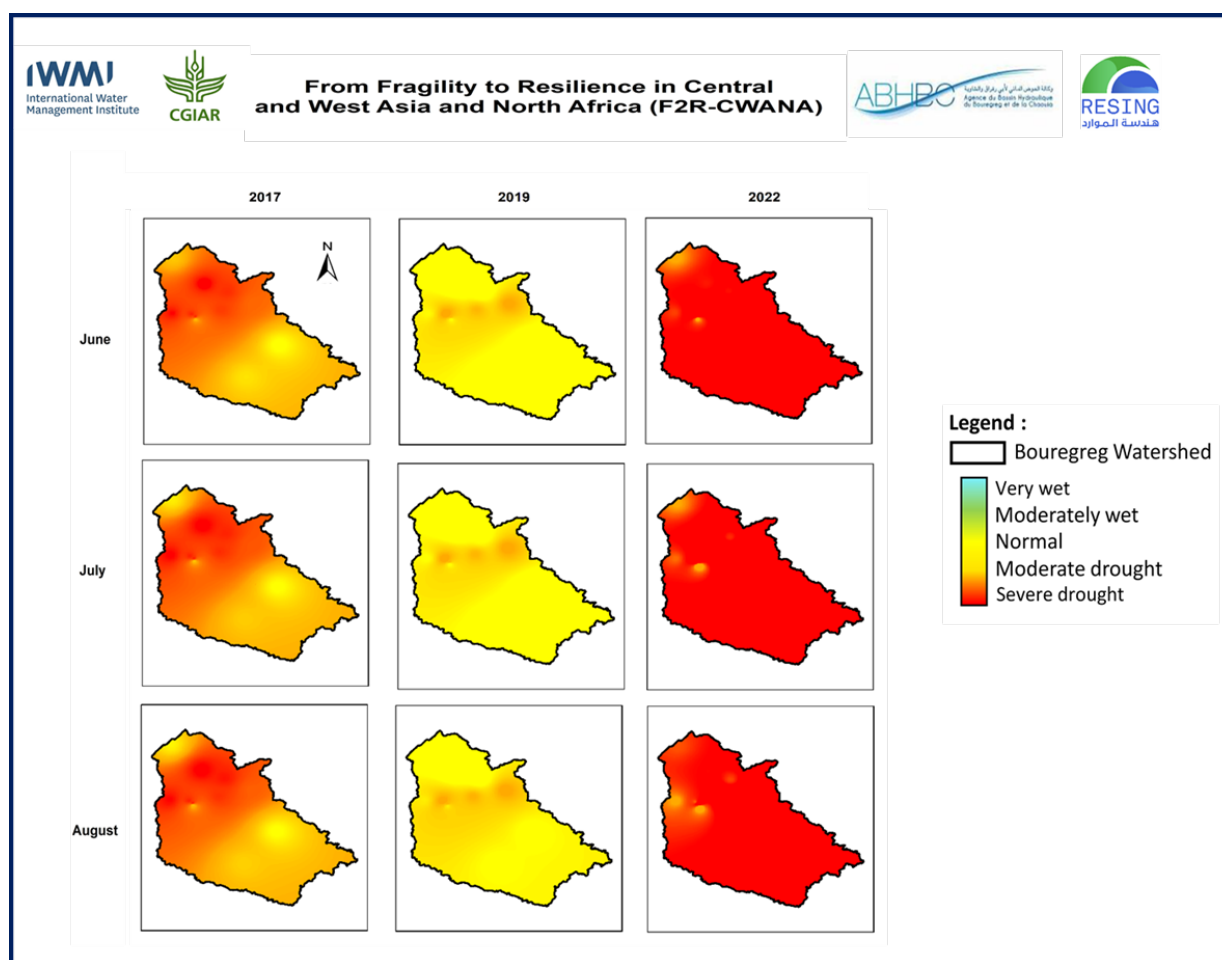


Figure 28. Spatial distribution of the SPEI-12 drought index for 2017, 2019 and 2022.

Source: IWM

Future state

A drought analysis was conducted for the Bouregreg Basin using the SPEI index under two distinct warming scenarios: RCP 4.5 and RCP 8.5 (Figure 29).

Future projections of the 12-month SPEI (SPEI-12) under RCP4.5 and RCP8.5 indicate that drought conditions are expected to worsen in the Bouregreg area, with an average drought occurrence frequency estimated at around 15% for both scenarios.

Spatial analysis of drought distribution across the basin region (Figure 30) reveals significant variations, particularly in June and August, with noticeable fluctuations over the years. Forecasts suggest relatively stable conditions for 2030, with rainfall and humidity levels generally aligning with seasonal averages. However, the years 2035 and 2040 are projected to experience above-average rainfall, leading to an extended wet season across the basin. This substantial increase in precipitation could enhance available water resources, creating a favorable context for agriculture and other activities that rely on a steady water supply.

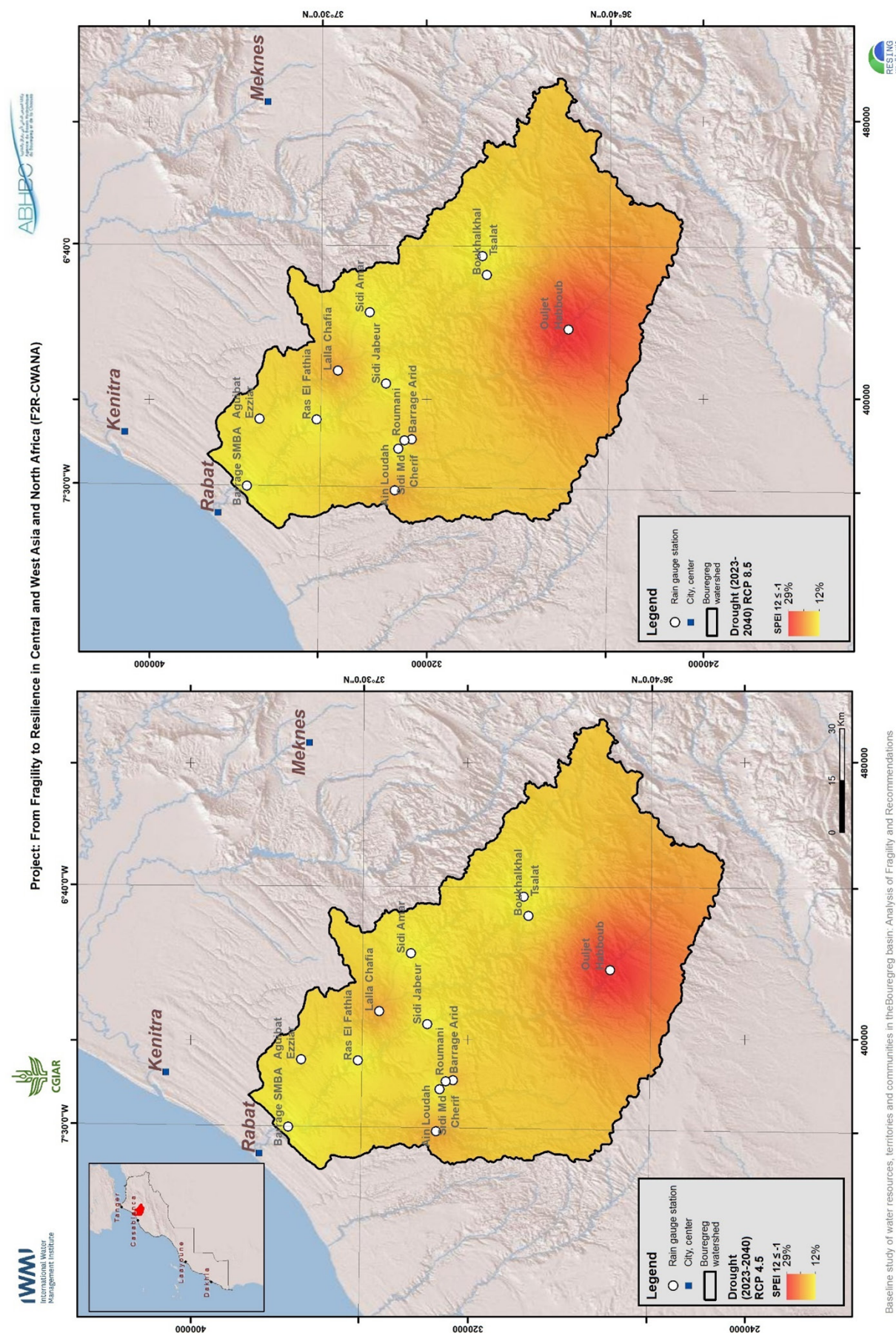


Figure 29. Spatial distribution of the frequency of drought SPEI-12 ≤ -1 RCP4.5 and RCP8.5 in August over the period 2023-2040.

Source: IWMI

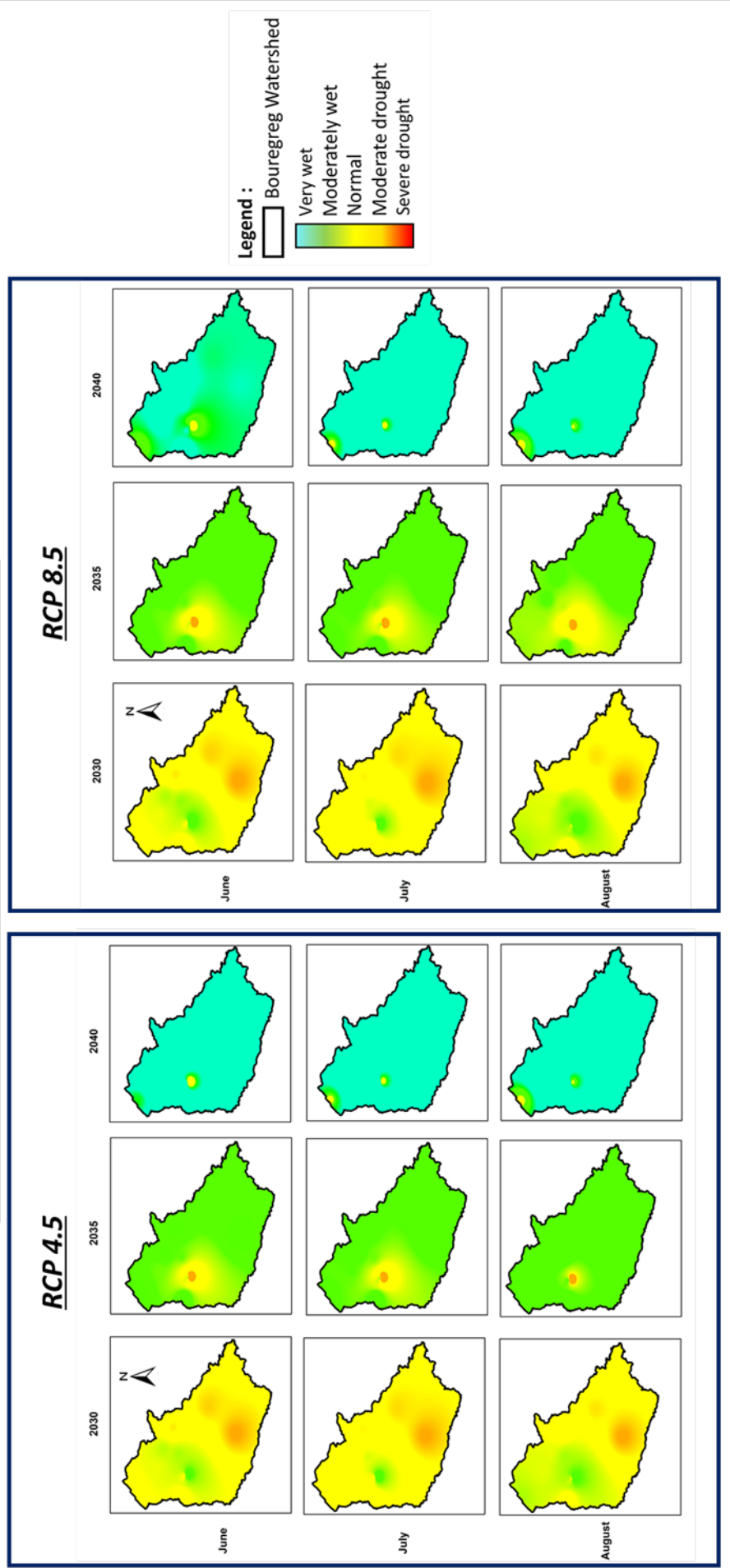


Figure 30. Spatial distribution of drought frequency SPEI-12 (RCP 4.5 and 8.5) for the years 2030, 2035 and 2040.
Source: IWMII

b. SPEI 6

The analysis of drought frequency using the standardized precipitation index (SPEI-6) for March, reveals a higher incidence of drought in the northwestern part of the basin (Figure 31). This suggests a historical trend and reveals that the northwestern region experiences drought more frequently during March than other areas in the basin.

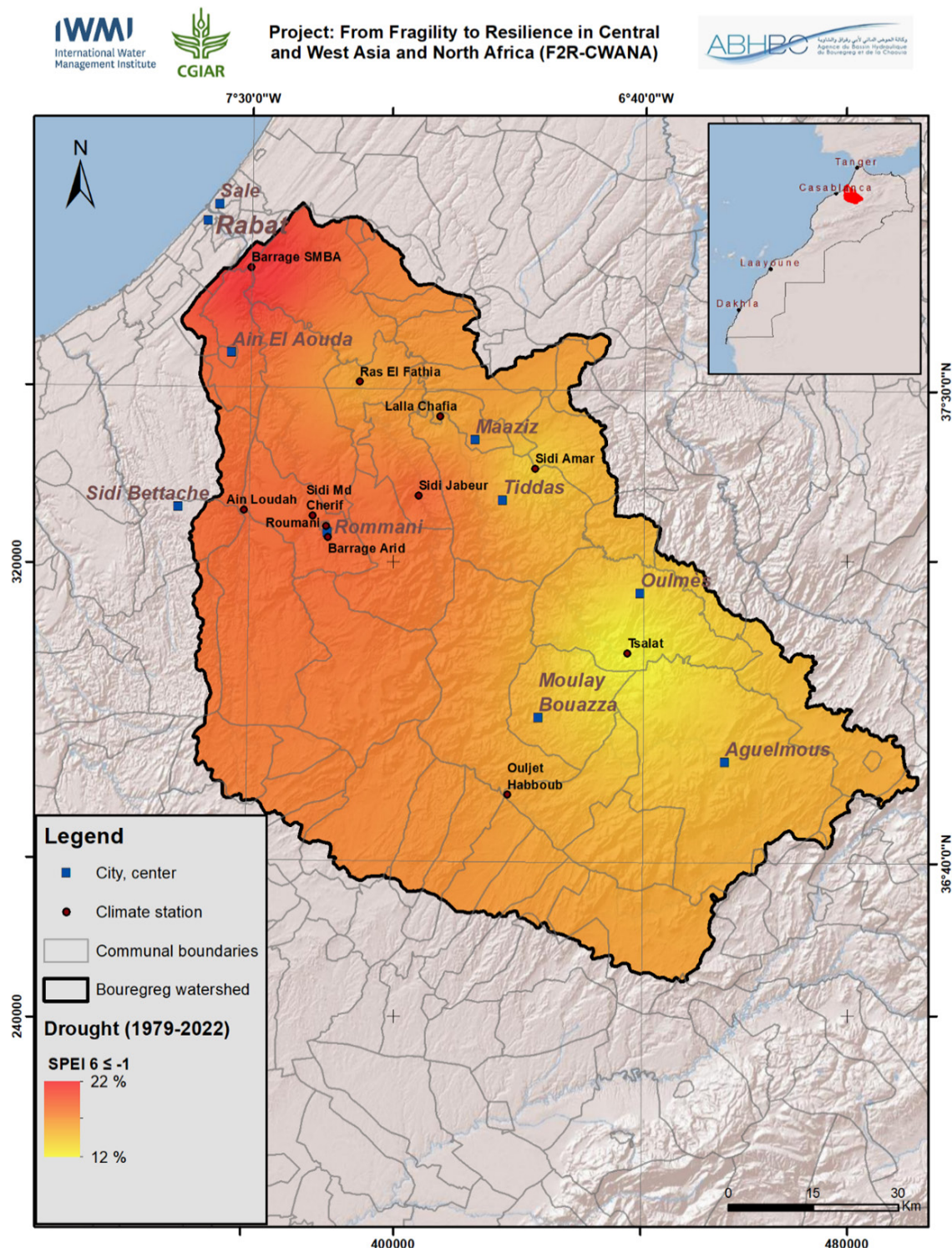


Figure 31. Spatial distribution of the drought index (SPEI-6 ≤ -1) for the month of March over the period 1979-2022. *Source:* IWMI

CDI

As part of this study, two composite indices were used: (i) the Combined Drought Monitoring Index (CDMI), and (ii) CDMIa_RF, a modified version of CDMI. Tables 9 and 10 describe the drought classification using these two indexes.

• CDMI

Equation : $\text{CDMI} = 0.36 * \text{PCI} + 0.25 * \text{TCI} + 0.19 * \text{VCI} + 0.21 * \text{ETCI}$

Table 9: CDMI classification scheme

Drought category	CDMI interval
Exceptional drought	$0.0 \leq \text{CDMI} < 0.1$
Extreme dryness	$0.1 \leq \text{CDMI} < 0.2$
Severe drought	$0.2 \leq \text{CDMI} < 0.3$
Moderate drought	$0.3 \leq \text{CDMI} < 0.4$
Abnormal dryness	$0.4 \leq \text{CDMI} < 0.5$
No drought	$\text{CDMI} > 0.5$

Source: Han et al., 2021

• CDMIa_RF

Equation: $\text{CDMIa_RF} = 0.36 * \text{PCI} + 0.25 * \text{TCI} + 0.19 * \text{VCI} + 0.21 * \text{ETCI}$

Table 10. CDMIa_RF classification scheme

Drought category	CDMIa_RF interval
Exceptional drought	$0.0 \leq \text{CDMIa_RF} < 0.2$
Extreme dryness	$0.2 \leq \text{CDMIa_RF} < 0.3$
Severe drought	$0.3 \leq \text{CDMIa_RF} < 0.4$
Moderate drought	$0.4 \leq \text{CDMIa_RF} < 0.5$
Normal	$0.5 \leq \text{CDMIa_RF} < 0.6$
Humid, not dry	$\text{CDMIa_RF} > 0.6$

Source: Houmma, 2020

The CDMI and the rainfall-adjusted CDMI (CDMIa_RF), which incorporates temperature, vegetation, evapotranspiration and soil moisture, are effective tools for monitoring drought conditions in the study area and have shown superior performance in accurately reflecting drought conditions compared to other indexes.

To calculate these indexes, the following data were utilized:

- Vegetation Condition Index (VCI);
- Precipitation Condition Index (PCI);
- Land Surface Temperature (LST);
- Evapotranspiration Condition Index (ETCI);
- Soil Moisture Anomaly (SMA).

a. CDMI

The CDMI analysis generated 164 "Raster" format files, representing monthly Bouregreg Basin data. Analyzing the CDMI data from 2012 to 2021 and applying the designated classification system revealed drought-level fluctuations over the years. The basin experienced moderate drought conditions from 2009 to 2015, which escalated to severe drought in 2016 and 2017. Notably, 2018 had minimal drought conditions, but increased vigilance became necessary in the following years, especially from 2019 onward (Figure 32).

The annual and inter-annual analyses reveal irregularities in the CDMI for the Bouregreg Basin, with significant variations observed in 2016, 2018 and 2022, indicating fluctuations in drought conditions over the years. The data indicates a particularly pronounced drought in 2016 (Figure 33).

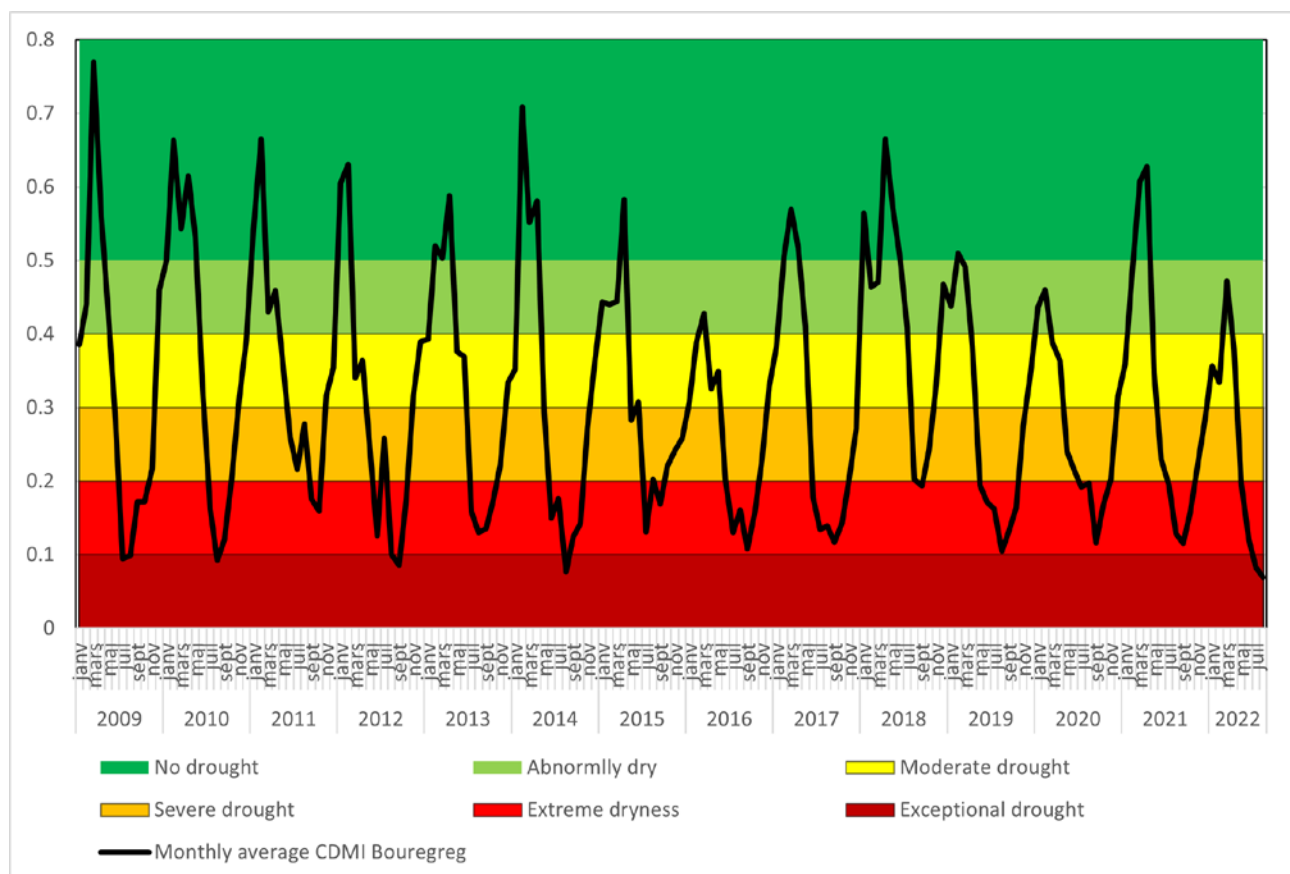


Figure 32. Monthly change in CDMI values

Source: IWMI

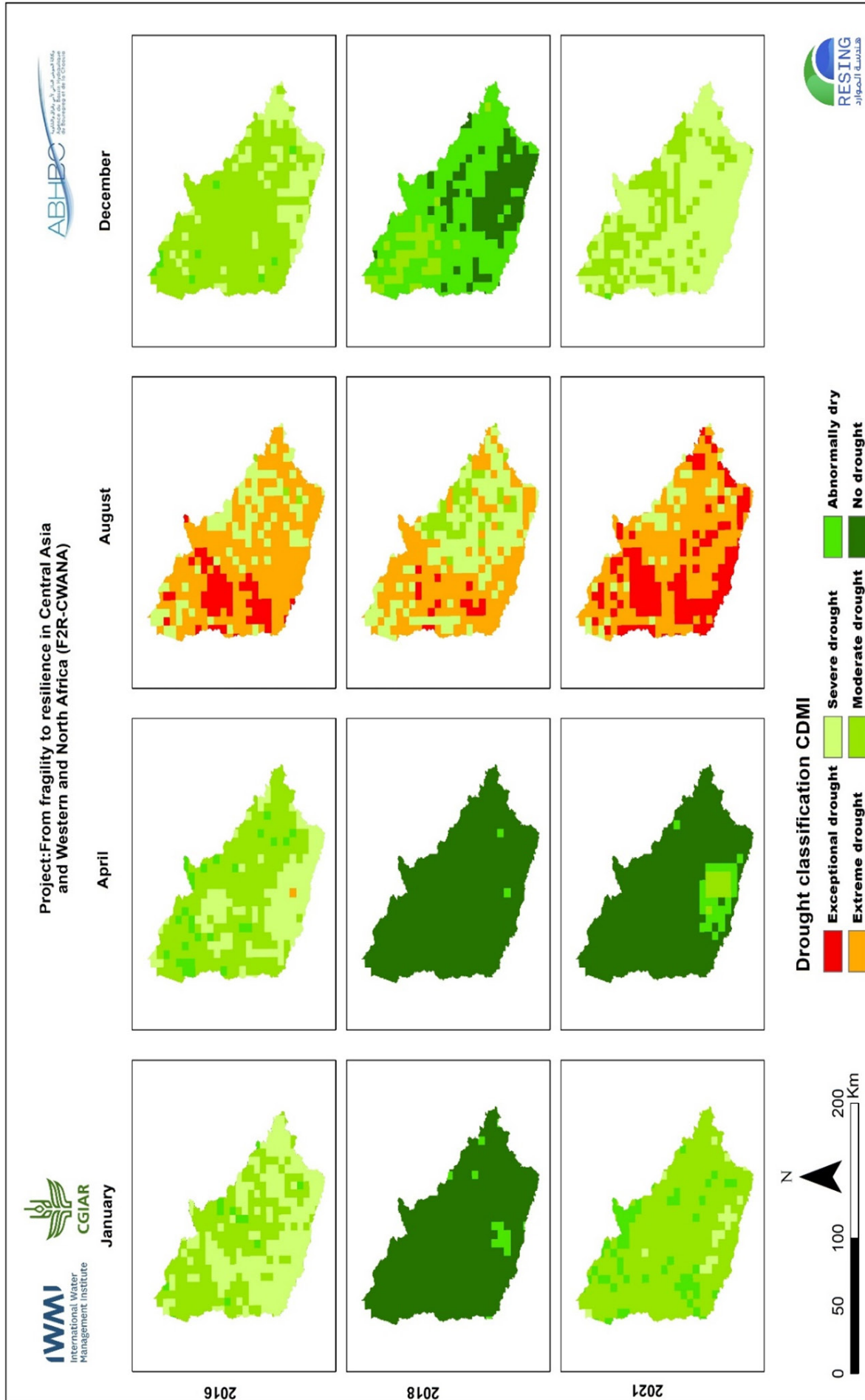


Figure 33. Interannual irregularity of CDMI values
Source: IWMI

Figure 34 shows the fluctuations of the CDMI index throughout the growing season, which spans from November to April in the Bouregreg region. This period is critically important for agriculture, as water availability during these months directly impacts crop yields and overall agricultural productivity.

The growing season coincides with favorable climatic conditions for plant growth in the Bouregreg Basin, particularly cooler temperatures which are optimal for seed germination and crop development.

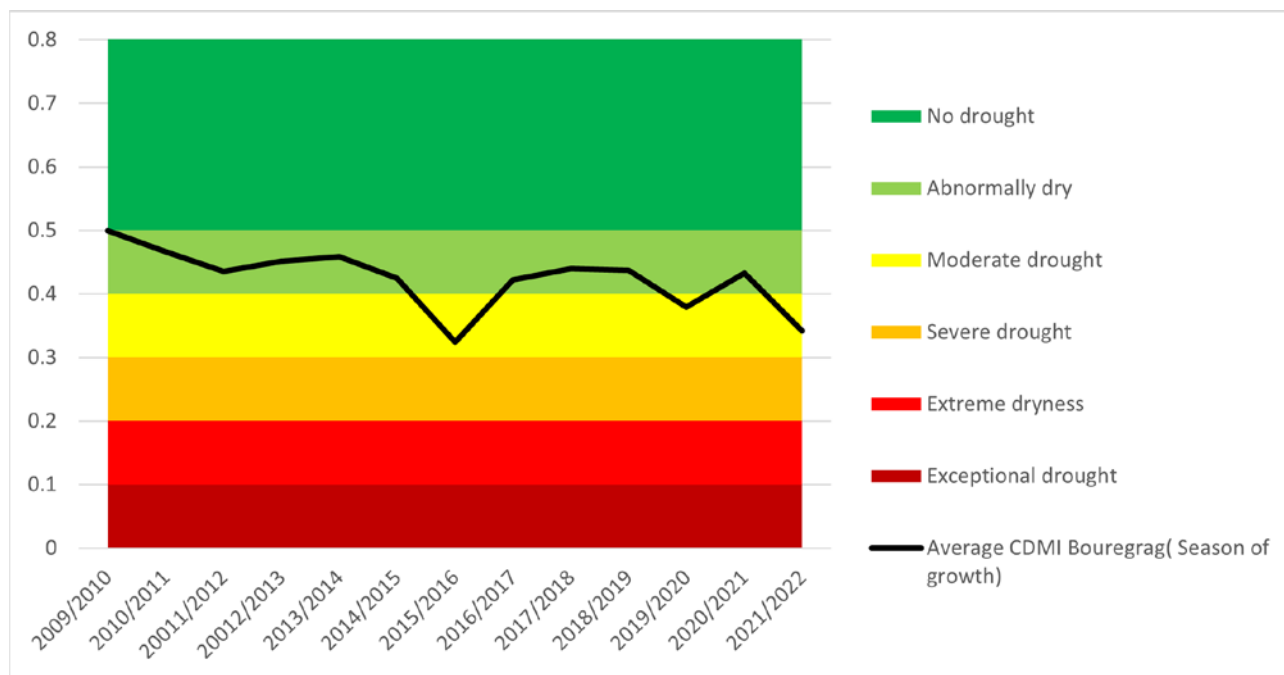


Figure 34. Annual change in CDMI in the Bouregreg Basin during the growing season (November to April)
Source: IWMI

This time frame is particularly important as it marks the planting season for winter cereals, winter vegetables and a variety of spring crops. The graph indicates that, with the exceptions of the anomalies observed 2016/2017, 2019/2020 and 2021/2022, the growing season generally follows a typical pattern. This finding suggests more favorable conditions for the agricultural sector within the basin during these periods.

CDMIa_RF

Similarly to the analysis conducted for the CMDI, the results for CDMI_RF incorporated data from 164 "Raster" format files representing monthly values for the Bouregreg Basin. The analysis was conducted on two scales: (i) at the Bouregreg catchment scale and (ii) at the communal scale.

Bouregreg catchment scale

Figure 35 below shows that from 2009 to 2015 and again in 2021, the region experienced a consistent pattern of moderate drought, with CDMIa_RF values ranging from 0.3 to 0.4. However, starting in 2016, conditions worsened significantly. Years 2016, 2017 and 2019 experienced extreme drought, reflected by CDMIa_RF values falling below 0.3. During this period, prolonged and severe drought conditions likely and adversely impacted agriculture, water supply and the local environment.

In 2018, moderate drought conditions prevailed, signaling slightly drier-than-usual conditions despite substantial rainfall. Additionally, the year 2020 stood out for its severe drought. This index' analysis shows the fluctuating nature of drought conditions over the years, highlighting the importance of continuous monitoring and the implementation of adaptative measures to reduce drought impacts on local communities and resources. Recent years have seen a troubling increase in drought conditions, emphasizing the urgent need to address this issue.

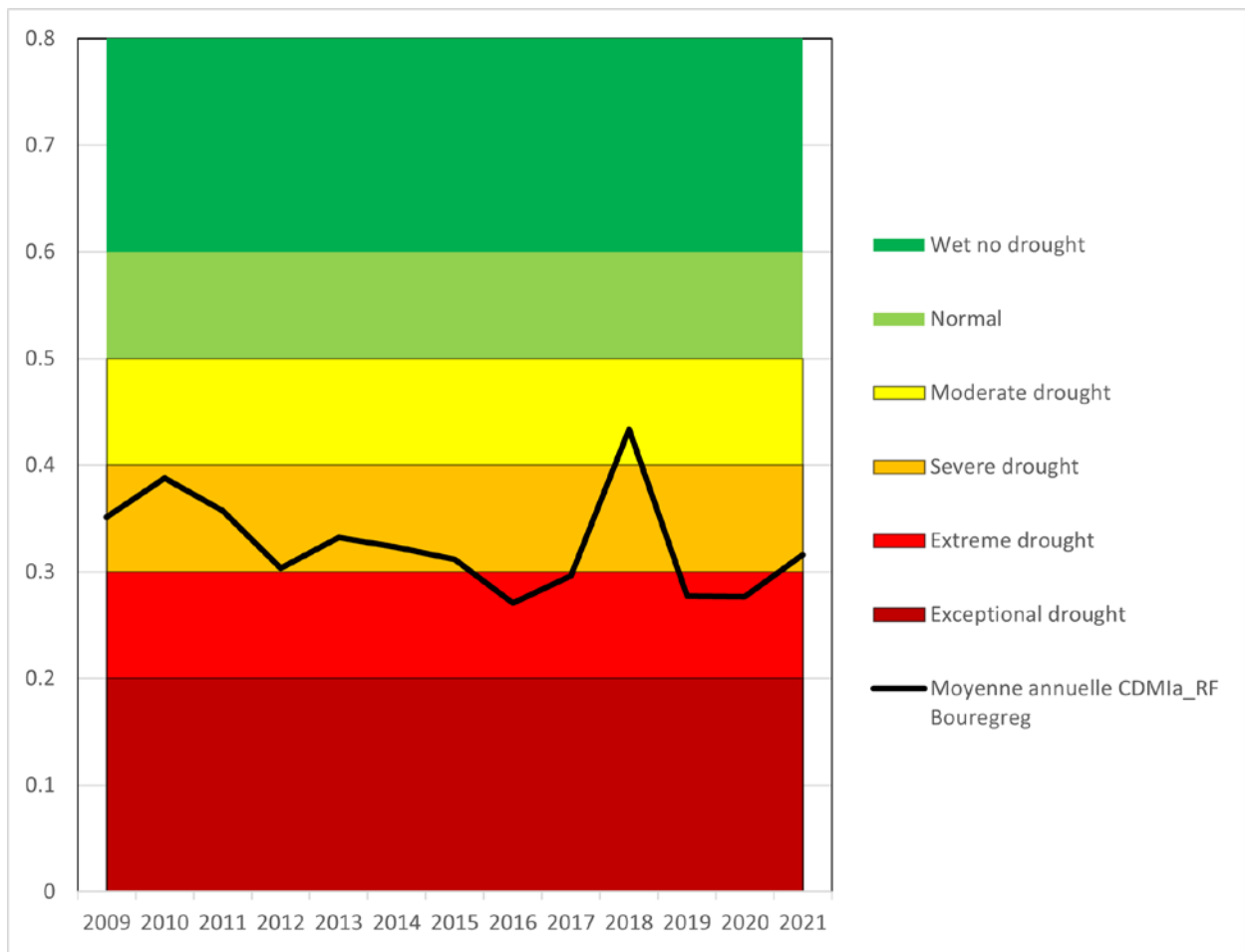


Figure 35. Annual change in CDMIa_RF in the Bouregreg Basin
Source: IWMI

The analysis of monthly CDMI values from 2009 to 2022 reveals significant irregularities, characterized by seasonal variations, with changing drought patterns over the years. The summer months frequently display lower CDMIa_RF values, indicating more severe drought conditions, while winter months typically show higher values, suggesting a period of seasonal recovery. Understanding these cycles is essential for effective water resource management and climate change adaptation.

Furthermore, an examination of inter-annual variations reveals notable deviations between years, highlighted by the varying CDMIa_RF values for specific months. This variability indicates the complexity of factors influencing water availability and emphasizes the need for resilient water management strategies to address unpredictable climate changes.

A comparison of drought conditions in 2016, 2018 and 2021, as shown in Figure 36, illustrates spatial differences, with a particularly stark drought observed in 2016. Variability exists not only from year to year but also within individual years; for example, in 2021, significant fluctuations were observed, with highs and lows in CDMI_RF values reflecting seasonal and meteorological changes.

From Fragility to Resilience in Central and West Asia and North Africa (F2R – CWANA)

December

August

April

January

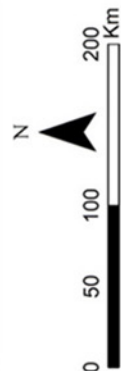
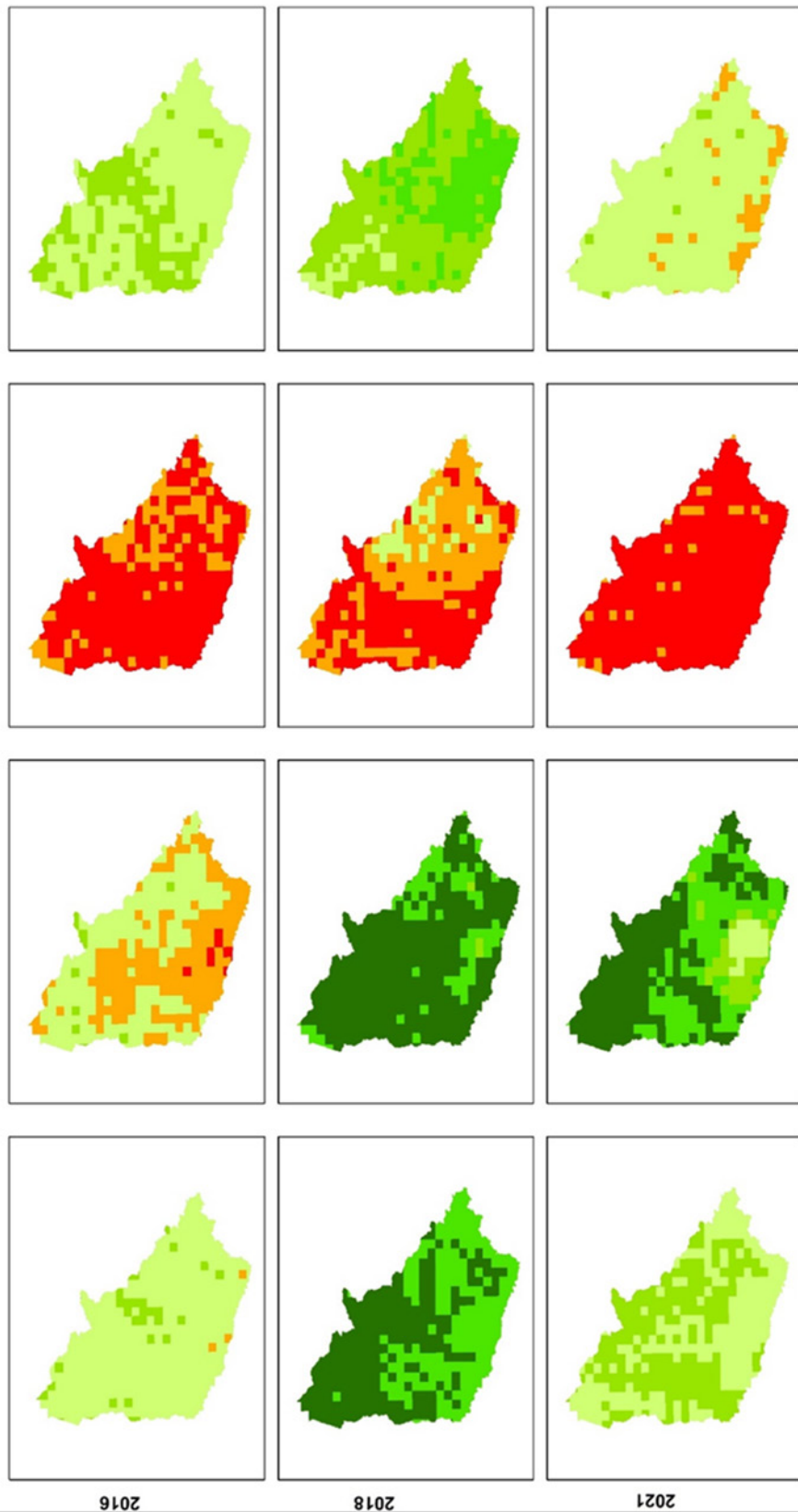


Figure 36. Interannual irregularity of CDMla_RF values
Source: IWMI

Commune scale

To analyze conditions at the local level, the CDMIa_RF index was used, which is better suited to the Moroccan context as it accounts for the growing season, which spans from November to April. The index created a precise picture of drought and aridity in the Bouregreg Basin communes at that time.

The analysis shows irregularity in average CDMIa_RF values during the growing seasons for the CDMIa_RF, with noticeable fluctuations at the municipal level for the 2011/2012, 2017/2018, and 2020/2021 seasons. Figure 37 shows that the south-southwestern part of the basin frequently experiences the most severe drought conditions.

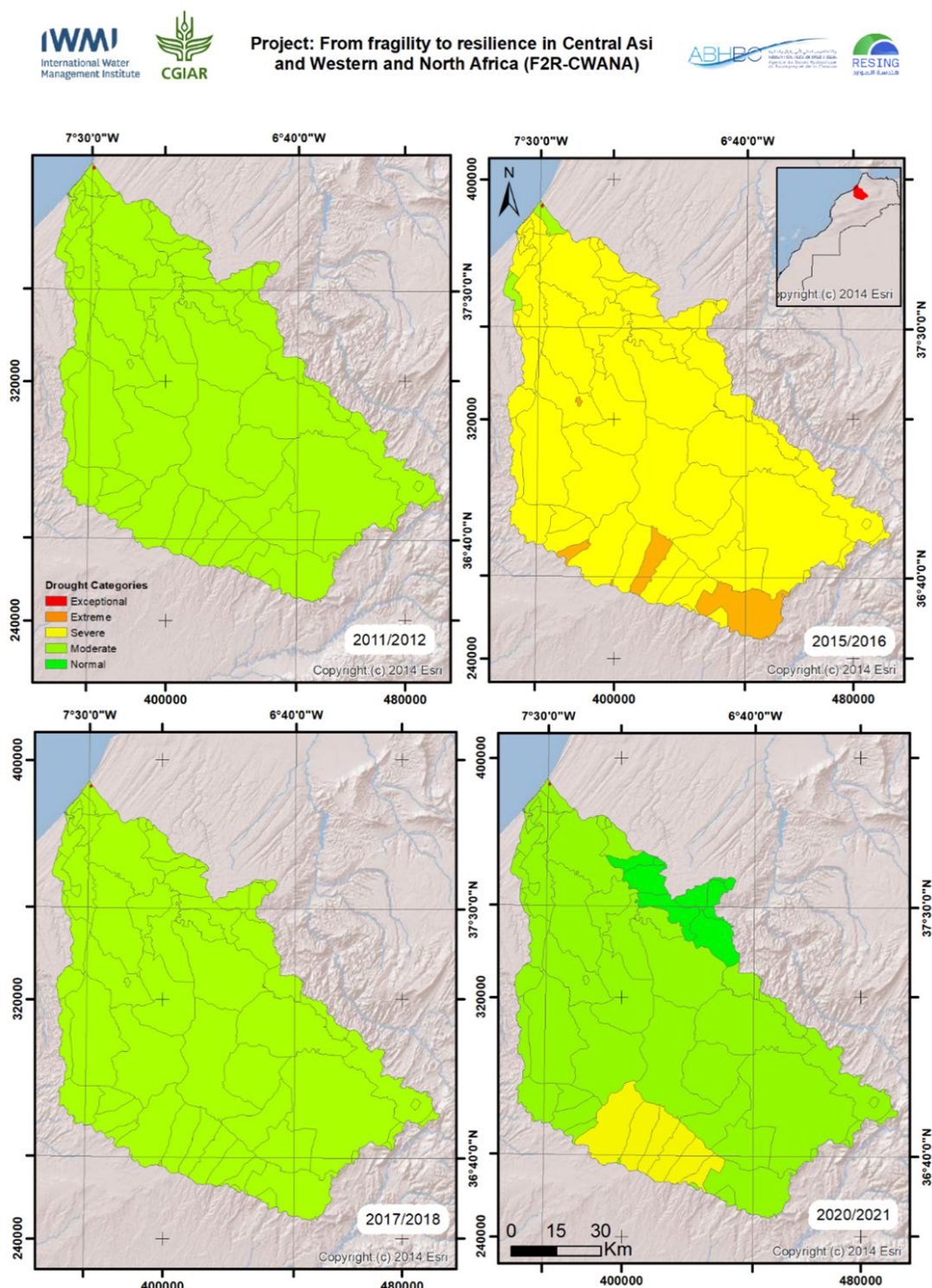


Figure 37. Variability of drought categories at commune level by growing season.

Source: IWMI

Erosion Analysis

Erosion is a natural process shaped by climatic conditions, soil erodibility, land use practices and slope characteristics. Understanding these factors is crucial for assessing soil loss on hillslopes and its spatial distribution. In the Bouregreg watershed, land degradation has worsened, transitioning from mild erosion to more severe forms, such as gullies and ravines. This escalation complicates restoration efforts and exacerbates the overall situation (Beaudet, 1969; Laouina et al., 2013; Mahé et al. 2013).

The model selected to evaluate soil erosion risk in the Bouregreg Basin is the Revised Universal Soil Loss Equation (RUSLE). This empirical model combines various factors, including topography, soil characteristics, climate and land use. Additionally, it effectively integrates elements that influences the rate of water erosion, such as the kinetic energy of intense rainfall, soil properties, terrain features, soil protection by vegetation cover and human activities.

Table 11 presents the soil loss classes used to qualify erosion intensity:

Table 11. Erosion intensity qualification categories

Annual soil loss class	Qualification of erosion
>100 tons/ha	Very high erosion potential
50 - 100 tons/ha	High erosion potential
20 - 50 tons /ha	Low to moderate erosion potential
0 - 20 tons/ha	No erosion to minimal erosion potential

Source: ABHBC

Current state

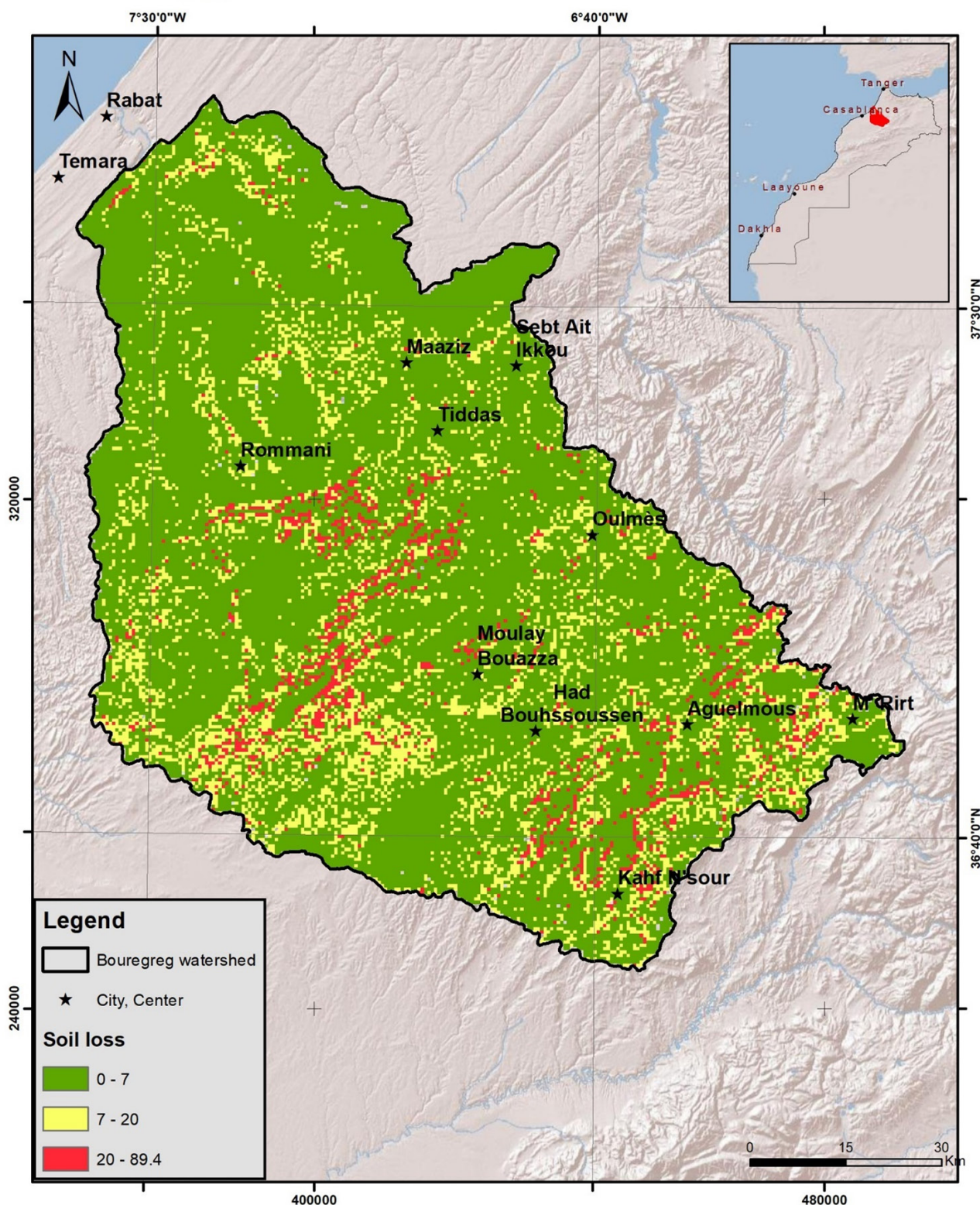
The interplay of physical and anthropogenic factors has facilitated the calculation of average annual soil losses (Factor A) using the RUSLE model. In the Bouregreg Basin, estimated soil losses range from 0 to 89.4 t/ha/year (Table 12), with a mean annual loss of 5.92 t/ha/year and a standard deviation of 9.31.

Most of the Bouregreg Basin falls within the tolerance interval of 7 t/ha/year, accounting for 78.48% of the total basin area (Figure 38). However, 22.32% of the basin exceeds the tolerance threshold.

Table 12. Soil loss indicators A

Factor A (t/ha/year)	
Maximum	89,4
Minimum	0
Average	5,92
Standard deviation	9,31

Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 38. Annual soil loss in the Bouregreg Basin.

Source: IWMI

Future state: main results of the *RUSLE* model (2040)

By integrating the projected data and applying the *RUSLE* model, a detailed soil loss map for the year 2040 was generated (Figure 39), providing a visual representation of the areas where water erosion is expected to be most pronounced in 2040.

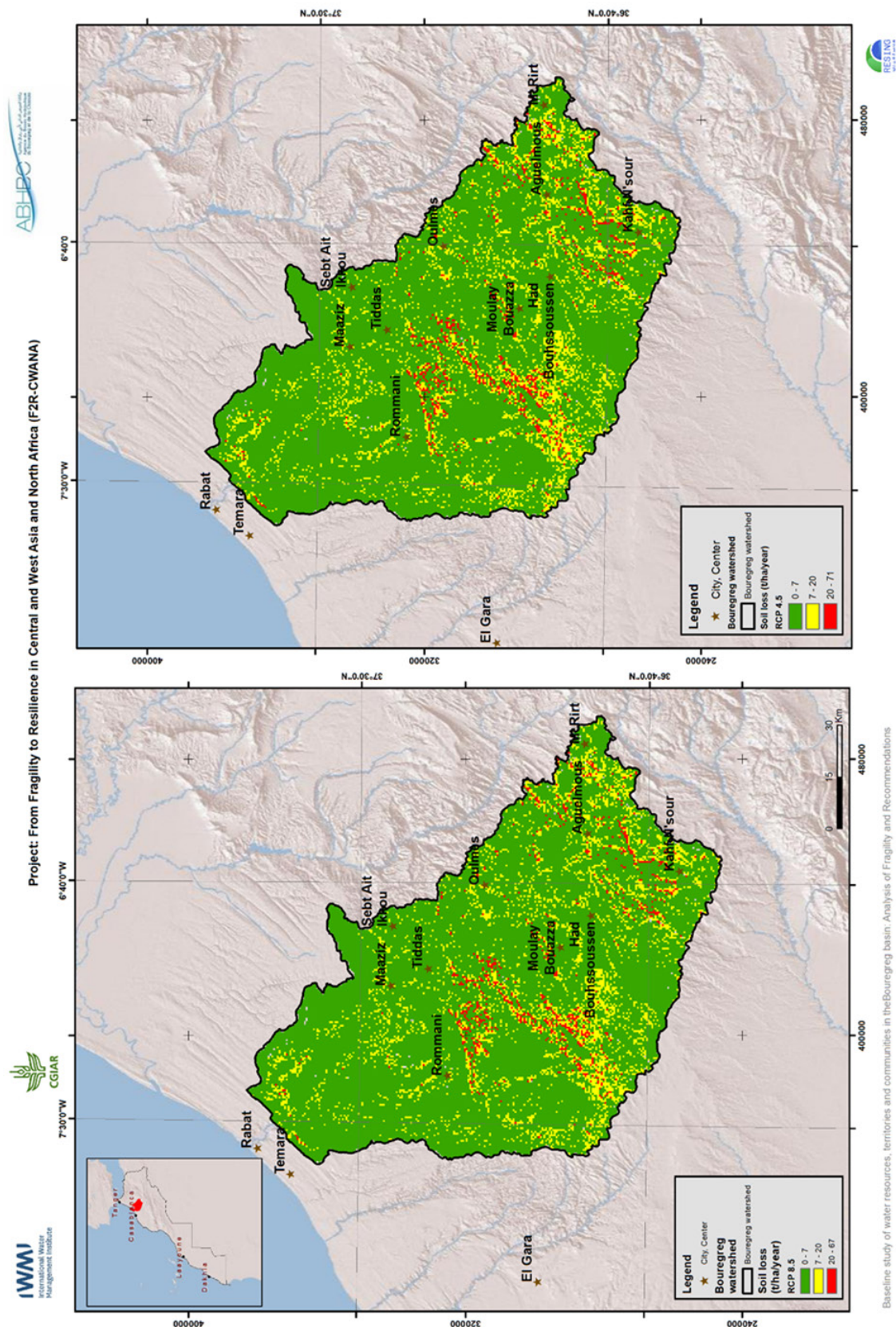


Figure 39. Soil Loss in the Bouregreg Basin (RCP 4.5 et 8.5). *Source:* IWMI

Table 13 below summarize the results of the RUSLE model based on projections for the RCP 4.5 and RCP 8.5 scenarios.

Table 13. Main results of the RUSLE model (2040)

	Factor A RCP 4.5 (t/ha/an..)	Factor A RCP 8.5 (t/ha/an..)
Maximum	70.6	66.9
Minimum	0	0
Average	4.03	3.82
Standard deviation	5.89	5.58

Source: IWMI

Exposure and Vulnerability Analysis in the Bouregreg Basin

Exposure analysis approach

Based on inputs from stakeholder consultations and a comprehensive literature review, various assets were identified to characterize and spatially assess exposure for each risk. The following paragraphs detail the identified assets and data sources used for the exposure analysis.

For flood exposure, the element at risk is the area of buildings potentially exposed to a flood event. To establish the flood exposure index, two types of data were utilized:

- The proposed urban development and expansions, derived from the land cover map created for this study, are used to assess the population's future flood risks.
- This dataset was overlaid with the flood hazard layer to determine each municipality's absolute and relative area of exposed buildings, considering a 100-year return.

Assessments focused on rainfed and irrigated farmland for drought exposure verses the population. The spatial distribution of the Bouregreg Basin's farmland was obtained from the Land Use/Land Cover (LULC) model developed for this project. Subsequently, SPEI-6 and SPEI-12 were used to calculate the probability of drought hazards on rainfed and irrigated farms. For population exposure, the dataset from the 2014 census was used to determine population density in each municipality.

An exposure index at the municipal level was calculated by multiplying the average probability of drought (SPEI<-1) by the areas of rainfed and irrigated farmland and by the population density for each administrative unit. This approach incorporates both hazard magnitude and the relative importance of affected farmland for the municipality's overall agricultural production.

For erosion, the municipal exposure index was calculated by multiplying the average soil loss within the municipality by its total area.

Table 14 synthesizes the approach used to assess exposure per hazard.

Table 14. Indicator per hazard for exposure

Hazard	Indicator	Description	U	Source
Drought IE _D	IE _{D11} : Drought frequency SPEI 12	Drought frequency over the last 40 years (average for the commune)	%	Frequency analysis SPEI12
	IE _{D12} : Drought frequency SPEI 6	Drought frequency over the last 40 years (average for the commune)	%	Frequency analysis SPEI6
	IE _{D2} : Bour area	Surface area of the bour/the surface area of the commune	-	NDVI/ land use map 2023
	IE _{D3} : Irrigated area	Irrigated area/area of commune	-	NDVI/ land use map 2023
	IE _{D4} : Population density	Population density in the commune	Hab	RGPH 2014
Floods IE _F	IE _{F1} : Flood extent	Extension of the 100-year flood	Ha	Hazard analysis
	IE _{F2} : Built-up area	Built-up area (proxy for population Drought)	Ha	Land use map 2023
Erosion IE _E	IE _E : Soil loss in the commune	Average soil loss for the commune	t/an	Analysis of erosion

Source: Author's creation

$IE_F = IE_{F1} \text{ intersection } IE_{F2} \text{ (SIG)} \rightarrow IE_F = IE'_F / \text{area Commune} = (\text{Built-up area located in 100-year flood zones}) / \text{Total area of the commune}$

$IE_D = (IE_{D11} * IE_{D2}) + (IE_{D12} * IE_{D3}) + (IE_{D1} * IE_{D3})$

$IE_E = \text{Average soil loss for the commune (t/ha/year)} * \text{Total area of the commune}$

The second step concerns the normalization of the indicators obtained in Step 1. Let I_i be the value of the relativized indicator in municipality i ($i = 1, \dots, n$); then:

$$I_i^{(n)} = \frac{I_i - \min(I_i)}{\max(I_i) - \min(I_i)}$$

Multiple exposure approach

The multi-risk exposure index was calculated by aggregating the single-hazard exposure scores – comparable on a scale from 0 to 1 – using an unweighted sum.

Vulnerability analysis approach

The methodology used to assess vulnerability, combines an extensive literature review and consultations with local and regional experts. The goal was to analyze socio-ecological vulnerability factors in relation to climate risks.

1. Literature review:

A comprehensive literature review was conducted to identify various vulnerability factors. RESING selected 45 relevant texts and studies from international sources and the Moroccan scientific community. These texts provided the foundation for defining a general framework for vulnerability, organizing it into several categories: biophysical, socio-economic, institutional and technological.

2. Indicator analysis:

Based on the literature, an initial list of 81 indicators was compiled, corresponding to 25 vulnerability factors. The RESING team reviewed and refined these indicators at multiple meetings, to ensure their relevance, measurability and adaptation to the specific context of the Bouregreg Basin. Ultimately, a cumulative matrix was developed, narrowing the indicators to 64 and encompassing 22 vulnerability factors.

3. Consultation and validation:

This indicator matrix was presented to stakeholders for feedback at a dedicated workshop. Each indicator was evaluated based on its relevance to the three main natural hazards identified (flooding, drought, and erosion), as well as the quality of information sources and the feasibility of measuring them.

This methodology has established a robust analytical framework for assessing vulnerability in the Bouregreg Basin, considering local specificities and the challenges of measuring indicators within a Moroccan context.

Multiple vulnerability approach

The methodological approach used to assess vulnerability indices for hazards such as flooding, drought and erosion, as well as the composite vulnerability index, consists of the following steps:

1. First step: relativization of variables at the municipal level.

Initially, we adjusted the variables to ensure that each municipality is given equal weight. This adjustment provides a fair basis for comparing the different regions.

2. Second step: normalization of relativized variables.

The relativized variables are then normalized using the min-max method. This process adjusts the values to a scale between 0 and 1, facilitating easier comparisons of the different variables between communes.

The formula used for normalization is as follows:

$$\alpha_i^j = \frac{\alpha_j - \min \alpha_i}{\max \alpha_i - \min \alpha_i}$$

3. Third step: calculation of vulnerability indices for each hazard.

Next, we calculated the vulnerability indices for each type of hazard (flood, drought, and erosion) using the formulas in Table 15 below. Each factor is weighted by a coefficient γ_i , resulting in a measure of vulnerability for each commune.

The coefficient γ_i is determined based on the prioritization work conducted by the stakeholders.

Table 15. Hazard equations

Hazard	Equation
Flood hazard (I_i)	$I_{ki} = \sum_{k=1}^n \gamma_i \alpha_i^j$ Where k is the number of factors included in the flood hazard analysis
Drought hazard (S_i)	$S_{mi} = \sum_{m=1}^n \gamma_i \alpha_i^j$ Where m is the number of factors included in the drought hazard analysis
Erosion hazard (E_i)	$= \sum_{q=1}^n \gamma_i \alpha_i^j$ With q is the number of factors included in the erosion hazard analysis

Source: Author's creation

4. Fourth step: calculation of the composite vulnerability index.

In this step, the composite vulnerability index is calculated by considering the vulnerability indices for each type of hazard, weighted by the respective coefficients (p_i , p_s , p_e) assigned to the flood, drought and erosion hazards. This formula summarizes the overall vulnerability of a municipality by incorporating the various risks associated with the area.

The composite vulnerability index (C_i) formula is as follows:

$$C_i = p_i * \sum_{k=1}^{n=4} \gamma_i \alpha_i^j + p_s * \sum_{m=1}^{n=5} \gamma_i \alpha_i^j + p_e * \sum_{q=1}^{n=3} \gamma_i \alpha_i^j$$

In this equation, p_i , p_s and p_e represent the respective weights assigned to flood, drought and erosion hazards. These weights are derived from stakeholders' contributions collected during the second institutional workshop.

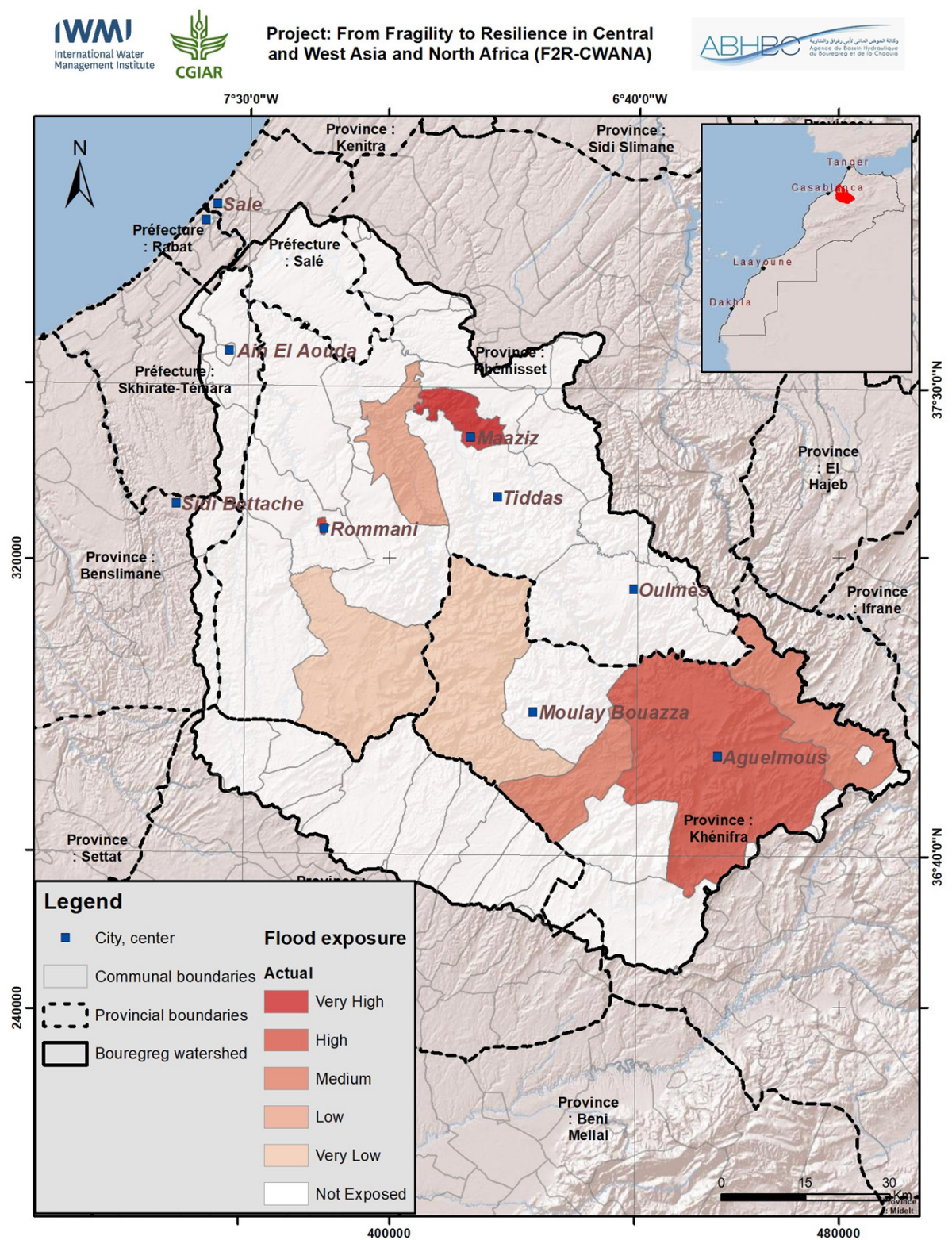
Exposure and Vulnerability to Flood

Exposure to Flood

A summary analysis of current flood exposure reveals that 12 municipalities within the Bouregreg Basin are at risk, with Maaziz and Aguelmous identified as the most vulnerable due to rapid urban development and inadequate infrastructure (Figure 40). Projections for 2040 (Figures 41 and 42) suggest an overall increase in exposure, driven by factors such as rising population density, expanding urban areas, and extreme climatic events.

These conclusions provide a strong foundation for developing strategic plans and implementing targeted adaptation measures that address the identified risks. It is essential to focus on regions susceptible to flooding, drought and erosion to strengthen their resilience.

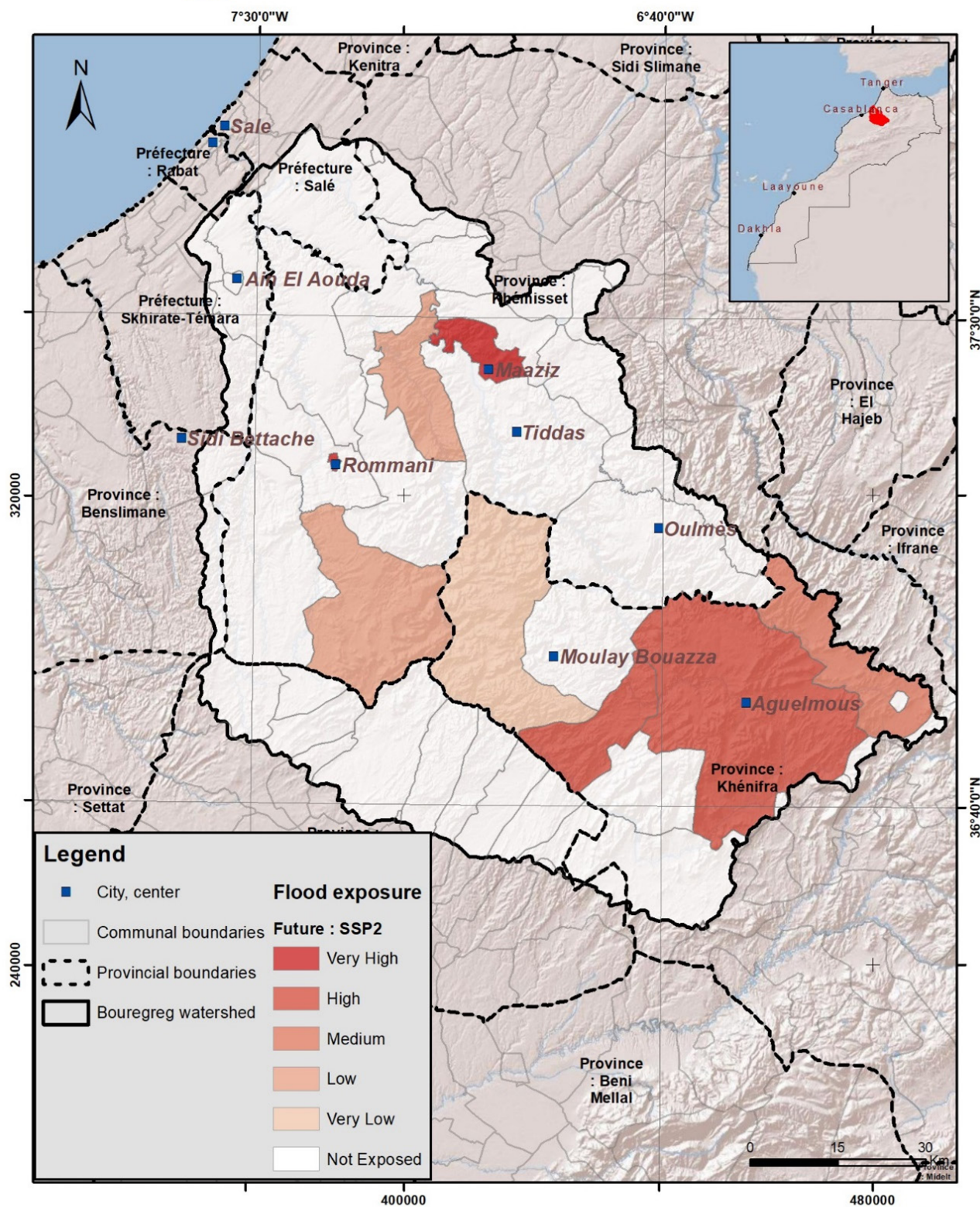
This exposure assessment offers valuable insights into the specific environmental challenges facing the Bouregreg Basin. The findings should guide future risk management decisions, emphasizing the need for targeted and adaptive actions to bolster the region's resilience.



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations



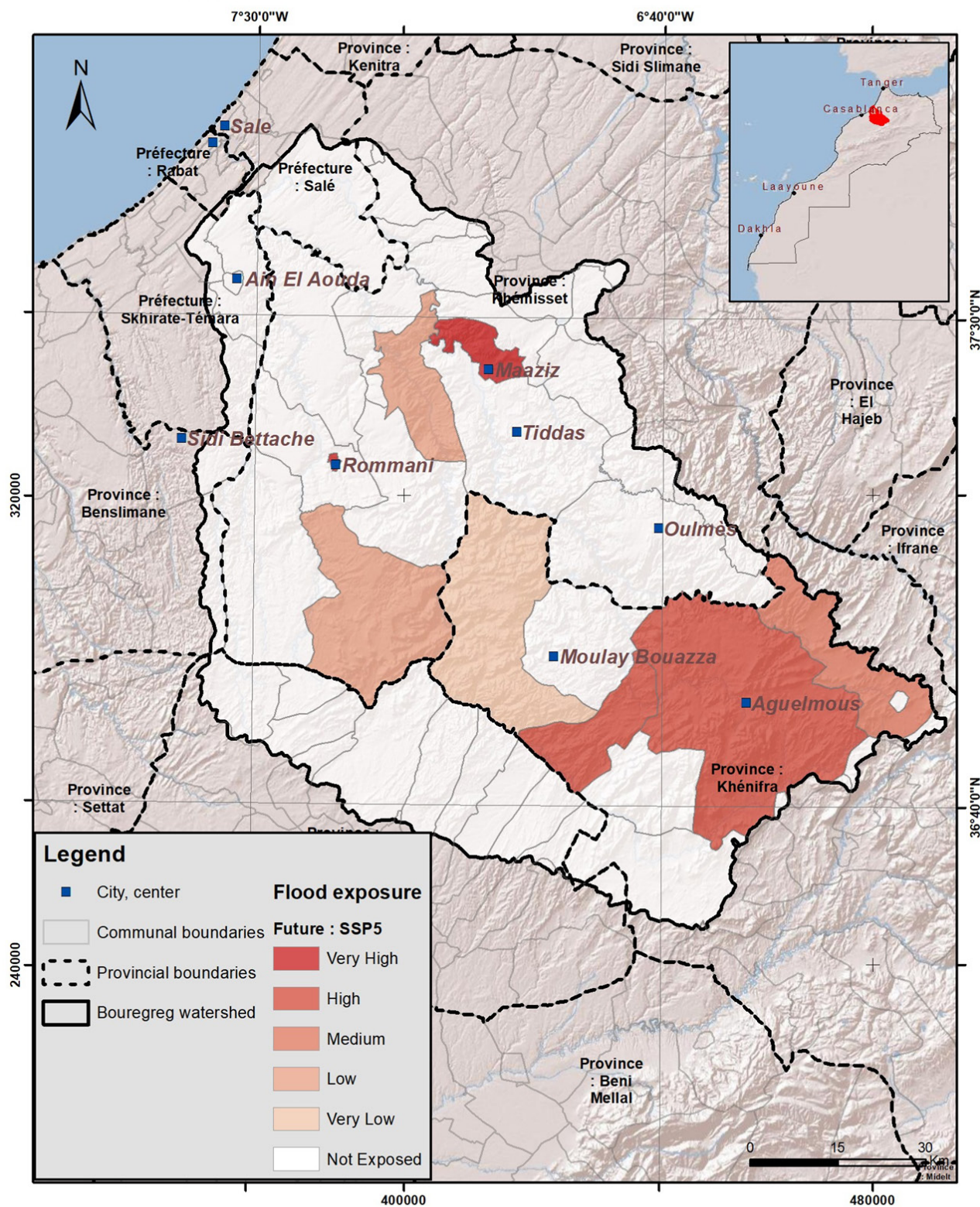
Figure 40. Exposure to flood in the Bouregreg Basin (current state). *Source:* IWM



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 41. Exposure to flood in the Bouregreg Basin (future state – SSP2- RCP4.5)

Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 42. Exposure to flood in the Bouregreg Basin (future state – SSP5-RCP8.5)

Source: IWMI

Vulnerability to Flood

The current vulnerability assessment (Figure 43) shows a significant concentration of high-risk municipalities, particularly in the upper reaches of the Bouregreg Basin. Projections for 2040 (Figure 44 and 45) indicate a decrease in overall vulnerability, largely due to planned investments in infrastructure, early warning systems and adaptive measures. These findings suggest that preventive strategies can be highly effective at managing flood risks.

A solid foundation for decision-making and planning adaptation measures has been established, paving the way for developing natural risk management policies and guiding actions that encourage proactive approaches. For continuous improvement, it is crucial to routinely monitor progress and integrate new data, while also periodically reassessing scenarios. Employing an interdisciplinary approach that considers social, economic and environmental factors will deepen the analysis and elevate the relevance of the findings.

This vulnerability analysis provides critical insights into the environmental challenges the Bouregreg Basin faces, underscoring the importance of proactive measures for building resilience against natural hazards. It informs future actions and promotes continuous reflection on sustainable management practices in the region.

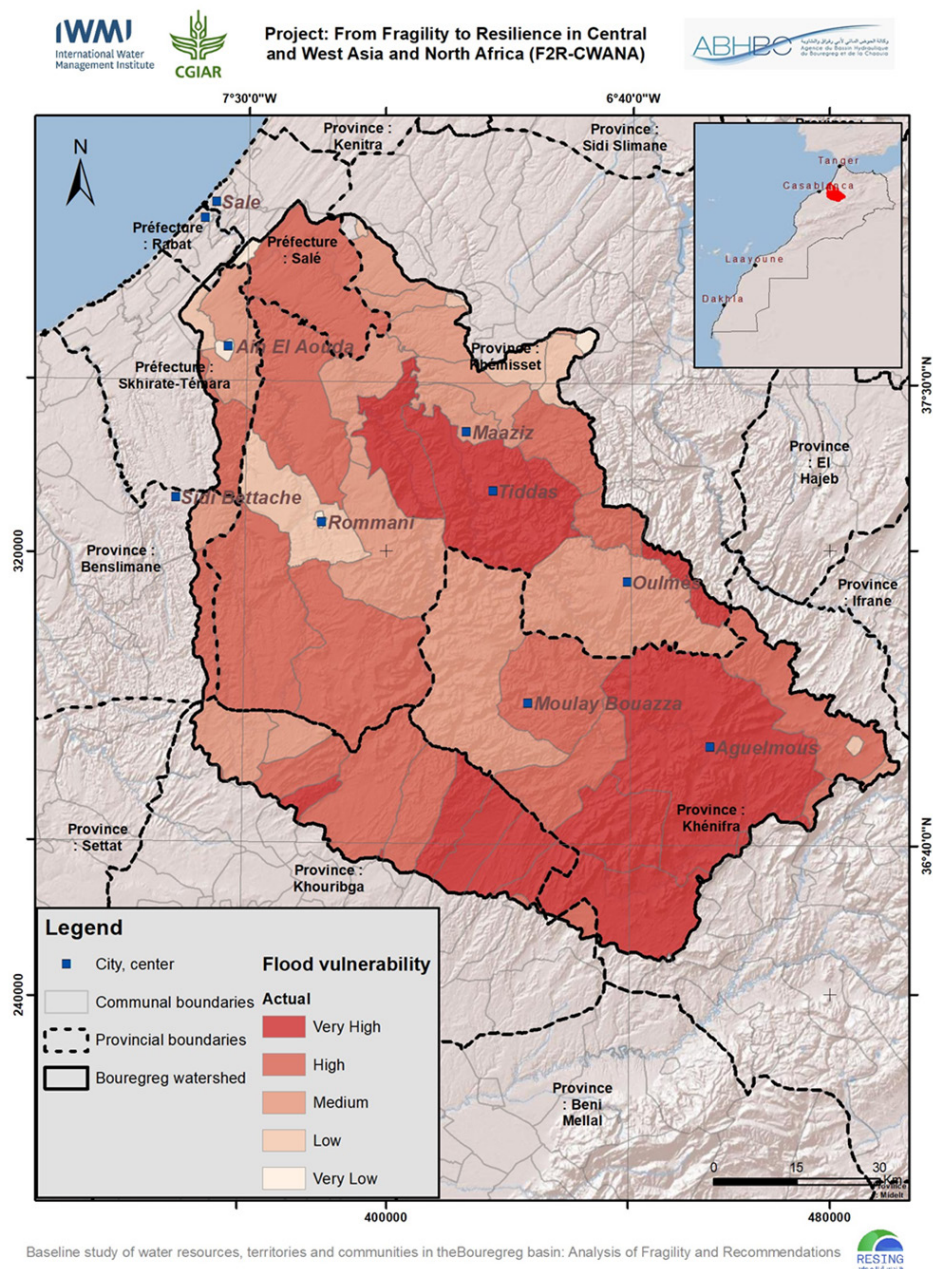
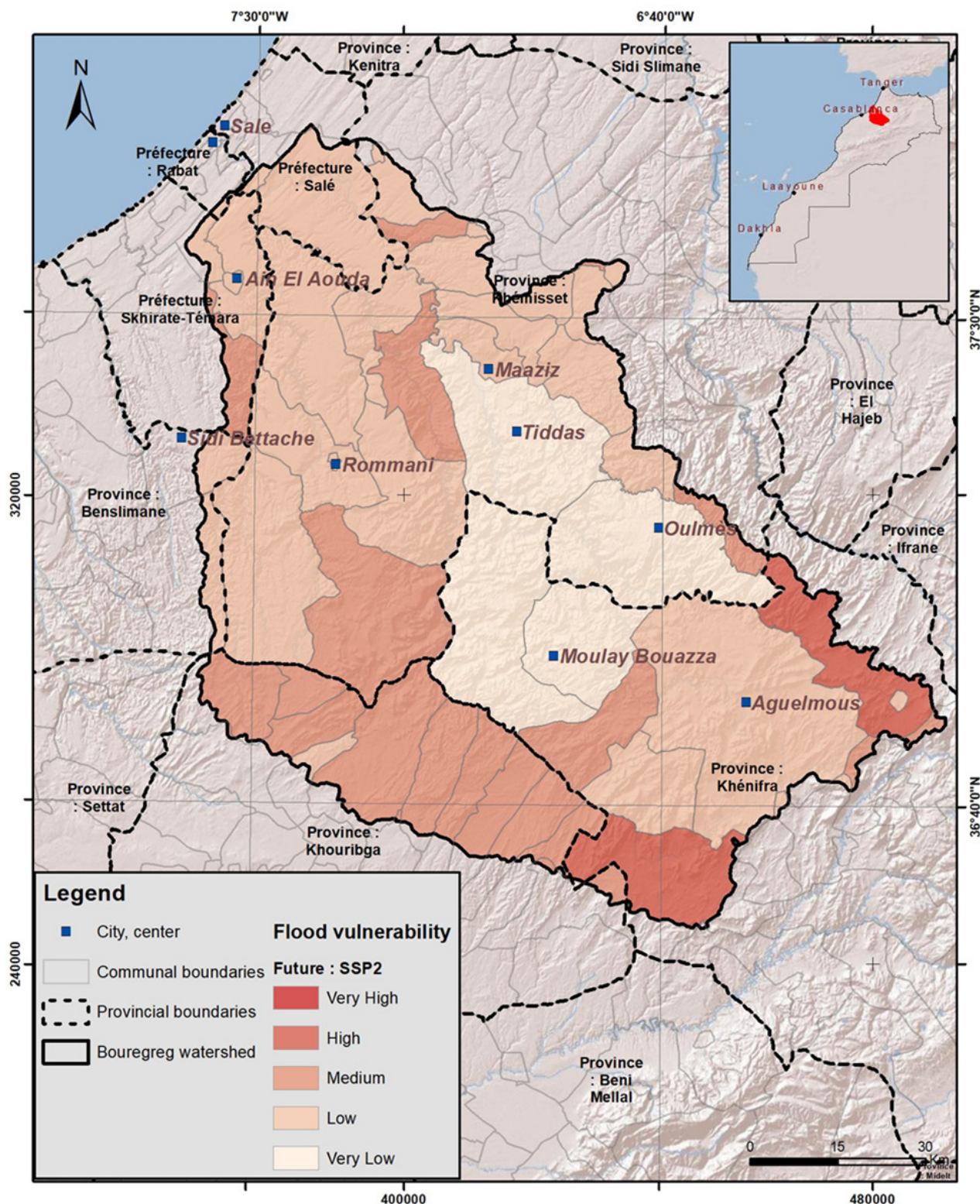


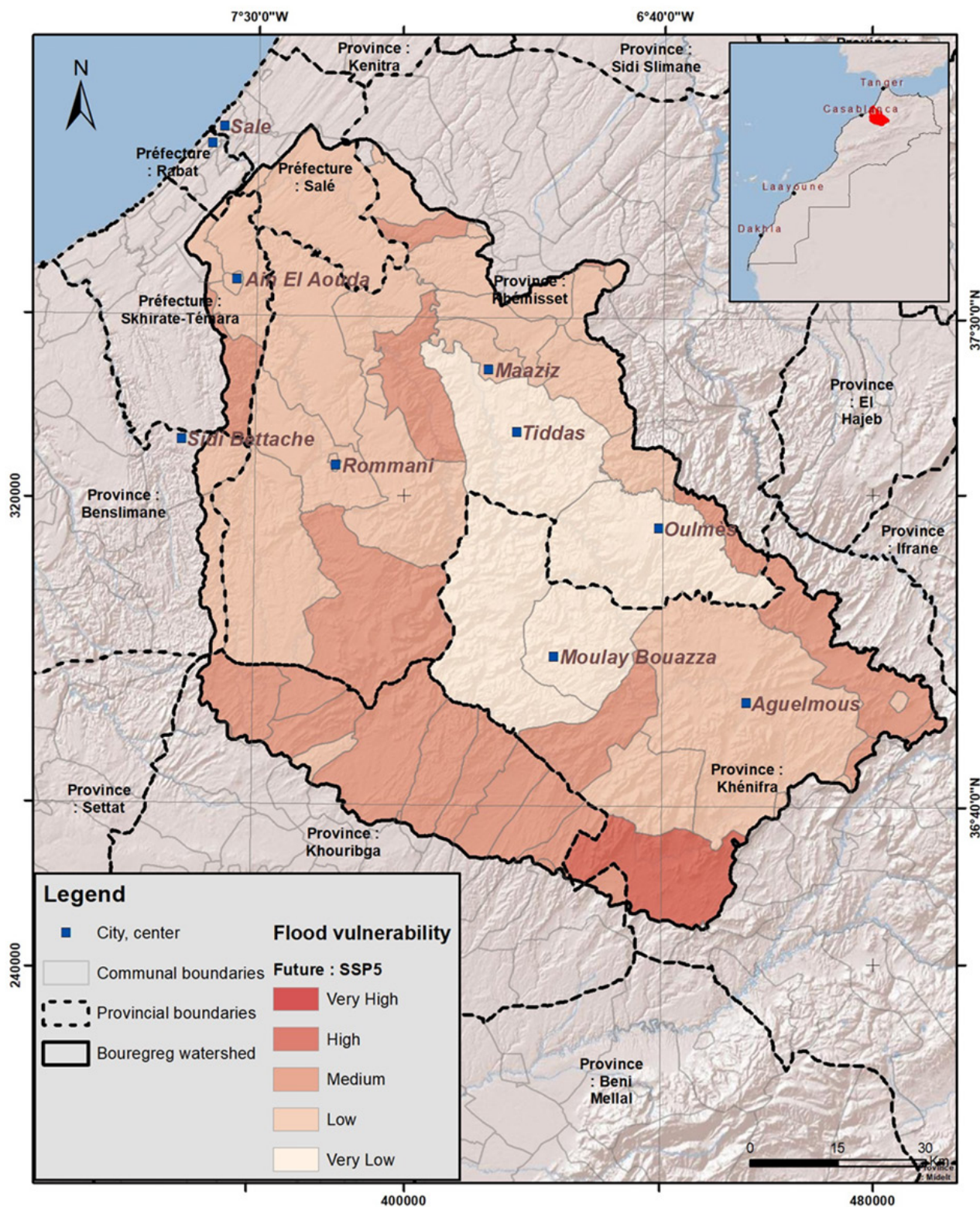
Figure 43. Vulnerability to flood in the Bouregreg Basin (current state). *Source:* IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 44. Vulnerability to flood in the Bouregreg Basin (future state – SSP2- RCP4.5)

Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 45. Vulnerability to flood in the Bouregreg Basin (future state – SSP5-RCP8.5)

Source: IWMI

Exposure and Vulnerability to Drought

Exposure to Drought

The analysis of drought exposure considers several factors, including the spatial distribution of agricultural land, population density and drought occurrences measured by the SPEI. Current findings show that exposure values are predominantly moderate to high, especially in southern municipalities that rely on rain-fed cereal crops and receive low precipitation (Figure 46). Future projections indicate an upward trend in drought exposure throughout the region (Figures 47 and 48).

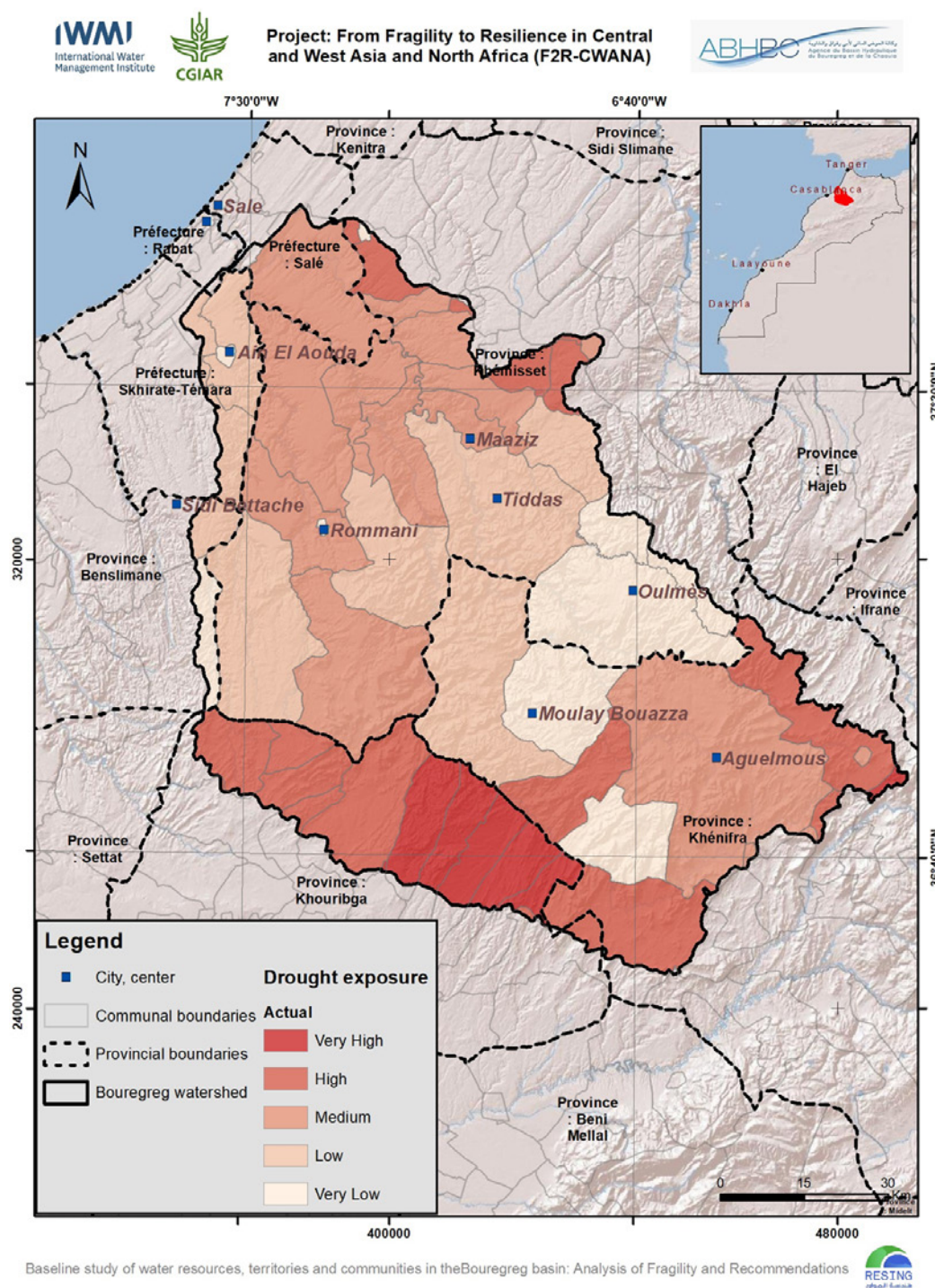
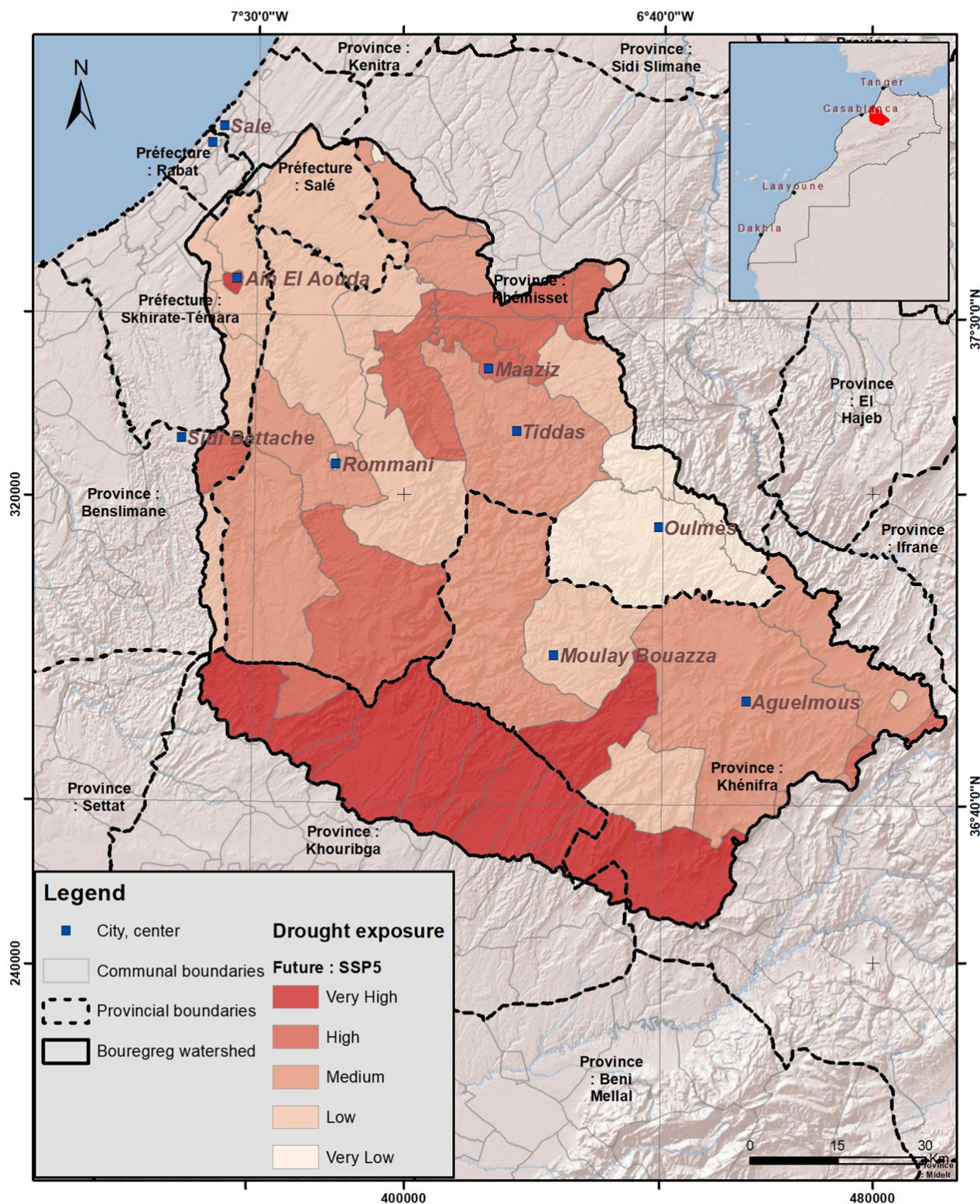


Figure 46. Exposure to drought in the Bouregreg Basin (current state)

Source: IWMI



RESIN



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 48. Exposure to drought in the Bouregreg Basin (future state – SSP5-RCP8.5)

Source: IWMI

Vulnerability to Drought

Mapping current drought vulnerability reveals at-risk areas, especially in the southeastern and southwestern portions of the basin (Figure 49). The SSP2-4.5 and SSP5-8.5 scenarios presented respectively in Figures 50 and 51 shows spatial variations, highlighting the complex factors that influence future vulnerability. These findings underscore the need for tailored adaptation strategies in different regions to enhance resilience to drought.

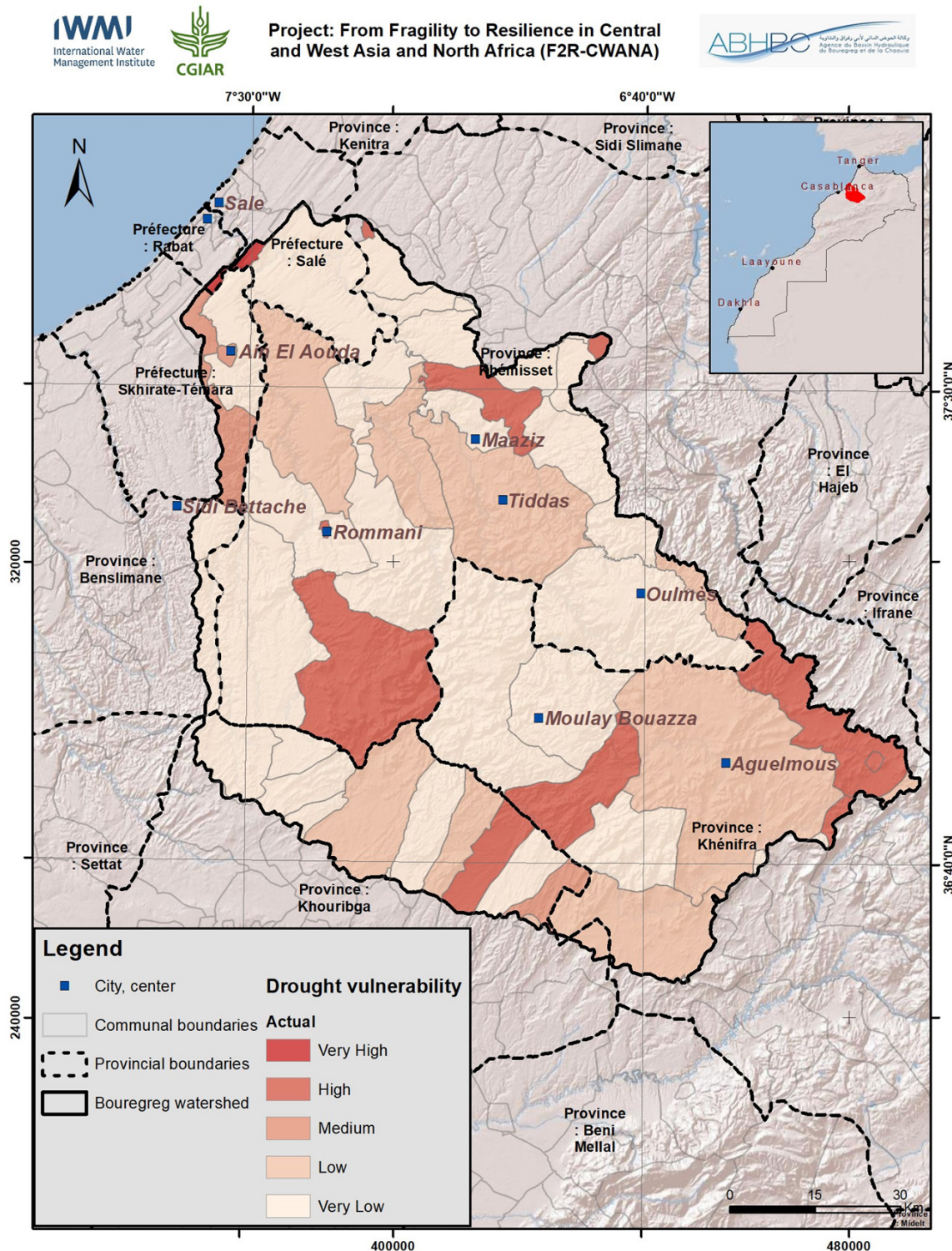
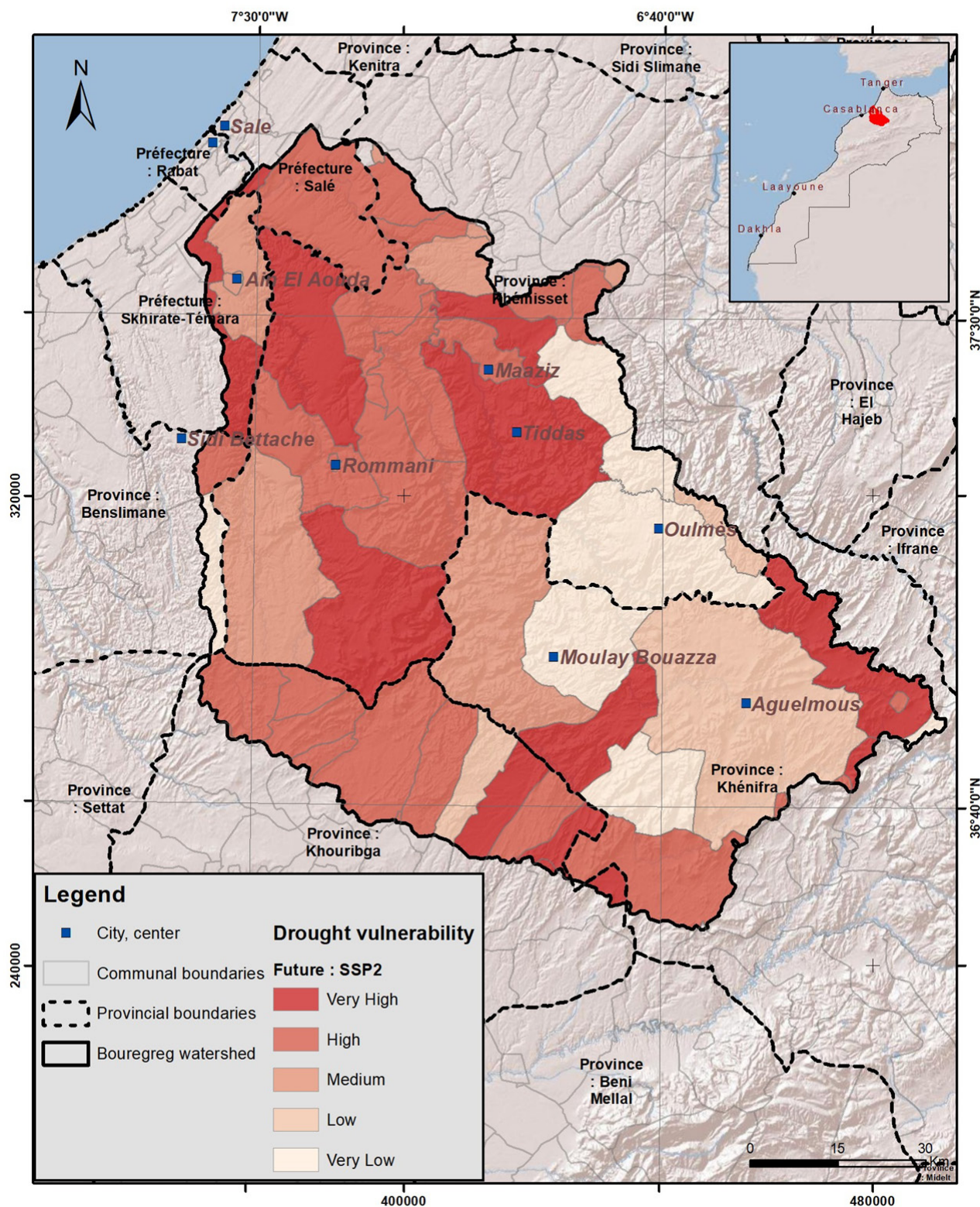


Figure 49. Vulnerability to drought in the Bouregreg Basin (current state)

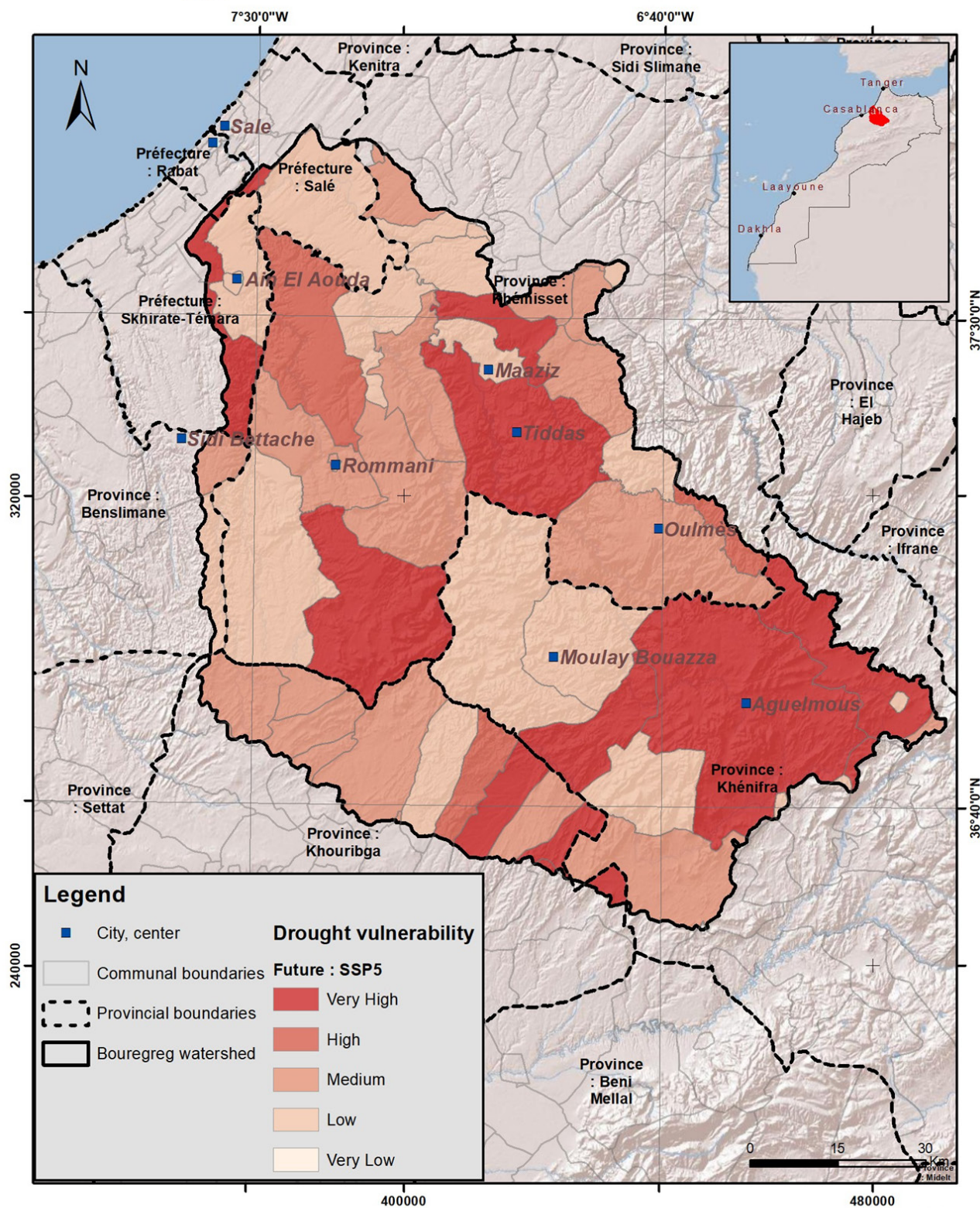
Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 50. Vulnerability to drought in the Bouregreg Basin (future state – SSP2- RCP4.5)

Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 51. Vulnerability to drought in the Bouregreg Basin (future state – SSP5-RCP8.5)

Source: IWMI

Exposure and Vulnerability to Erosion

Exposure to Erosion

The analysis of erosion exposure considers the effects of livestock farming on vegetation cover. Current findings reveal that erosion exposure increases as one moves upstream, resulting in high exposure in nearly all communes throughout the basin (Figure 52). Future projections indicate that these high exposure levels will persist (Figures 53 and 54).

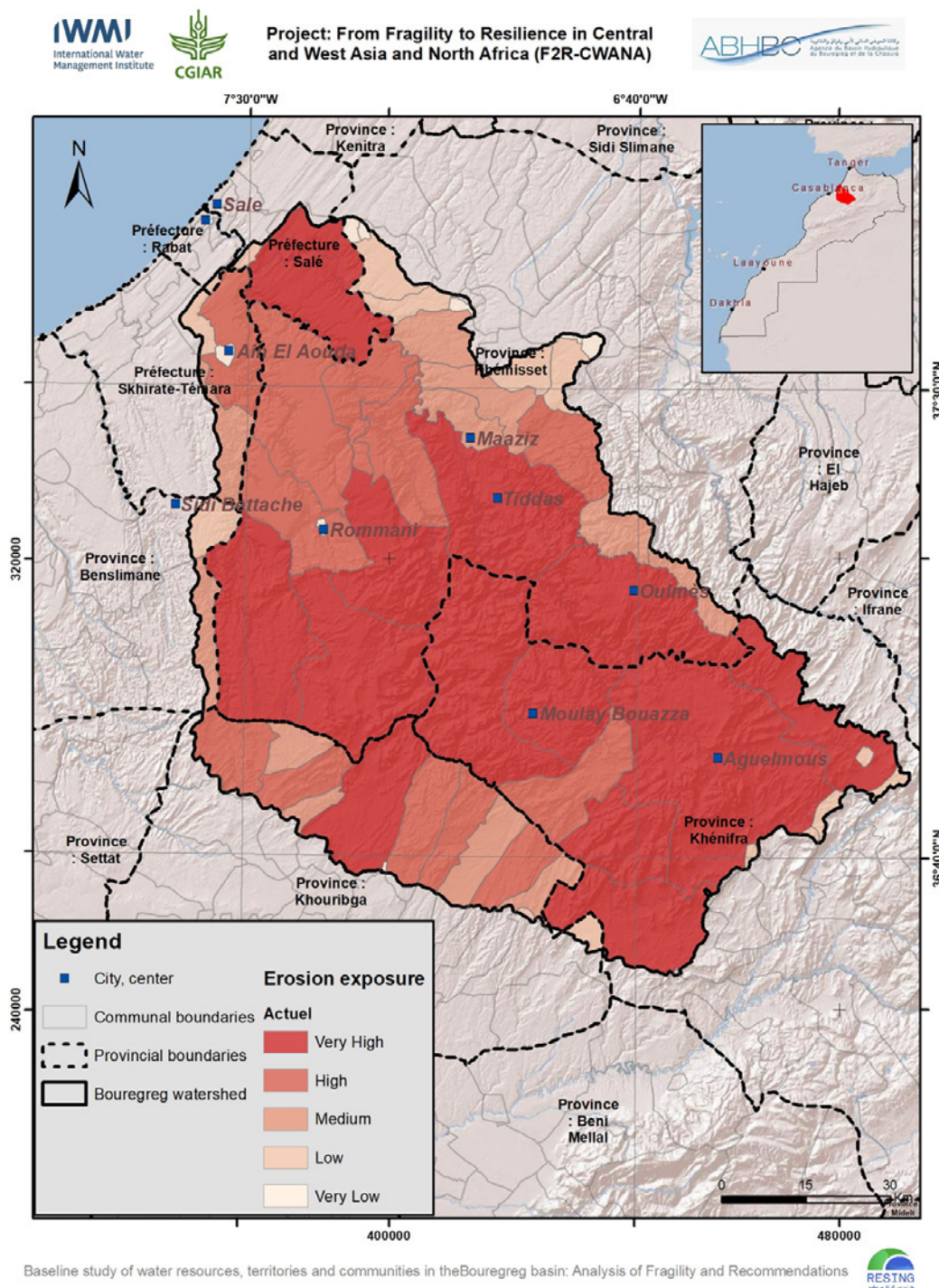
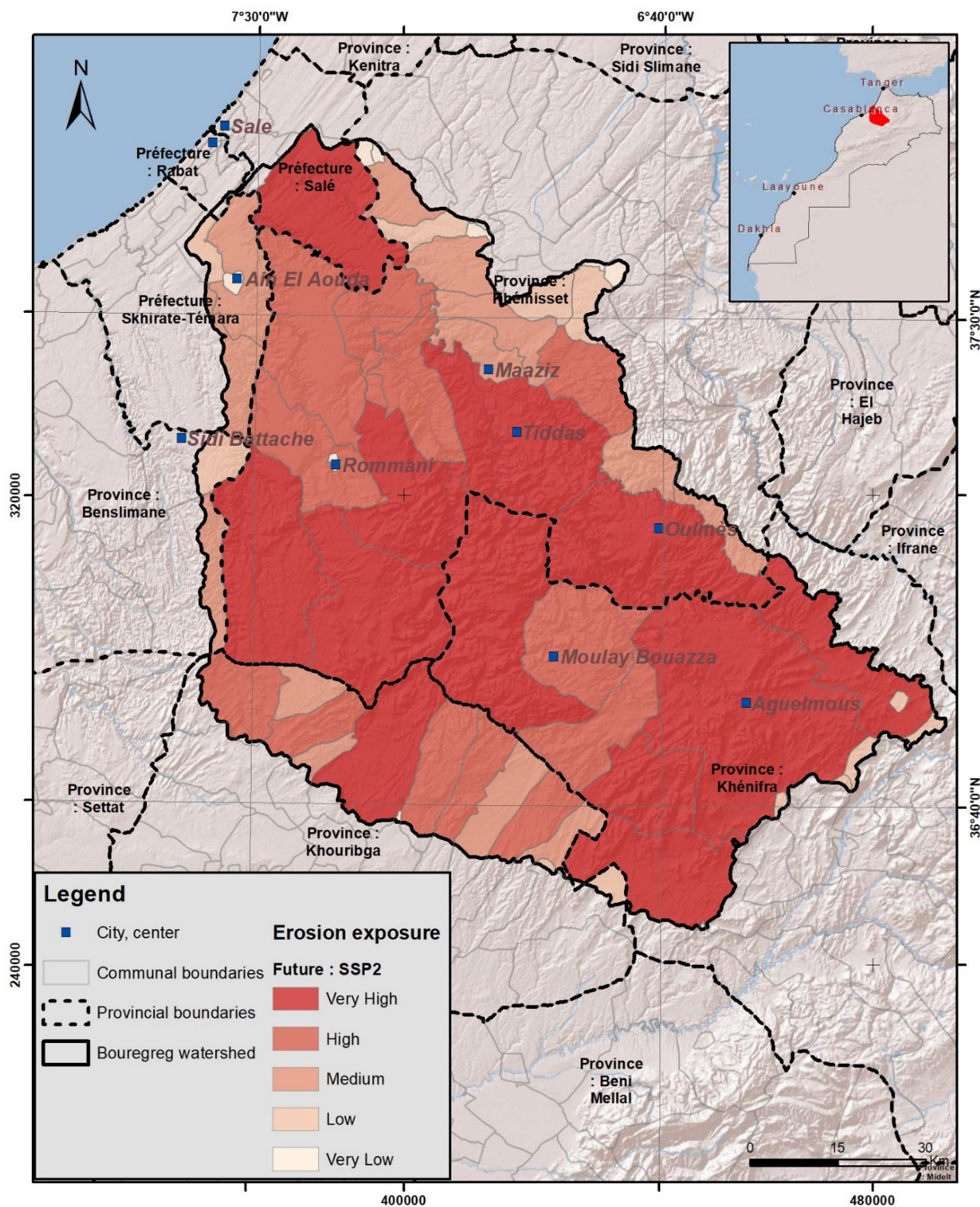


Figure 52. Exposure to erosion in the Bouregreg Basin (current state)

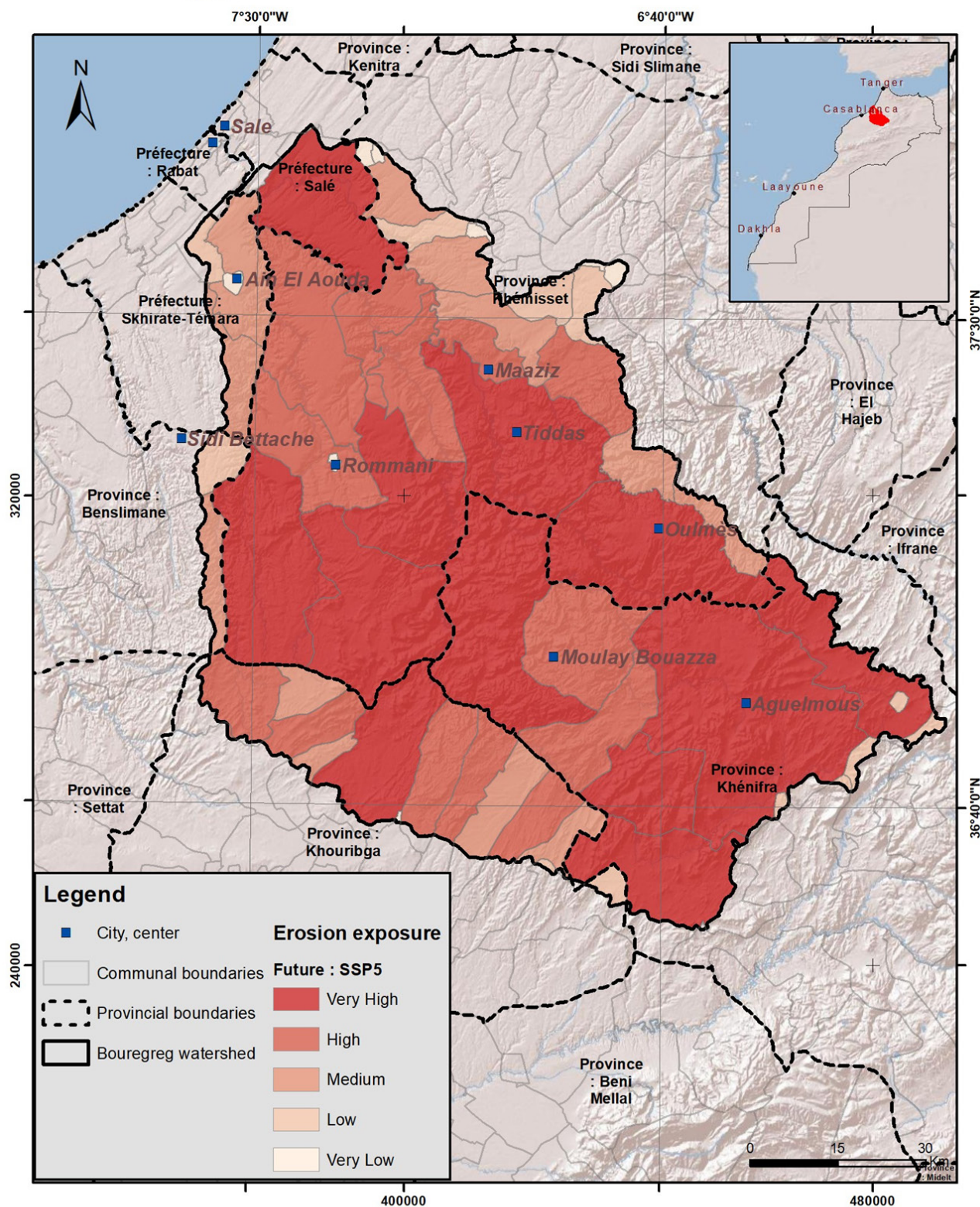
Source: IWM



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 53. Exposure to erosion in the Bouregreg Basin (future state – SSP2- RCP4.5)

Source: IWMI



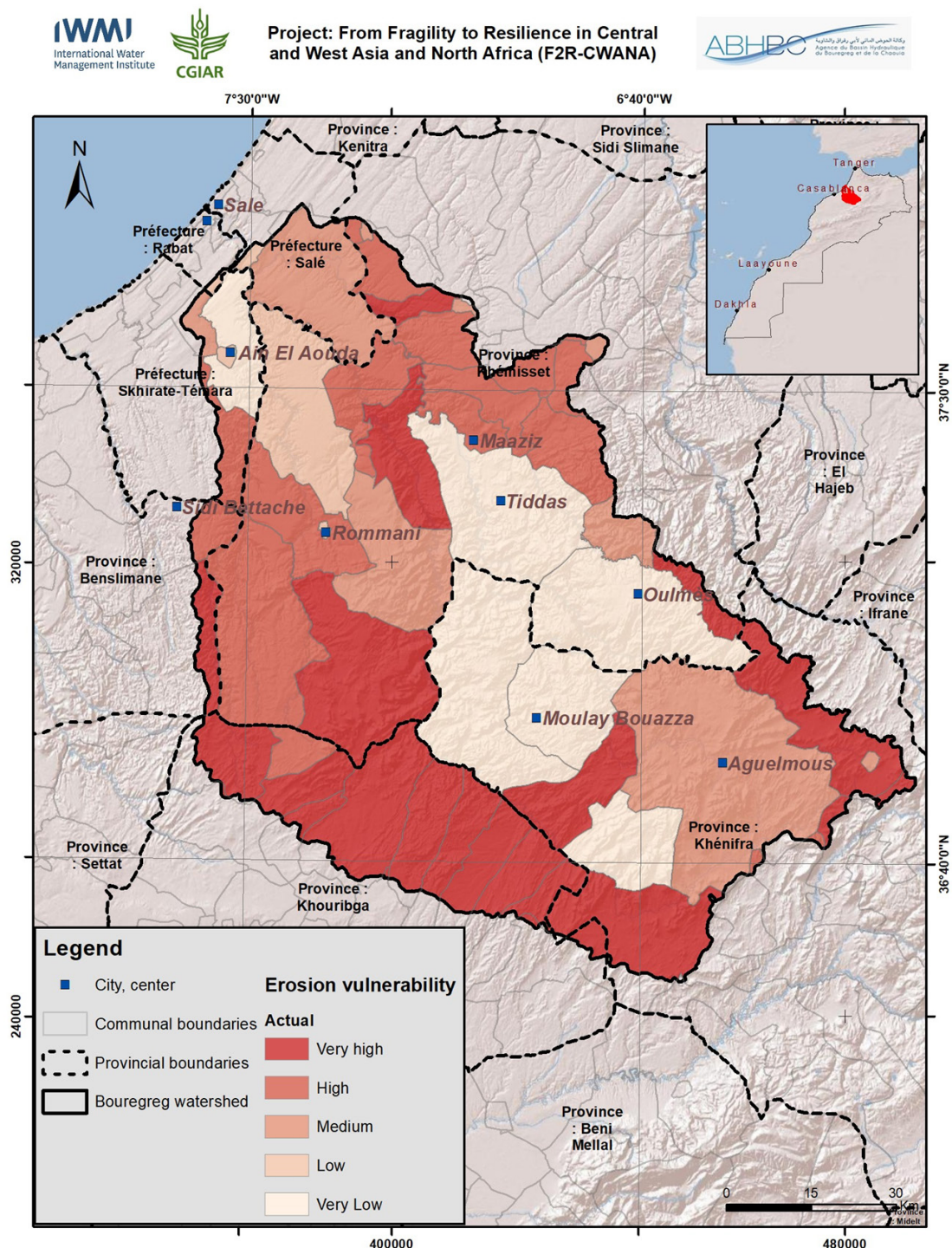
Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 54. Exposure to erosion in the Bouregreg Basin (future state – SSP5-RCP8.5)

Source: IWMI

Vulnerability to Erosion

The analysis of erosion vulnerability reveals significant differences among the municipalities in the basin (Figure 55). Projections based on the SSP2-4.5 and SSP5-8.5 scenarios presented in Figures 56 and 57 suggest that vulnerability will decrease in the central region of the basin, while the southwestern and eastern areas will remain highly vulnerable. These results underline the importance of targeted strategies to mitigate erosion risks effectively.

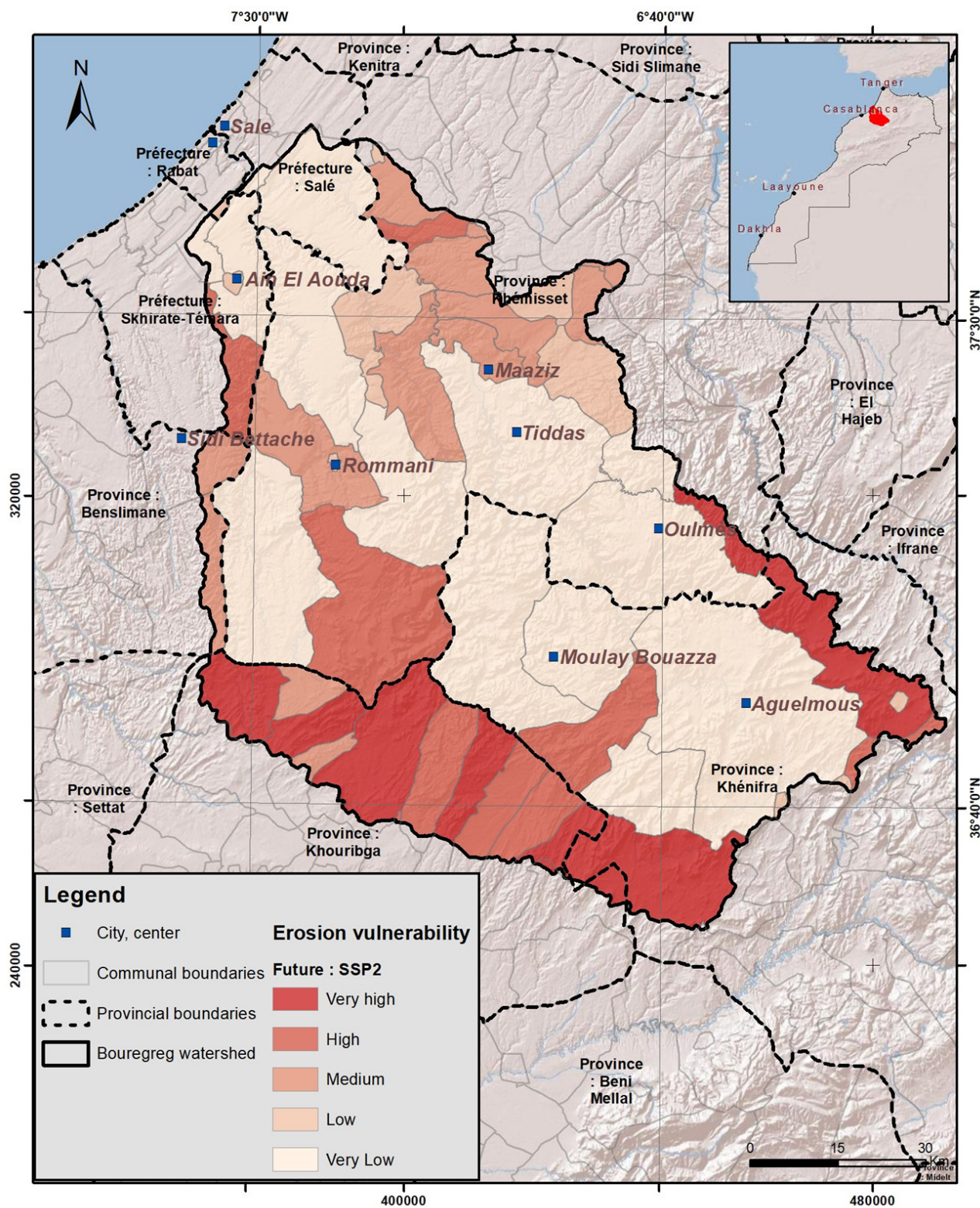


Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations



Figure 55. Vulnerability to erosion in the Bouregreg Basin (current state)

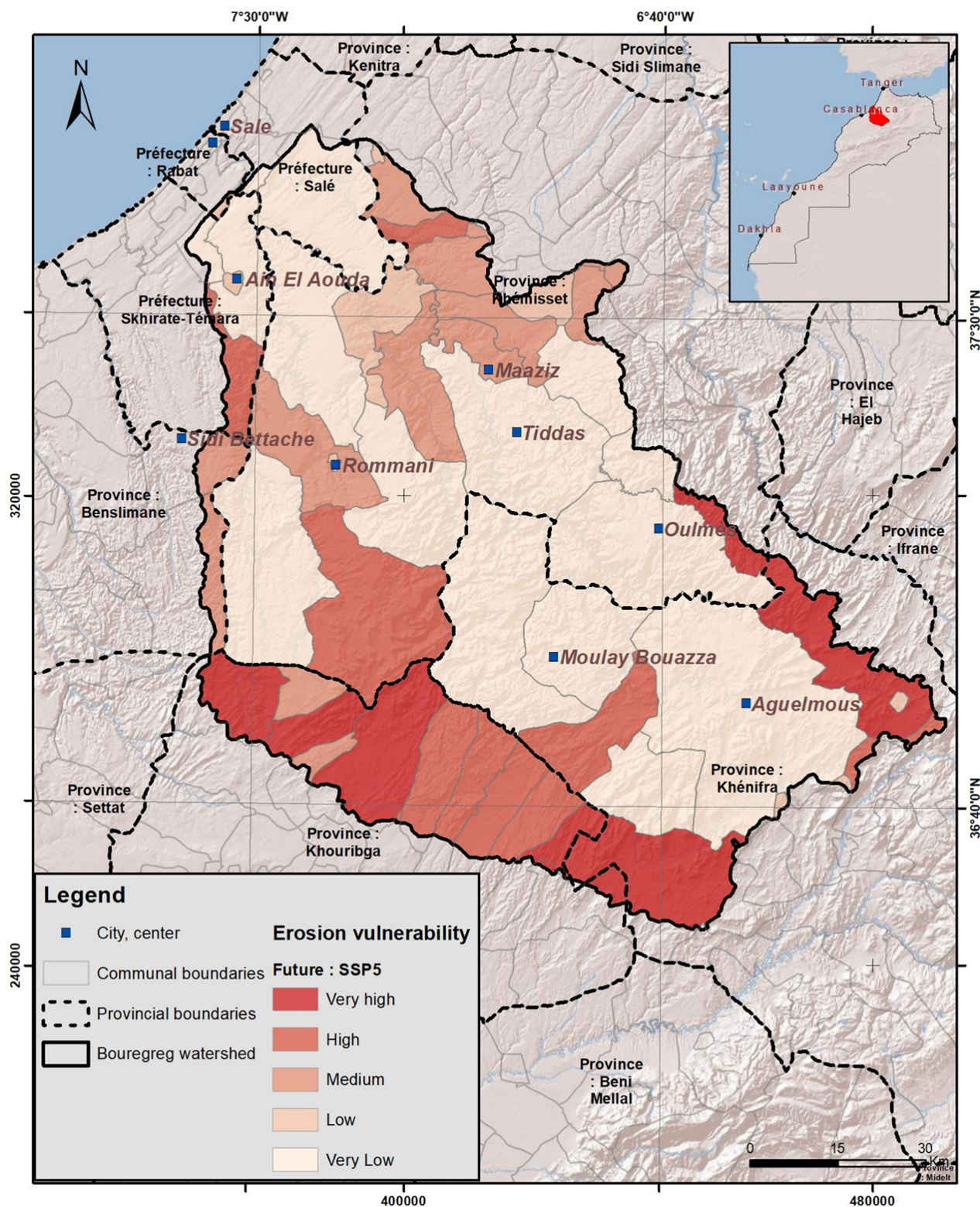
Source: IWM



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 56. Vulnerability to erosion in the Bouregreg Basin (future state – SSP2- RCP4.5)

Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 57. Vulnerability to erosion in the Bouregreg Basin (future state – SSP5-RCP8.5)

Source: IWMI

Multiple Exposure and Vulnerability

Multiple Exposure

The overall multi-exposure assessment in the municipalities of the Bouregreg Basin is based on aggregating all exposure factors as presented in Figure 58, revealing a heterogeneous distribution across the region. Riverine floods primarily affect urban areas adjacent to major riverbeds, while drought impacts the entire basin, albeit to varying degrees. Although all municipalities experience drought and erosion, only 34% are exposed to flooding due to the localized nature of this hazard. Currently, most communes in the basin experience medium exposure levels; however, Ait Ichou – northwest of the basin – shows a low composite exposure. Looking ahead, Ait Ichou's exposure is projected to rise from very low to low, while other communes are expected to maintain their current exposure levels (Figure 59 and 60).

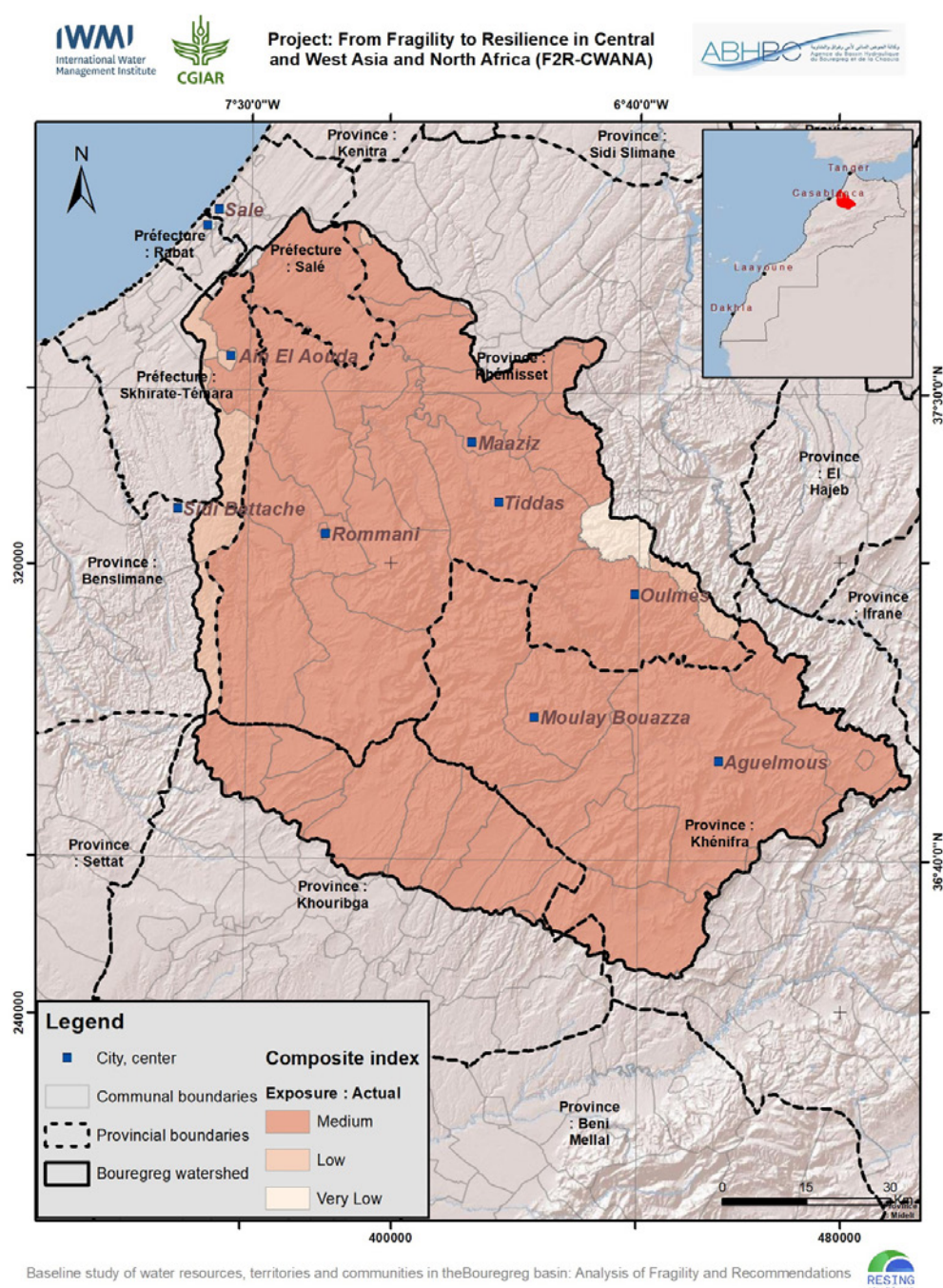
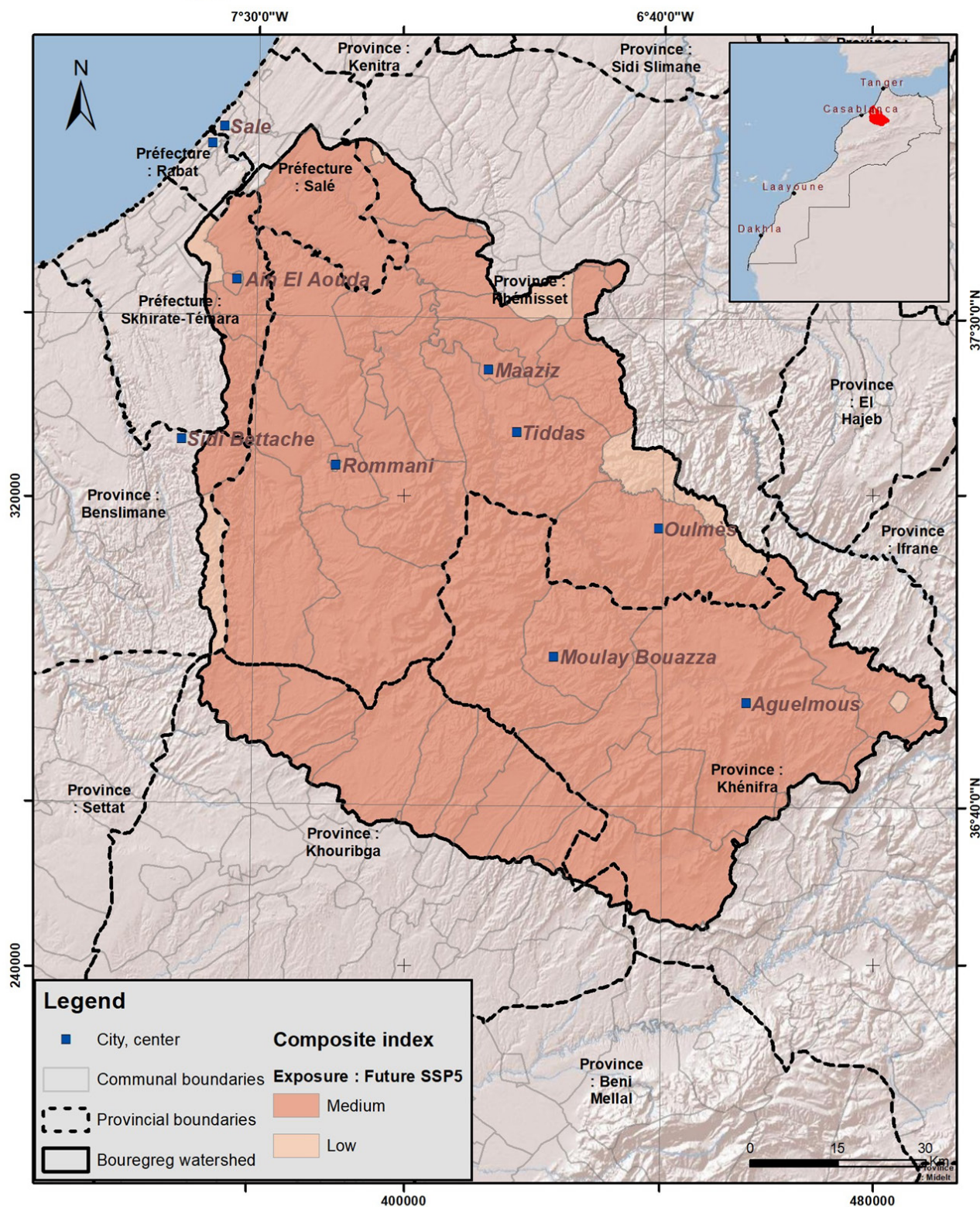


Figure 58. Multiple exposure in the Bouregreg Basin (current state)

Source: IWWI



Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

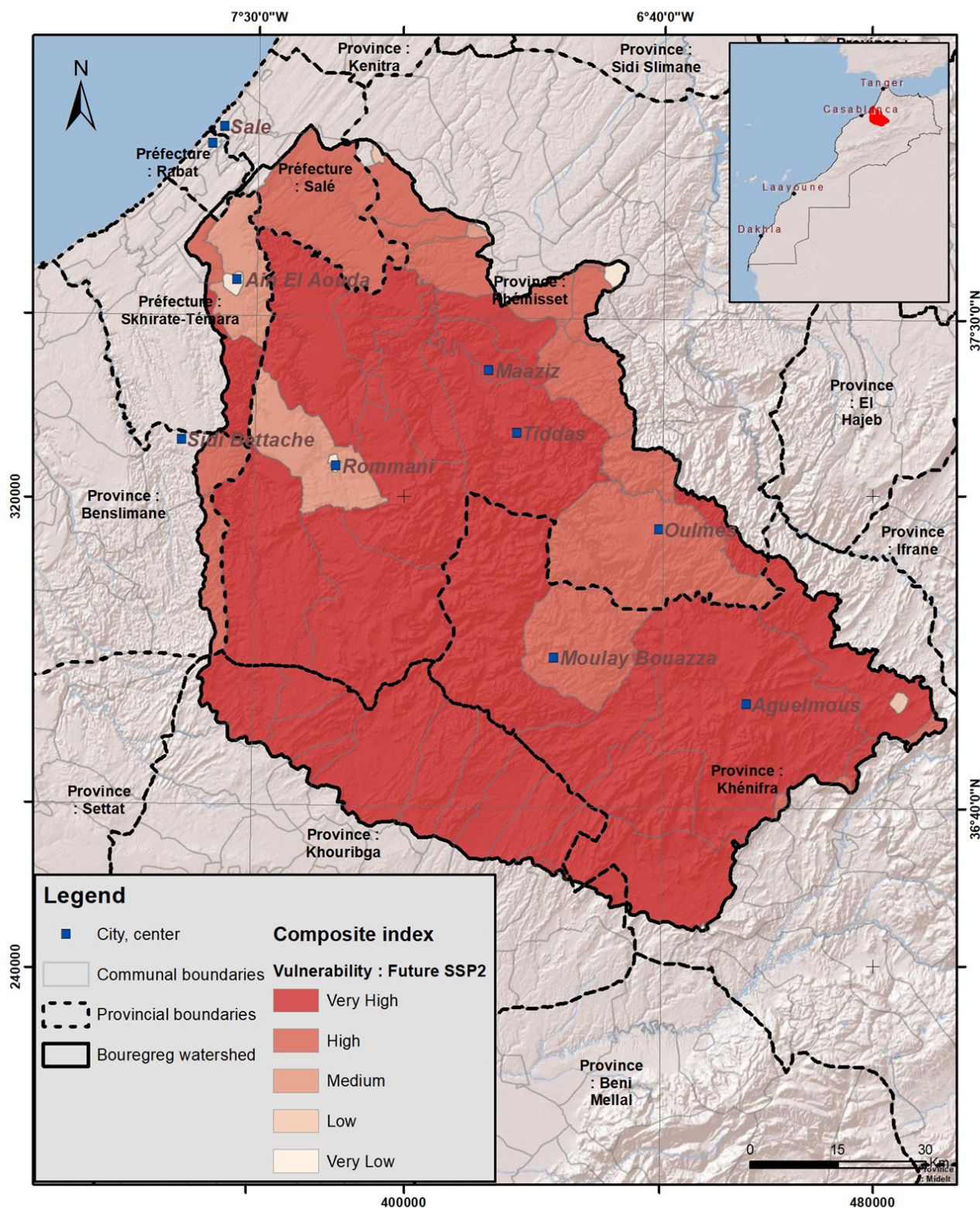
Figure 60. Multiple exposure in the Bouregreg Basin (future state – SSP5-RCP8.5)

Source: IWMI

The current composite vulnerability analysis of the Bouregreg Basin reveals a heterogeneous distribution of vulnerability levels, with upstream municipalities exhibiting higher vulnerability than those downstream (Figure 61).

Conversely, the SSP5-8.5 scenario suggests a significant reduction in vulnerability by 2040 (Figure 63). This improvement is attributed to substantial investments in human and social capital, as well as planned improvements in protective infrastructure, the implementation of early warning systems and strengthened adaptation measures. Together, these efforts should significantly reduce the region's vulnerability to natural hazards.

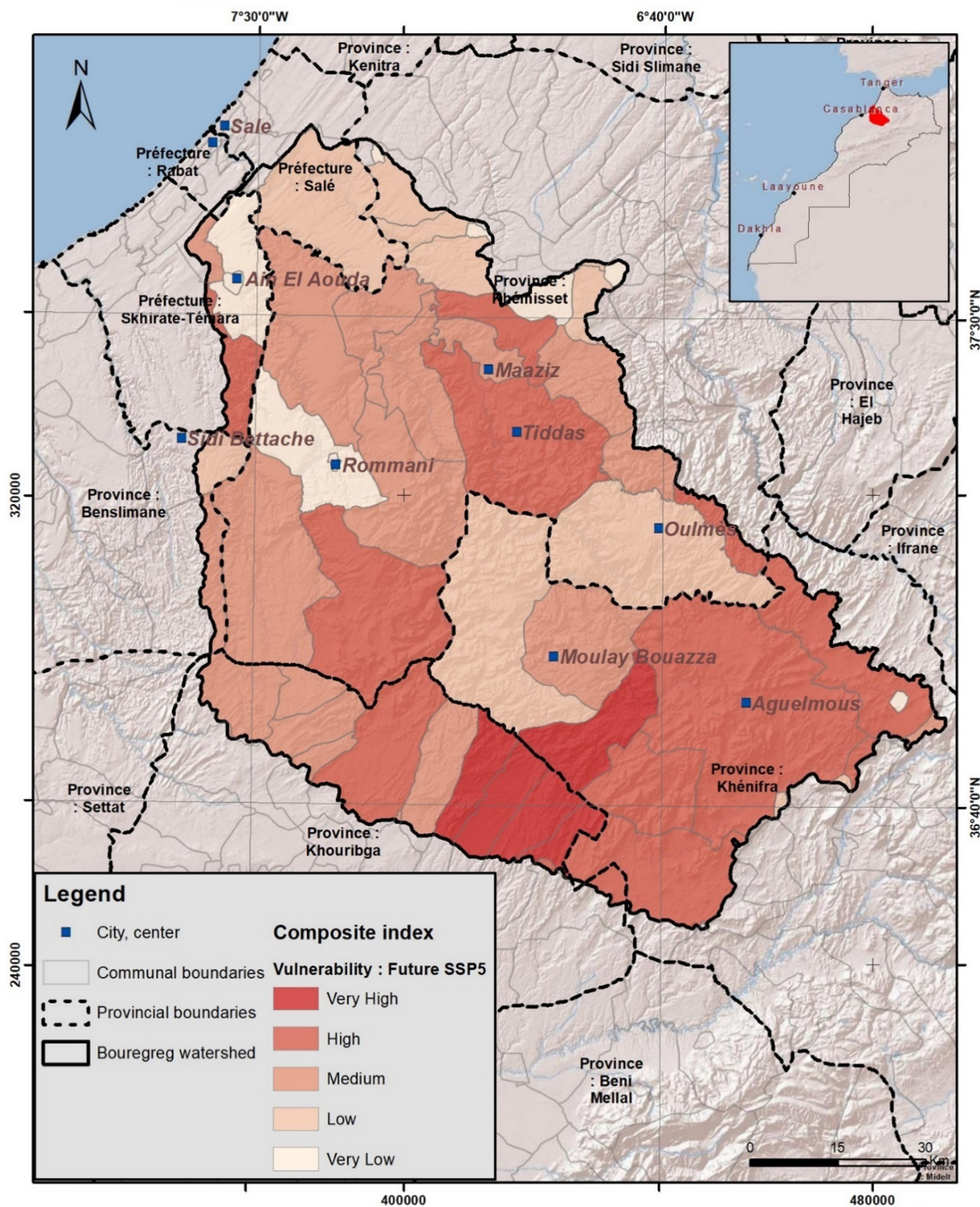




Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 62. Multiple vulnerability in the Bouregreg Basin (future state – SSP2- RCP4.5)

Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 63. Multiple vulnerability in the Bouregreg Basin (future state – SSP5-RCP8.5)

Source: IWMI

Fragility Analysis in the Bouregreg Basin

Fragility of the Bouregreg systems

Participatory engagement with stakeholders in workshops and focus groups has enabled a thorough examination of the impact chains that connect risks and impacts (Figure 64) – such as those related to water, food, and land – to various climatic factors, exposure and vulnerability. This collaborative effort has deepened our understanding of the elements contributing to the fragility of these systems.

The Bouregreg Basin's systems are mainly affected by three key risks: flooding, erosion and drought. Thus, examining these risks offers a clear perspective on the overall vulnerability of the basin's water, food and land systems.

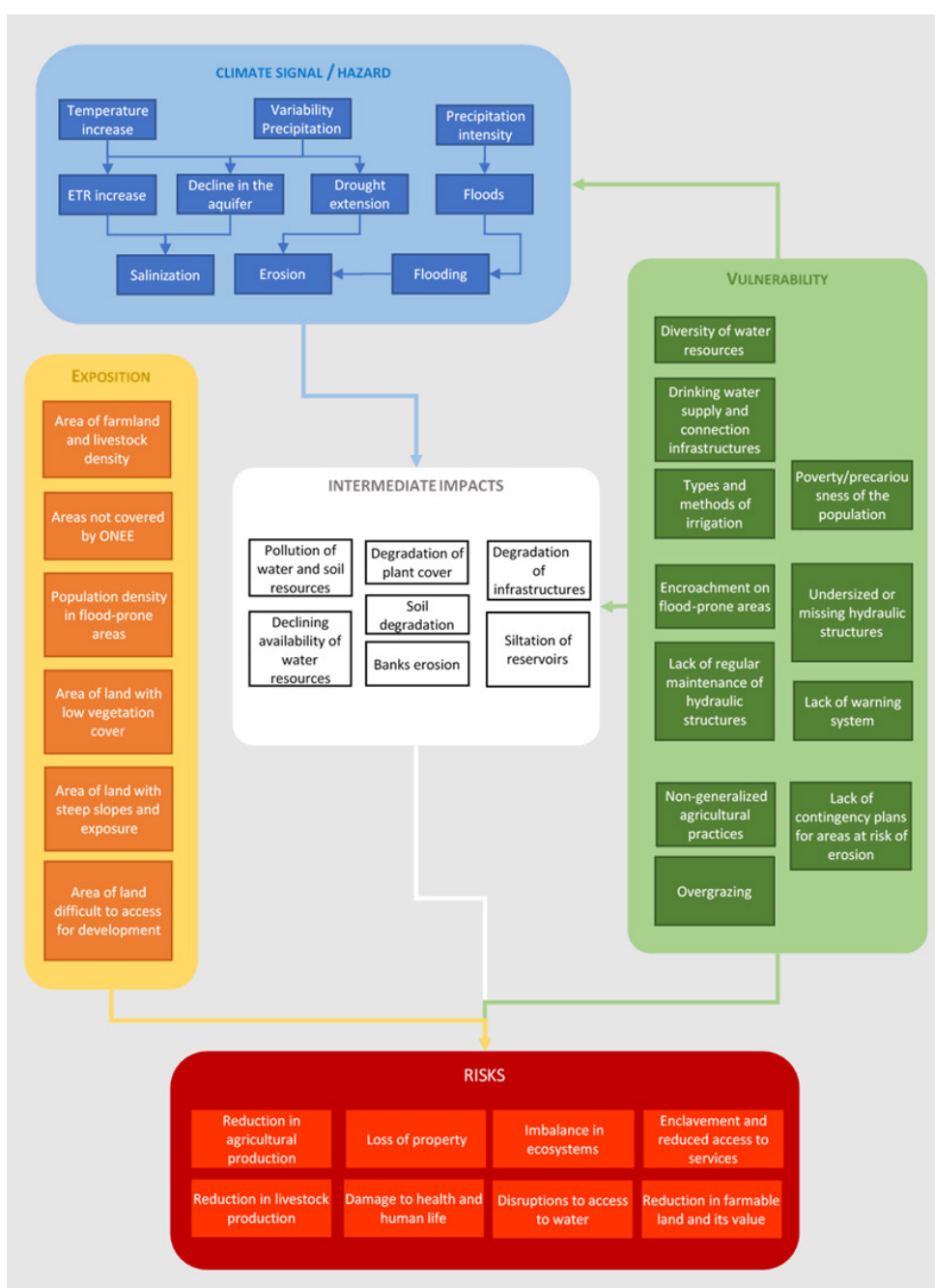


Figure 64. Analysis of the impact chains of climate change, focusing on the identification of vulnerability factors and their interdependence. *Source:* IWMI

Water System

Hazards pose significant challenges to the water system in the Bouregreg Basin, which is heavily affected by human activities. Like other regions in Morocco, the basin is experiencing unstable and unevenly distributed rainfall. This shift in precipitation patterns contributes to extreme phenomena such as droughts and floods while also increasing water demand, which is projected to rise by 10% by 2050. Furthermore, precipitation is anticipated to decrease by 10-20% by 2050, resulting in an even greater reduction in water runoff.

The Bouregreg Basin is home to the Tanoubert aquifer, which spans 40 km² around Maaziz. This vital resource is threatened by consecutive years of drought, persistently low rainfall and groundwater over-abstraction. As a result, the Tanoubert aquifer currently faces an annual deficit (PDAIRE-ABHBC, 2019) of 0.5 Mm³ due to low recharge rates and excessive extraction.

Rising water temperatures, low recharge, prolonged drought and the overuse of pesticides are contributing to the deterioration of water quality. Analysis of the groundwater's physico-chemical parameters in the Tanoubert aquifer indicates that its quality ranges from average to poor, primarily due to high salinity and nitrate levels.

The SPEI index shows that the factors contributing to drought have been on the rise since 2019. Between 1979 and 2022, drought frequency in the basin fluctuated between 14% and 24%, with severe drought occurring in nearly 3% of cases.

Notably, 2017, 2019 and 2022 marked some of the most severe droughts ever recorded, significantly impacting water resources, agriculture and the local environment. These conditions have significant implications for water resources, agriculture and the local environment, resulting in decreased water levels, reduced groundwater reserves and heightened pressure on available water resources. Additionally, the recurring drought poses challenges for water supply, water management and agriculture, potentially disrupting the local ecological balance.

Flooding in the basin causes significant population displacement, affecting demographic density in both temporary and permanent relocation sites. Floods also cause considerable damage to transportation infrastructure, including roads and bridges, compromising access to various regions within the Bouregreg Basin and possibly leading to loss of life. In October 2022, a tragic flood in Rommani took the life of an eleven-year-old boy, revealing how inadequately equipped the local infrastructure was to manage such high-water levels.

Similarly, when water supply infrastructure is damaged, they cause disruptions in access to drinking-water for affected communities, negatively impacting the local economy – affecting commercial, agricultural and industrial activities in the region.

Flooding is critical in maintaining aquatic ecosystems, regulating water flows and ensuring year-round water availability despite its adverse impact on people and infrastructure. However, the increased frequency and intensity of floods in recent decades – partly attributed to climate change and soil degradation – have detrimental impacts on hydraulic infrastructure and vegetation, destabilizing the overall balance of aquatic ecosystems. Nonetheless, these floods contribute to the natural water resource cycle, recharging aquifers and wetlands and supporting the long-term sustainability of these vital resources.

Vulnerability to flooding in the Bouregreg Basin has far-reaching impacts on the water system at various scales. Unregulated construction in flood-prone areas, especially in the communes of Maaziz and Ezzhiliga (According to observations of the research team during field visits conducted in 2023) has resulted in the loss of natural spaces and increased flooding risks. Urban encroachment undermines the basin's ability to absorb and manage floodwaters, resulting in material damage and loss of life.

Furthermore, with the exception of urban centers, most communes in the Bouregreg Basin are not serviced by ONEE's drinking water supply network, increasing residents' vulnerability to climatic hazards, especially drought.

The Tanoubert Wadi, located downstream from the wastewater discharge point in Maaziz, has poor water quality during the summer, because of organic and phosphate pollution. Similarly, Dayet Roumi experienced significant fish mortality (Ref.: Incident écologique survenu à Dayet Roumi Octobre 2016 highlighted during the key informant interviews by Mr Abdelaziz Houjjaji : Head of water division at the province) due to reduced oxygen levels associated with pollution, leading to asphyxiation.

Inadequate maintenance of existing hydraulic infrastructure further diminishes their effectiveness, jeopardizing the safety of residents. The economic repercussions are also significant, resulting in substantial losses for residents related to property, infrastructure and crops.

Furthermore, the limited size of the water table, coupled with the high demand for surface water, limits freshwater availability and increases the risk of water shortages in the Bouregreg Basin, affecting domestic needs as well as agricultural, industrial and commercial activities. Imbalances in water ecosystems pose major risks. Overexploitation of water resources, degradation of vegetation cover, pollution and climate change can disrupt the natural equilibrium, leading to lower water quality, restricted access and the spread of water-borne diseases. In addition, variations in hydrological regimes may exacerbate flooding and drought conditions.

The fragility of the water system is closely linked to several socio-economic factors. Population growth is exerting rising pressure on water resources by raising domestic use and irrigation demands. Rapid urbanization contributes to unsustainable water use, growing waste and disruption of natural hydrological cycles, affecting water quality and availability.

Unsustainable agricultural practices, marked by excessive water use and environmentally harmful methods, contribute to the over-exploitation of water resources, drainage issues and water quality degradation. Additionally, poverty and limited access to drinking water services leave disadvantaged populations reliant on unsafe water sources, resulting in health problems.

Lastly, inadequate management of water resources—characterized by ineffective regulation, insufficient monitoring and lack of coordination between stakeholders—further exacerbates the fragility of the water system. Water-related conflicts arising from competition over scarce resources, can heighten socio-economic and political tensions, adding further complexity to challenges in the water system.

Agri-food System

Rising temperatures and increased evapotranspiration, combined with limited precipitation, may significantly restrict the access of the agri-food system to freshwater, exacerbating water scarcity. This situation will likely lead to higher water demand, impacting aquatic ecosystems, shifting crop distribution and ultimately affecting the agricultural economy.

Projections indicate that mean annual temperatures could increase by 2°C to 3°C above the levels recorded from 1986 to 2005 by the mid-century (2046-2065). By the end of the century (2081-2100), under the high-emission RCP8.5 scenario, temperatures may rise by 3.3°C to 5.5°C, with the most significant increases occurring upstream compared to coastal areas.

Frequent droughts, driven by climate change, lead to decreased water availability for irrigation, which in turn causes a drop in usable farmland. This reduction poses significant challenges to food supply and may have long-term implications for access to basic food resources. Drought directly threatens water availability in agri-food ecosystems, impacting crops and livestock.

Reduced rainfall in and around the Bouregreg River during droughts adversely affects local farms, slowing their development and resulting in severe yield losses. The recurring drought conditions in the basin have reduced yields for Bour³ crops, cultivated on more than 90% of the basin's productive arable land.

³ Bour: designates a dry, non-irrigated cultivated area that is completely dependent on rainfall

This situation jeopardizes the economic viability of many farms in the Bouregreg region, which are already under water stress, thus, posing a significant threat to food security.

Drought also impacts farmland fertility, as water deficits dry out the soil, leading to a loss of organic matter and increased salinization from the concentration of mineral salts. The growing pressure on water resources threatens animal and plant production in the Bouregreg region, further compromising food security.

The fragility of the agri-food system in the Bouregreg Basin is shaped by socio-economic factors unique to the region. Firstly, reliance on climatic conditions makes local agriculture vulnerable to climate change and extreme weather events, disrupting agricultural production for communities whose livelihoods depend on this activity. Additionally, local socio-economic inequalities regarding access to resources, markets and technologies, generate disparities within the farming communities of the Bouregreg Basin, affecting both social cohesion and economic stability.

Local demographic pressure intensifies the fragility of agri-food systems in the Bouregreg Basin by straining limited natural resources, especially land and water, while simultaneously increasing food demands due to population growth – adding new challenges to regional food security.

Land System

Climate change is negatively impacting soil health, leading to increased erosion. This erosion is primarily driven by heavier rainfall and storms associated with extreme temperatures, which accelerate soil leaching. Additionally, extended droughts reduce protective vegetation cover, further increasing the risk of erosion.

Erosion can have severe consequences, including the loss of agricultural land and damage to infrastructure. In addition to reduced vegetation cover, erosion and its impacts can lead to socio-economic difficulties, including lower incomes and precarious living conditions. Farmland in the basin that is exposed to erosion faces detrimental impacts—such as nutrient loss, soil structure degradation and decreased productivity—all of which threaten farming livelihoods. Moreover, eroded steep slopes are more prone to landslides due to reduced soil stability. In the Bouregreg Basin, the total sediment produced amounts to 3.7 million tons per year, with the Ksiksou Wadi and Tabahhart Wadi sub-basins accounting for 61% of this total (ABHBC, 2021).

Erosion significantly affects vegetation cover, resulting in the loss of fertile soil. Practices like unsustainable agriculture and deforestation contribute to soil erosion, with topsoil washed away by water or wind, resulting in reduced soil fertility. Without a robust vegetation cover, plants are exposed to harsh conditions, which can lead to loss of agricultural productivity and heightened risk of flooding. The degradation of vegetation cover undermines terrestrial ecosystems, compromising soil stability and overall quality while also diminishing their resilience. In the Bouregreg watershed, soil degradation is moderately high, with rates ranging from 451 to 1130 t/km²/year. (ABHBC, 2021)

In addition to degrading soil and plant cover, erosion significantly contributes to the siltation of dams and reservoirs, particularly the SMBA dam, which supplies drinking water to the Rabat-Témara-Casablanca region. Erosion also threatens investments aimed at mobilizing surface water to meet demand.

Overgrazing—particularly by cattle—in the basin, is also a key factor of soil degradation, as it reduces vegetation, vital for preventing erosion and maintaining soil stability. By exposing soils to harsh weather, overgrazing accelerates erosion and affects soil health, ultimately impacting agricultural productivity in the basin. Approximately 52% of the land in the Bouregreg Basin is affected by overgrazing. This leads to a shortage of 56 million forest units compared to the estimated annual requirement of 108 million units.

Furthermore, the absence of contingency plans for erosion-prone regions in the basin exacerbates the situation. In the absence of effective preventative strategies and quick response actions, these at-risk areas will face considerable harm to agricultural land, infrastructure and the wider ecosystem.

Specific socio-economic factors influence the fragility of the land system in the Bouregreg Basin. Poverty rates and livestock herd sizes are closely correlated to weather conditions and the availability of food resources. Extreme weather events and erosion, chip at the livelihoods and stability of local community members, leading to disruptions. In addition, the size of forest areas directly influences the fragility of the terrestrial system in this basin, due to the diverse socio-economic and biodiversity options offered by this ecosystem to local communities.

Results of the Fragility in the Bouregreg

Approach to calculating the composite fragility indicator

The overall composite fragility for each municipality of the Bouregreg Basin is determined by combining all impact-specific risks. However, this potential fragility is not evenly distributed across the basin, due to varying spatial patterns of hazards and exposed elements. For example, riverine floods are highly localized, affecting areas immediately surrounding major riverbeds. At the same time, drought—assessed through precipitation and temperature—can occur with varying severity throughout the entire basin.

Vulnerability and exposure scores were integrated into a risk assessment using a “fragility-matrix” approach (Figure 65). This matrix serves as a category-based evaluation tool that assigns a level of fragility based on the combination of nominal categories of two components. Although initially designed to evaluate specific events' probability and severity, this tool has been adapted here to combine vulnerability and exposure.

For both components, scores were transformed into categories—very low, low, moderate, high and very high—using fixed thresholds based on equal intervals relative to the maximum value for exposure and vulnerability types, respectively. According to the risk framework developed by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5), the absence of either exposure or vulnerability indicates no risk. Therefore, municipalities without exposure to a specific risk, are not considered at risk even if they have some level of vulnerability. The resulting categories for exposure and vulnerability were then combined using the following risk matrix:

EXPOSURE	Very High	Moderate	High	High	Very high	Very high
	High	Low	Moderate	Moderate	High	Very high
	Moderate	Low	Moderate	Moderate	Moderate	High
	Low	Very low	Low	Moderate	Moderate	High
	Very Low	Very low	Very low	Low	Low	Moderate
		Very Low	Low	Moderate	High	Very High
		VULNERABILITY				

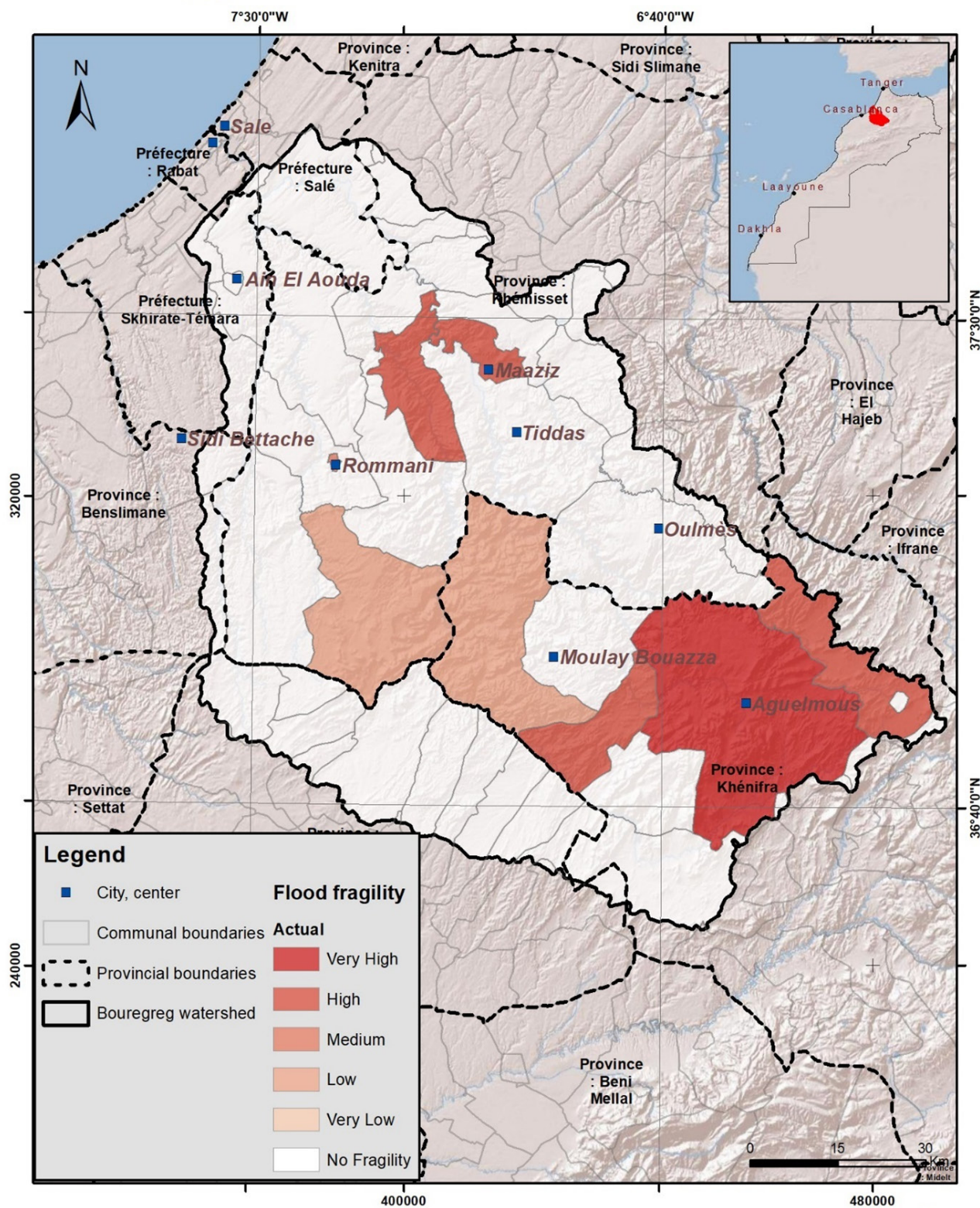
Figure 65. Risk matrix (Exposure and vulnerability combined)

Source: Author's creation

Flood-related Fragility

The analysis of flood-related fragility in the Bouregreg Basin identifies 12 communes, particularly Aguelmous, as highly vulnerable due to inadequate hydraulic infrastructure (Figure 66). However, future projections under the SSP2-RCP4.5 and SSP5-RCP8.5 scenarios (Figure 67 and 68) suggest a significant reduction in flood vulnerability across all communes.

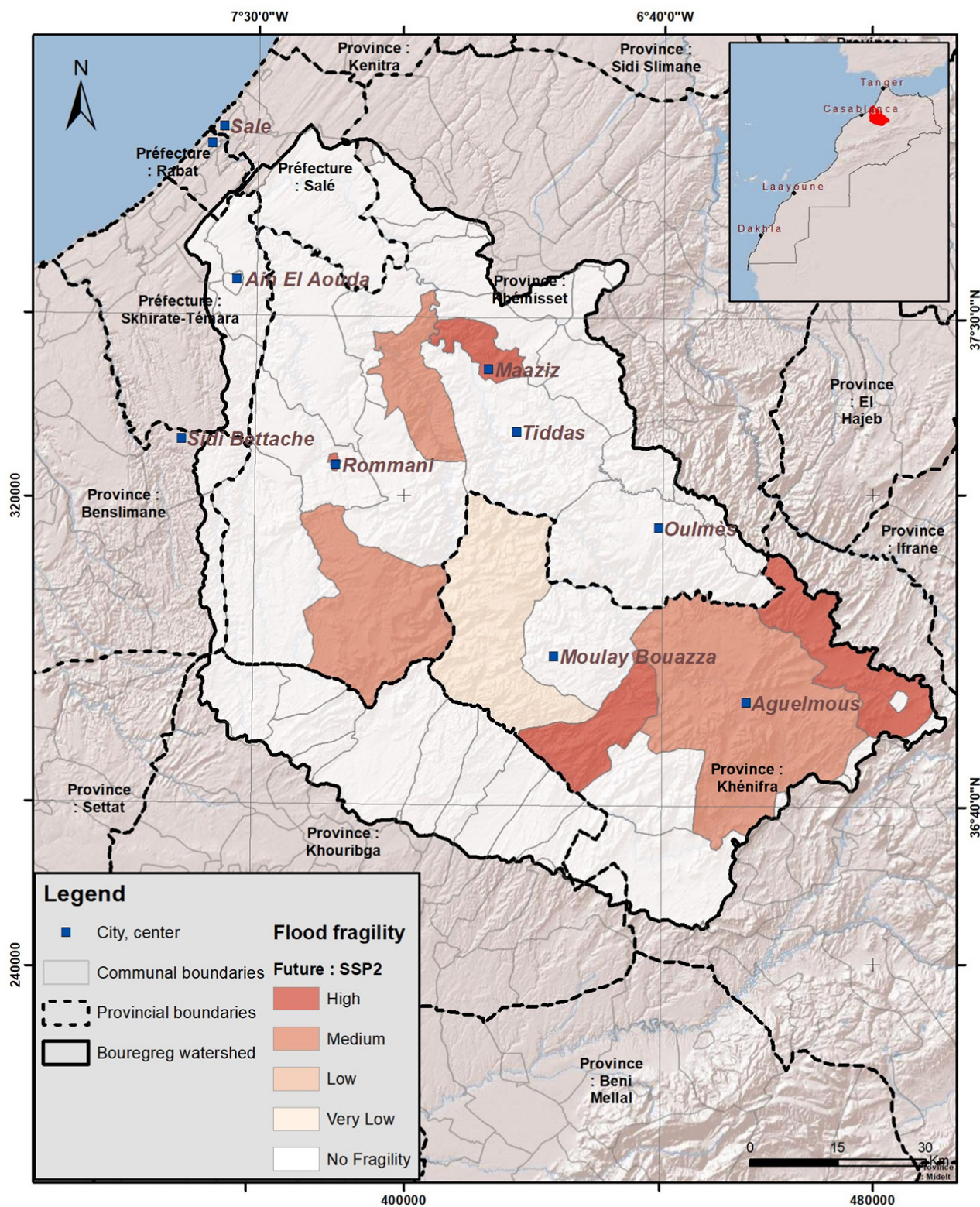
It reflects successful efforts to enhance protective infrastructure, implement early warning systems and adopt adaptive measures. Such proactive strategies have contributed to a substantial decrease in the region's overall vulnerability to floods, demonstrating the effectiveness of strategic planning and intervention in mitigating impacts on the Bouregreg Basin communities.



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 66. Flood-related fragility in the Bouregreg Basin (current state)

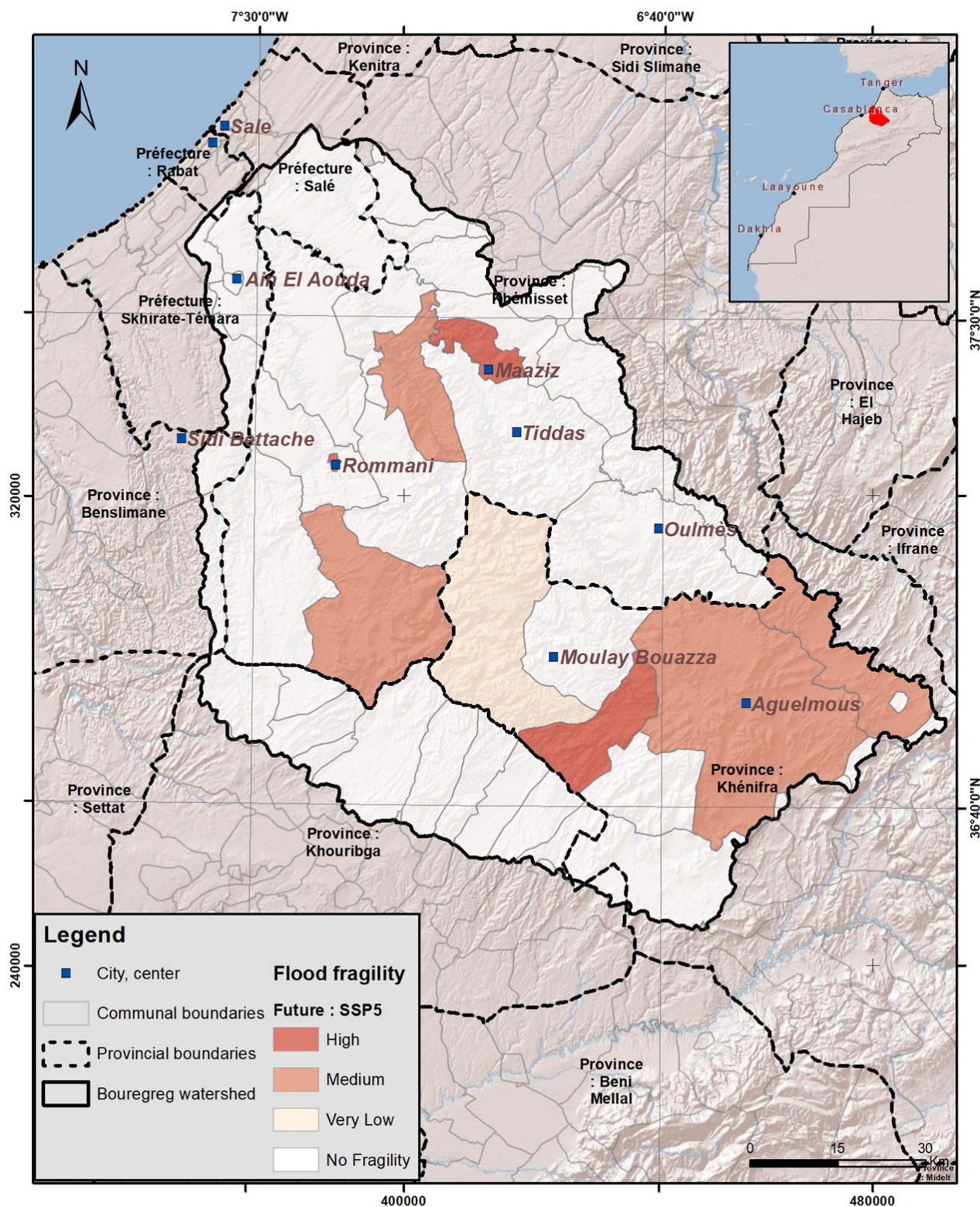
Source: IWMI



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Figure 67. Flood-related fragility in the Bouregreg Basin (future state – SSP2- RCP4.5)

Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 68. Flood-related fragility in the Bouregreg Basin (future state – SSP5-RCP8.5)

Source: IWMI

Drought-related Fragility

The combined assessment of drought vulnerability and exposure, reveals that fragility is highest in the southeast and southwest of the Bouregreg Basin, indicating increased susceptibility to the effect of drought in these regions (Figure 69).

Under the SSP2 scenario (Figure 70), most communes experience a substantial shift from low to high fragility levels, indicating an overall increase in vulnerability and exposure, and emphasizing the need for adaptive measures. Conversely, the SSP5 scenario (Figure 71) shows a noticeable reduction in fragility, suggesting that specific communities may enhance their resilience potential. This optimistic outlook implies that proactive measures or regional changes could improve resilience and reduce fragility, in response to impacts of drought. This information is essential for developing targeted strategies and policies to mitigate adverse effects of drought in the Bouregreg Basin, taking into account varying scenarios and the potential for enhanced resilience in specific situations.

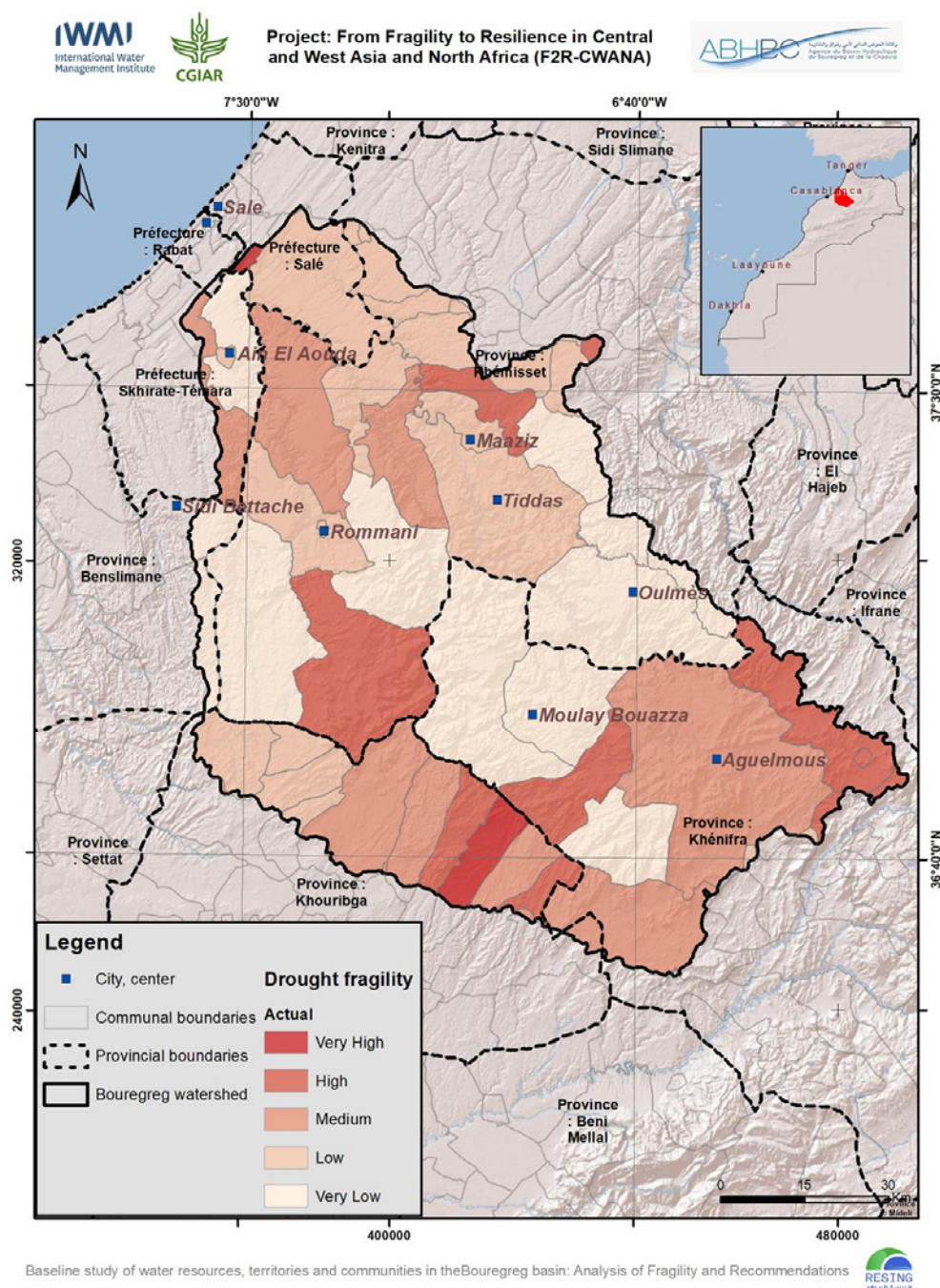
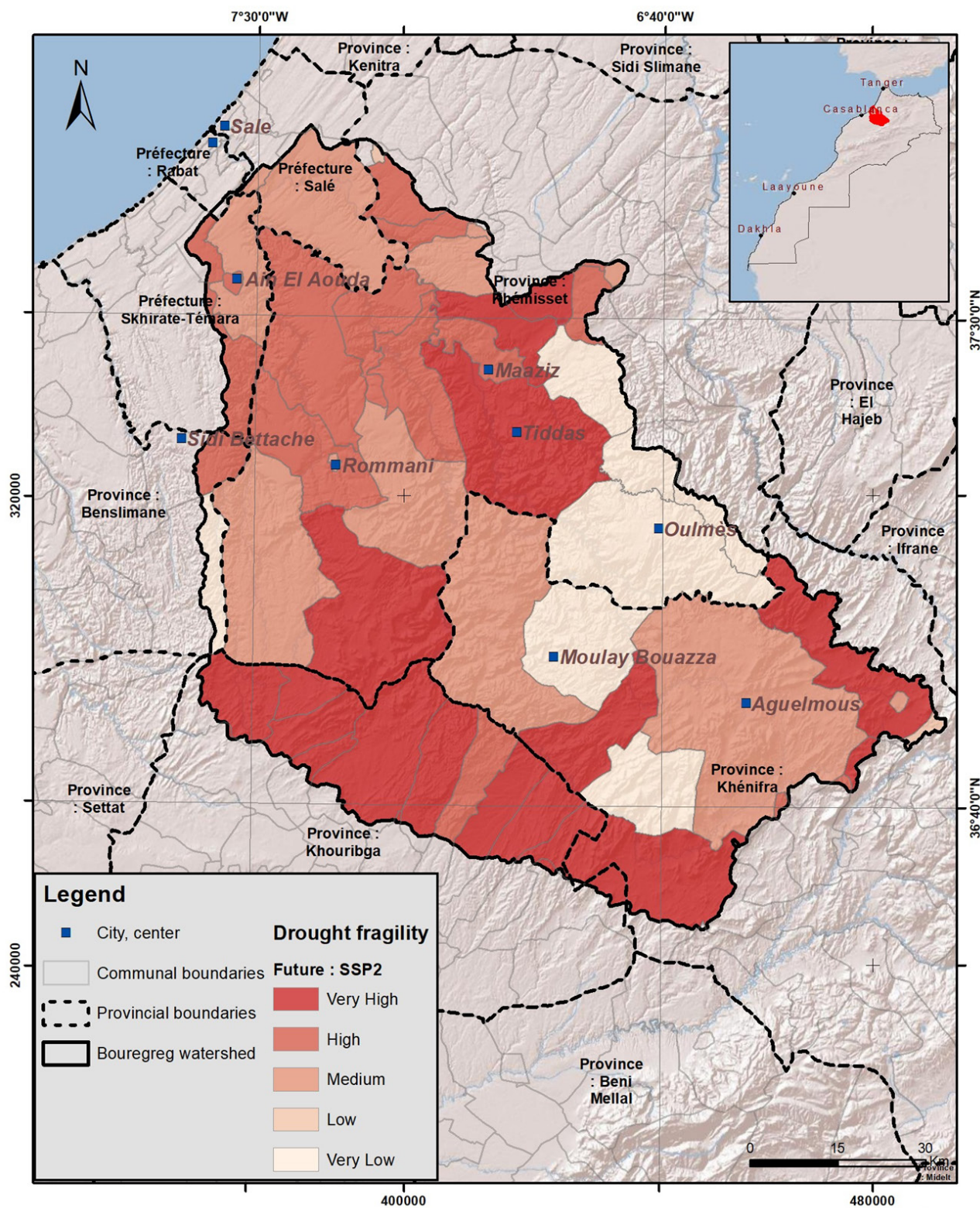


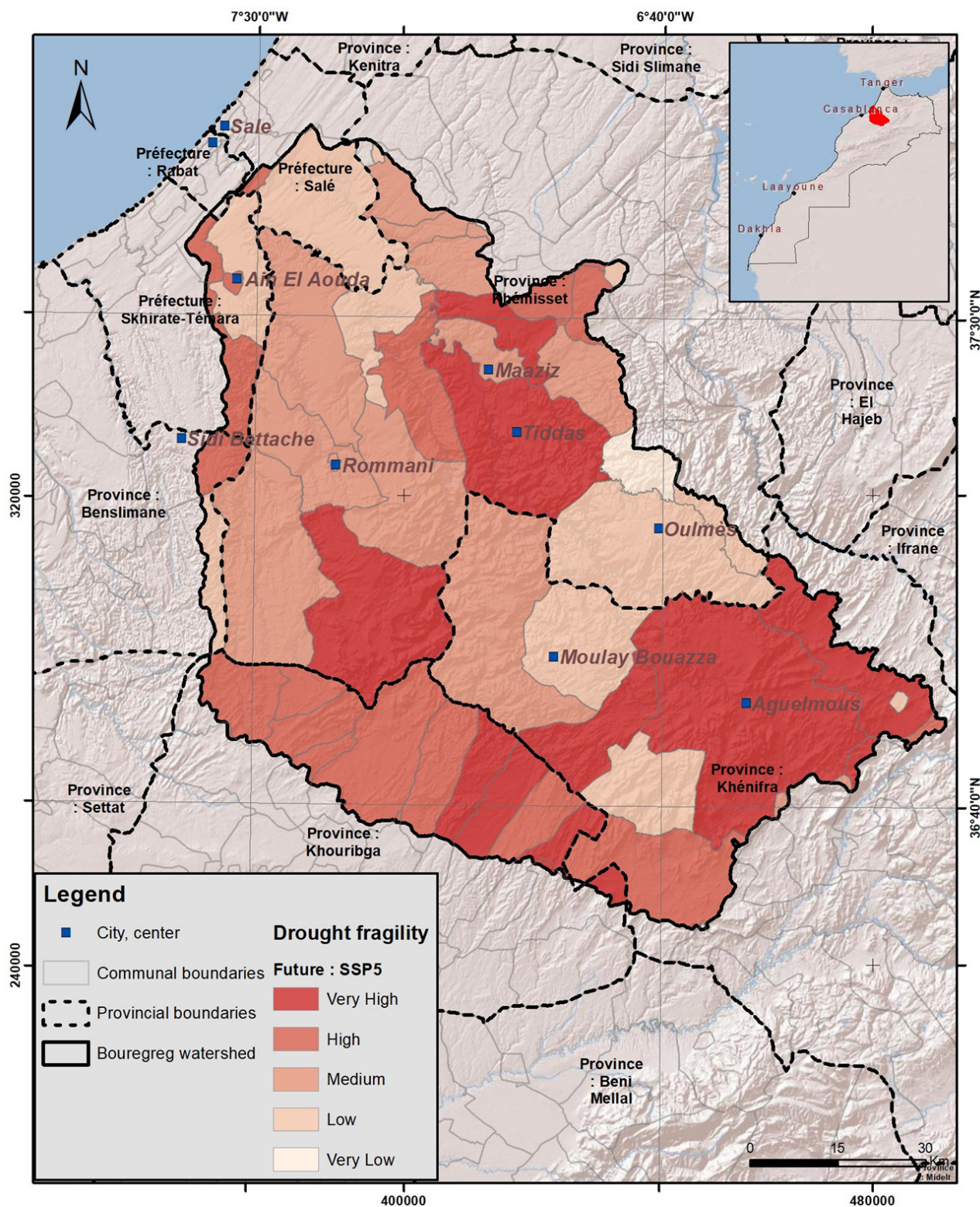
Figure 69. Drought-related fragility in the Bouregreg Basin (current state). *Source:* IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 70. Drought-related fragility in the Bouregreg Basin (future state – SSP2- RCP4.5)

Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 71. Drought-related fragility in the Bouregreg Basin (future state – SSP5-RCP8.5)
Source: IWMI

Erosion-related Fragility

The detailed analysis of erosion fragility in the Bouregreg Basin reveals a prevalent pattern of high to very high fragility across most communes, especially in the southwestern and eastern regions, with El Hammam particularly affected. Conversely, the central area exhibits relatively lower levels of erosion-related fragility, which suggests that spatial variations are intricately linked to heightened vulnerability in specific regions (Figure 72).

Projections under the SSP2-RCP4.5 and SSP5-RCP8.5 scenarios (Figure 73 and 74) predict a reduction in erosion-related fragility, indicating significant changes in risk. Communes in the central basin are expected to benefit from this risk reduction, coinciding with a decrease in the Bouregreg Basin's overall vulnerability. This positive trend emphasizes the critical relationship between vulnerability and fragility, reinforcing the necessity of considering both factors to fully understand the evolving environmental risks in the region.

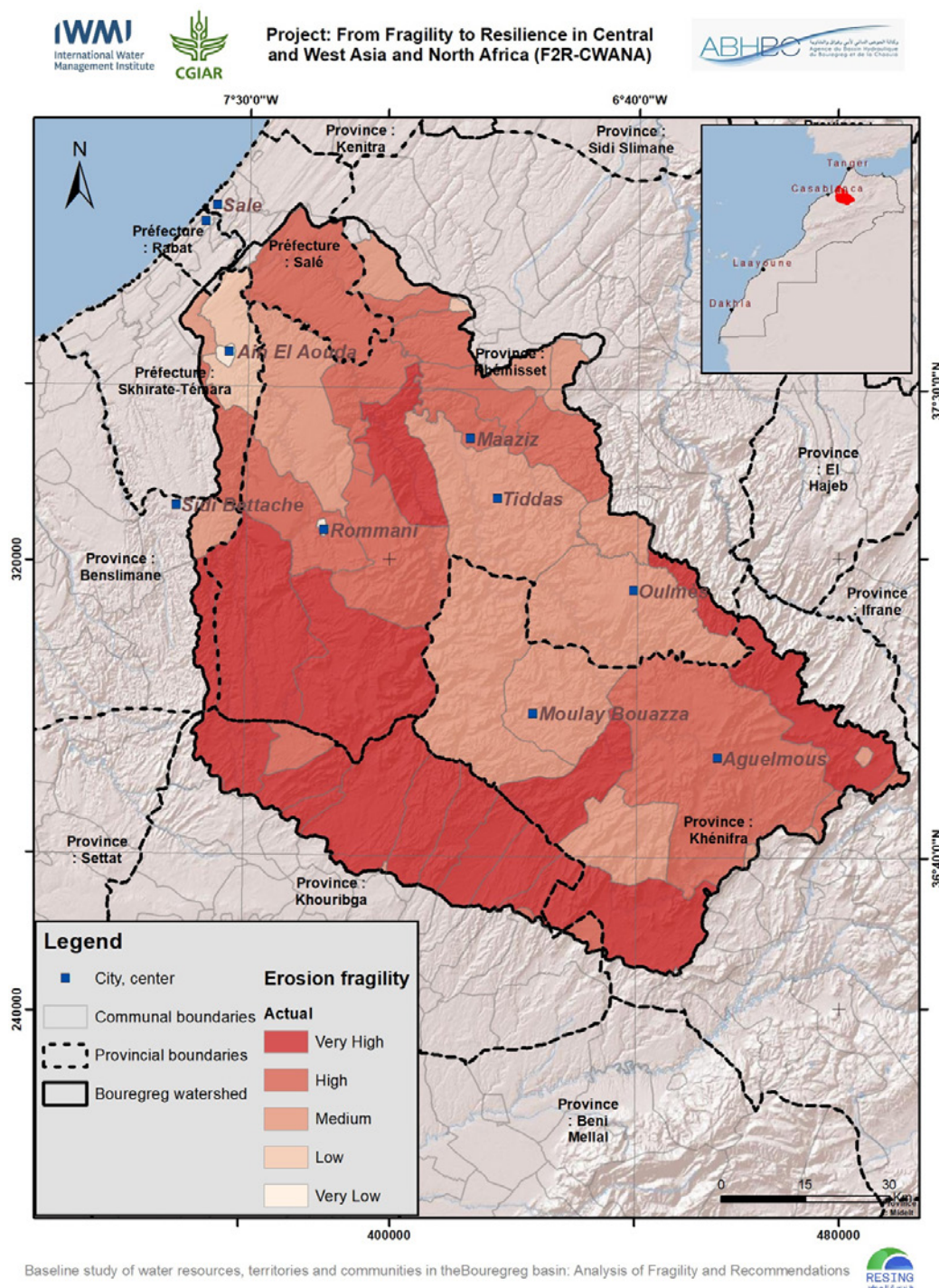
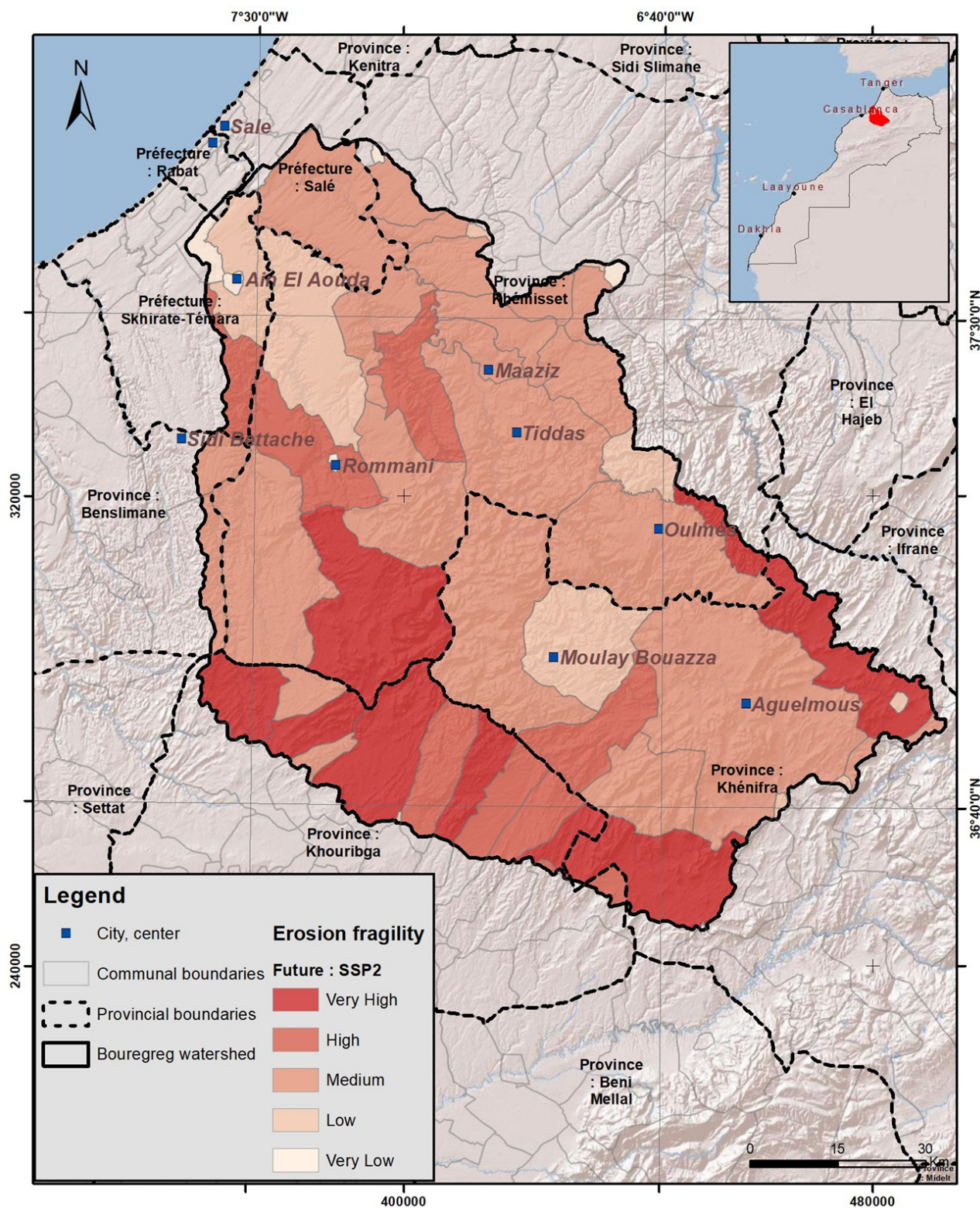


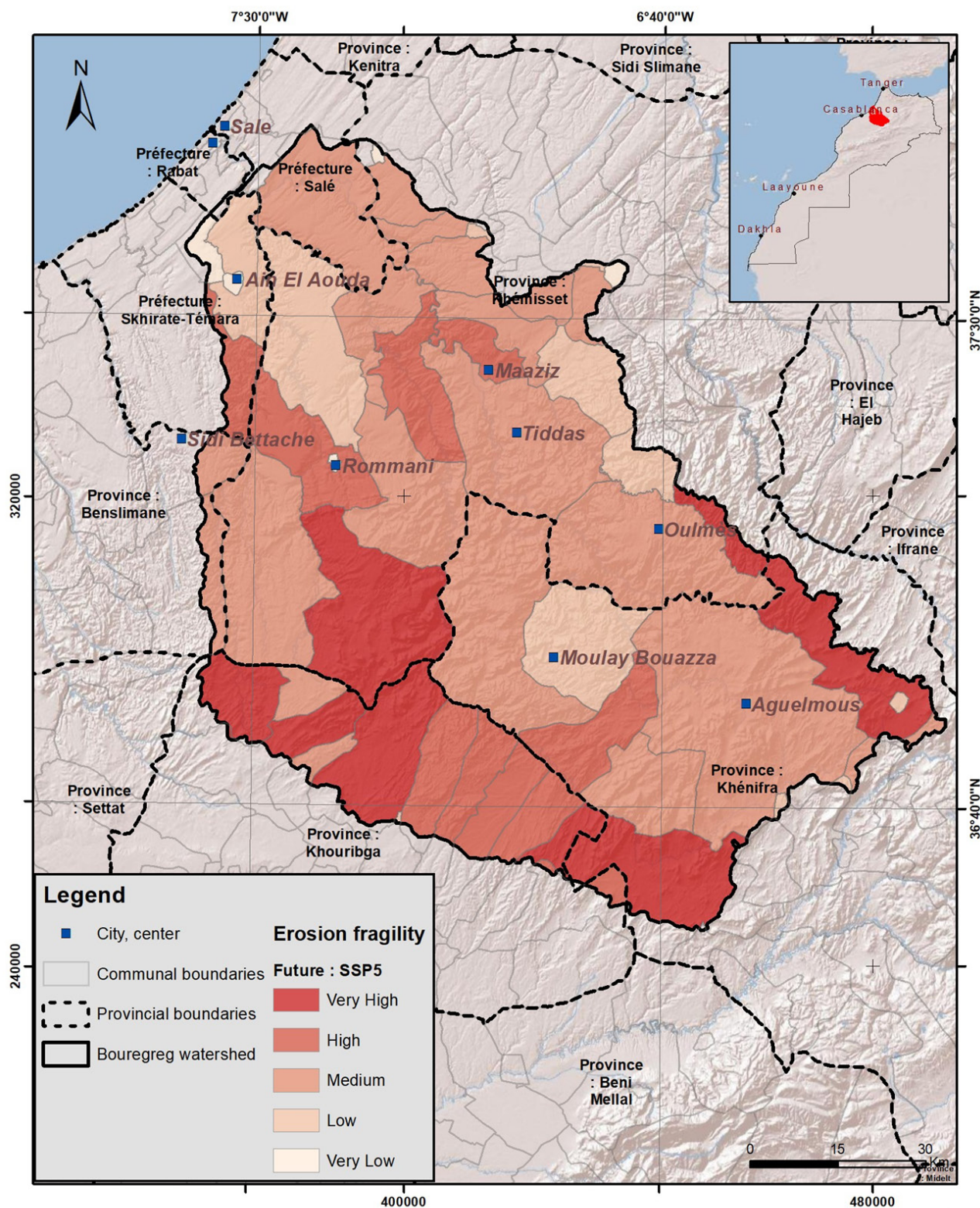
Figure 72. Erosion-related fragility in the Bouregreg Basin (current state). *Source:* IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 73. Erosion-related fragility in the Bouregreg Basin (future state – SSP2- RCP4.5)

Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 74. Erosion-related fragility in the Bouregreg Basin (future state – SSP5-RCP8.5)

Source: IWMI

Fragility of the Nexus Water-Agrifood-Land Systems

The Bouregreg Basin currently exhibits four distinct fragility levels, with a prevalence of low and medium fragility and a notable absence of very high fragility. This indicates a relatively stable and manageable risk landscape at present (Figure 75). However, a prospective analysis, particularly under the SSP2 scenario (Figure 76), reveals a significant potential increase in fragility levels throughout the entire basin, which could challenge the current resilience of municipalities. Similarly, the SSP5 scenario (Figure 77) shows a similar upward trend in fragility, though at a less pronounced rate than SSP2. This subtle difference suggests impacts with varying degrees of severity, providing valuable insights for informed decision-making and adaptive strategies, in response to evolving environmental risks in the Bouregreg Basin.

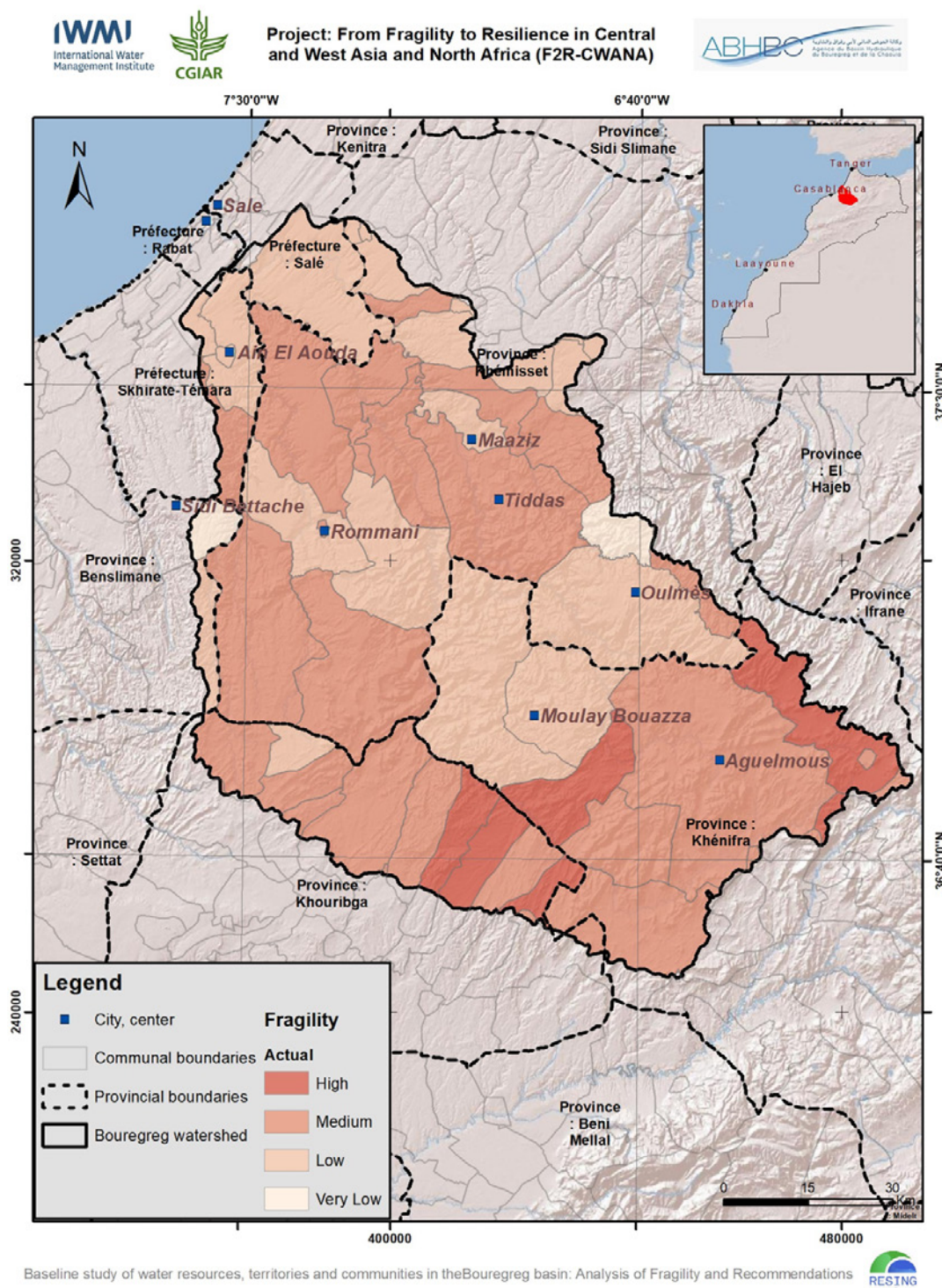
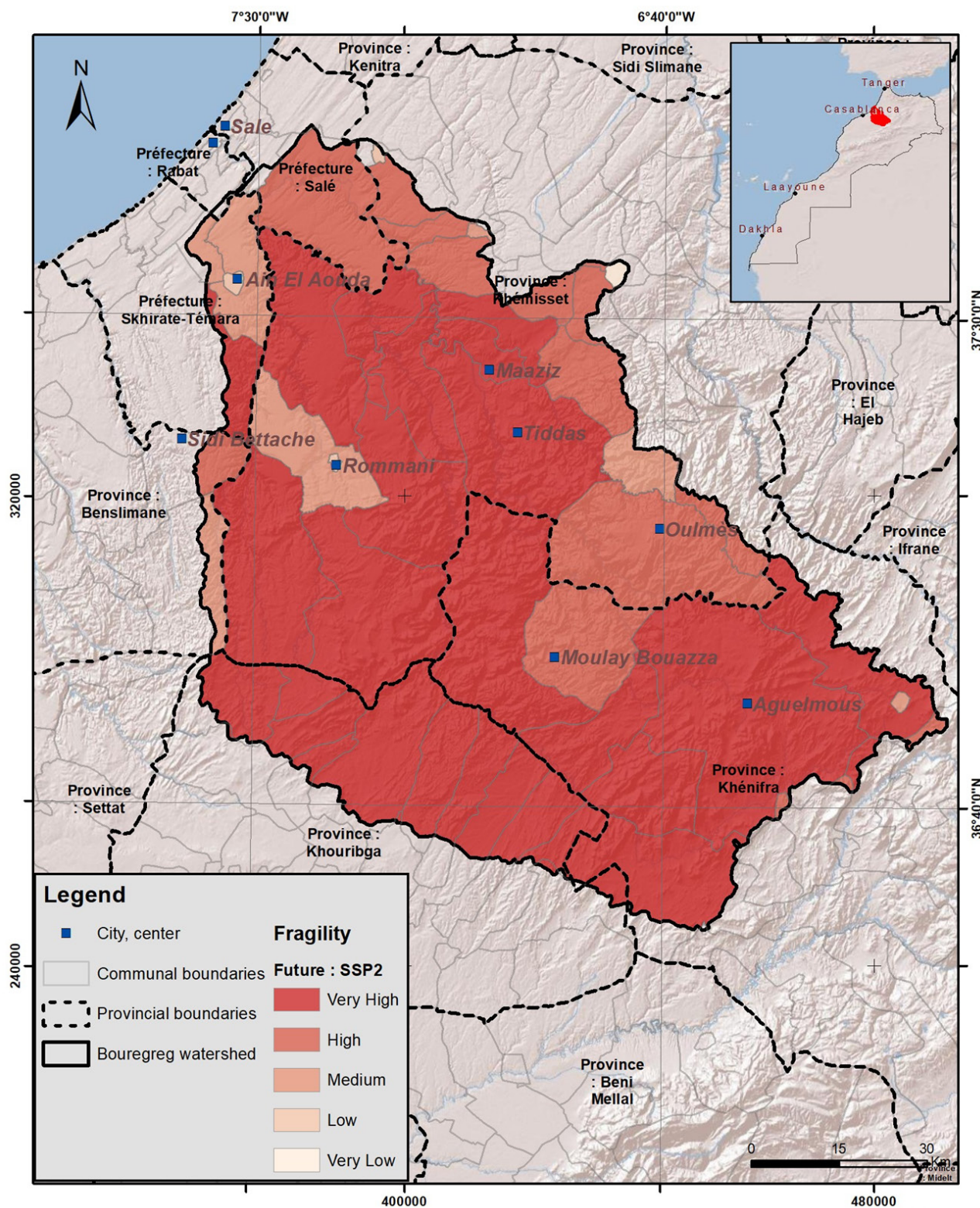


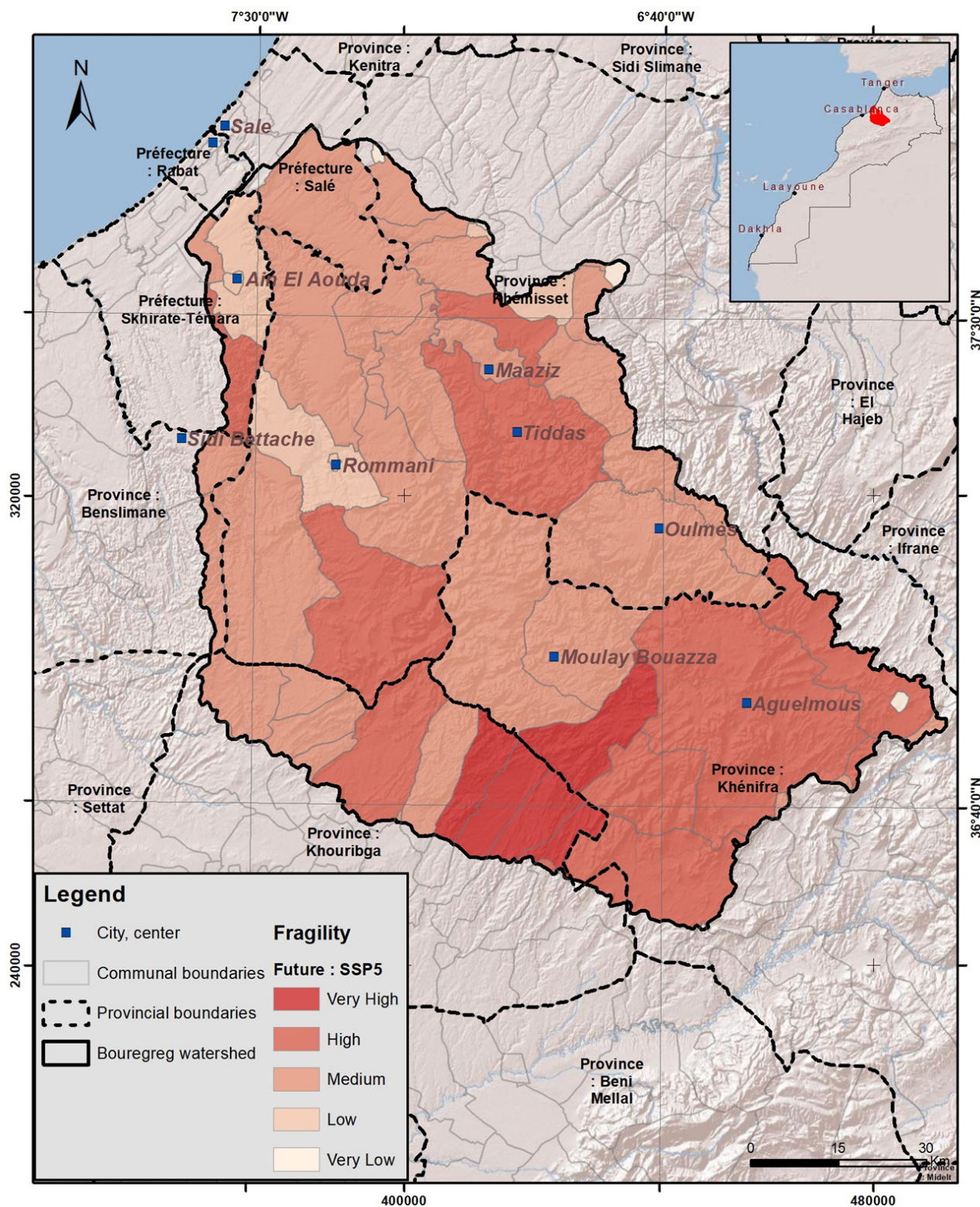
Figure 75. Fragility of the water-agrifood-land systems nexus. Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 76. Fragility of the water-agrifood-land systems nexus (future state – SSP2- RCP4.5)

Source: IWMI



Baseline study of water resources, territories and communities in the Bouregreg basin: Analysis of Fragility and Recommendations

Figure 77. Fragility of the water-agrifood-land systems nexus (future state – SSP5-RCP8.5)

Source: IWMI

Recommendations for Strengthening Resilience

Table 16 below summarizes these recommendations formulated by category and hazard. The details are presented in the sections below.

Table 16. Summary of recommendations and solutions by categories

	Water System	Agrifood System	Land System
Floods	- Develop a deeper understanding of the hydrological system - Enhance the flood forecasting system - Improve flood management - Organize awareness campaigns on flood risks	- Adopt improved irrigation techniques - Promote water reuse and treatment - Implement agricultural strategies, including drought-resistant crops, crop diversification and conservation agriculture - Enhance community engagement and education through capacity building and participatory conservation - Utilize satellite imagery to control and monitor agricultural productivity and manage water withdrawals for irrigation - Implement a program to rationalize the use of fertilizers and pesticides	Preserve flood zones and limit their urban development
Drought	- Develop water storage infrastructure - Implement drought awareness programs - Enhance policy and governance: water governance reform, early warning systems, incentive programs, water accounting and auditing - Increase knowledge on groundwater - Mandate the installation of meters at groundwater abstraction points - Improve the efficiency of drinking water distribution networks	Enhance environmental conservation efforts on ecosystem restoration and soil and water conservation	
Erosion	- Implement collection and sustainable management of rainwater: - retention basins - water harvesting cisterns - rainwater harvesting systems in urban areas - sedimentation ponds - sustainable drainage systems - stormwater management landscaping	- Plant native trees, shrubs and plants to stabilize soils, reduce runoffs, enhance biodiversity, restore degraded areas, improve soil quality and provide protection against water erosion - Limit risk factors (particularly anthropogenic factors): implement effective management of cultivated land, engage companies operating in the quarry extraction sector and mitigate deforestation - Continue and enhance physical or biological watershed management with an integrated and sustainable approach - Raise awareness of sustainable soil management practices with educational workshops, information campaigns, involve schools in outreach efforts and facilitate participatory meetings	
	Invest in research and technological innovation		

Benchmarking Analysis

As a complementary aspect of this study, we examined international practices to explore how the management of natural hazards—specifically floods, droughts and erosion—has been enhanced in various river basins around the world. Our focus was on reviewing international examples relevant to the themes discussed in this study. In other words, we aimed to identify successful "cases"⁴ that can inform effective practices applicable to the Bouregreg Basin, helping to reduce environmental and social fragility while increasing the resilience of the communities therein.

To build on these practices and adapt them to the Bouregreg Basin, we recommended that capacity-building activities and awareness-raising initiatives adhere to the following guidelines:

- **Be locally driven:** These initiatives should consider geographical and social disparities across the basin.
- **Be short-term:** Initiatives should be short-term and adjust to the participants' busy schedules.
- **Be held in accessible locations:** Since much of the Bouregreg population is spread across vast areas rather than concentrated in urban centers, ensuring that the message reaches everyone and no one is left behind, is crucial.

Finally, it is crucial to apply a gender-inclusive perspective in disaster management. This perspective considers how gender intersects with other vulnerability factors, such as disability, migration and gender identity, at all stages of disaster management, with specific attention to the youth and the elderly.

Moreover, practices can be particularly effective if framed within the two following approaches:

- **Community-based risk management:** This approach emphasizes recognizing the potentials and abilities of local communities, empowering them and actively involving them in decision-making processes.
- **Nature-based solutions:** This strategy focuses on the sustainable, effective and adaptive management and restoration of natural or modified ecosystems, which benefits human well-being and biodiversity.

These are complex and highly interrelated approaches, and their implementation is unlikely to be perfect, especially in the early stages. It takes time for these approaches to take root. Successful application requires dialogue among parties, awareness-raising activities, capacity building for different stakeholders and establishing common "game rules" for project and activity implementation.

However, it is crucial to keep in mind that:

- Both approaches are bottom-up initiatives that should be integrated with top-down elements, recognizing the authority of governments and of the technical and scientific community. It would be ideological—and potentially dangerous—to argue otherwise.
- Both are primarily local approaches that should be aligned with national and international development visions.
- Both "soft" approaches should be supported with "hard" infrastructure-based interventions.

⁴ Cases well-known by the author and/or very well documented in literature

Water System

Deeper Understanding of the Hydrological System

Field surveys and analysis of the studies and documents reviewed during this research indicate that:

- The number of precipitation monitoring stations is insufficient, given the watershed's size and the high levels of spatial variability in rainfall. Some rainfall events, such as the flooding in Mirt on December 10, 2022, were not captured by the ABHBC rain gauge network. Strengthening this network will markedly improve heavy rainfall monitoring across the Bouregreg Basin. Most floods in the past have not been followed by post-flood field surveys.
- Historically, most floods have lacked follow-up field surveys. By conducting these surveys to assess past flood events, we can improve predictions and enhance readiness for future floods.

Improving Groundwater Knowledge

ABHBC is engaged in groundwater monitoring and reconnaissance in the area, conducting hydrogeological studies, piezometric campaigns and borehole surveys to assess and monitor the status of groundwater resources. Deepening our understanding of groundwater is essential for the sustainable and efficient management of this vital resource. This intervention aims to improve knowledge of groundwater resources and provide a more accurate picture of the region's water situation through specific measures such as:

- Reinforcing the piezometric monitoring network: This measure entails increasing the density of piezometric measurement points, particularly for the Tanoubart and Sehoul aquifers. By strengthening this network, more accurate data on water level fluctuations in the aquifers can be obtained, which is essential for groundwater management.
- Enhanced understanding of hydrodynamic parameters: Understanding key hydrodynamic parameters of groundwater, such as transmissivity and storage coefficient, is crucial. Improved insight into these parameters will facilitate better assessment of the aquifers' capacity to store and supply water, as well as improve predictions regarding their response to anthropogenic and environmental pressures, through the development of hydrogeological simulation models.
- Reconnaissance of deep aquifers: Besides studying the MioPlioQuaternary aquifers, it is crucial to explore them to form a comprehensive picture of the water situation. This reconnaissance will enhance knowledge of the overall groundwater dynamics in the region and identify potential interconnections between different aquifer layers.

Require the Installation of Meters at Groundwater Abstraction Points

Installing meters at groundwater abstraction points is essential for monitoring the quantity of groundwater withdrawn from the aquifers (Temara, Sehoul and Tanoubart). This monitoring will help regulate withdrawals and promote sustainable management of the available resource. The objective is to mandate the installation of these meters to enhance understanding and management of the aquifers. It involves:

- Developing and implementing regulations for law 36-15, regarding the mandatory installation of groundwater meters
- Organizing training and awareness-raising campaigns for farmers and other economic actors on meter installation and the necessity of reporting water withdrawals
- Requiring economic actors, such as those in tourism and industry that use groundwater, to install meters, with penalties to be defined for non-compliance
- Conducting regular metering campaigns

Substitution of Groundwater for Drinking Water Supply by Surface Water

Meeting drinking water needs with surface water resources has become crucial to reduce the pressure on groundwater reserves across the basin. The interconnection between the Sebou guard dam and the SMBA dam allows for the transfer of excess water from the Sebou basin to the Bouregreg Basin. A portion of this water can boost drinking water supplies in the communes located upstream of the SMBA dam. Additionally, the Tiddas dam could be utilized for the same purpose.

Before proceeding, a feasibility study must be conducted to evaluate the technical, economic and environmental viability of supplying the area with drinking water from surface sources, such as the SMBA dam and the Tiddas dam. Identifying priority areas for substituting groundwater with surface water is essential, particularly in regions where the quality of groundwater is poor or where borehole productivity has declined due to overexploitation. The findings from these studies could inform the planning and implementation of groundwater substitution with surface water in identified priority areas.

Investing in Water Storage Infrastructure

Invest in constructing small-scale water storage facilities to capture and store rainfall during dry periods. It is important to adopt and disseminate techniques that resonate with the villagers and farmers and are appropriate for the basin's context. Promoting natural water storage systems—such as permeable surfaces and recharge areas—will enhance groundwater replenishment and increase resilience against droughts.

Improving Flood Forecasting Systems

The ABHBC has established an operational flood forecasting platform that relies on the following components:

- Spatialized 48-hour rainfall forecasts received daily from the National Directorate of Meteorology
- Data from the agency's telemetry network, including real-time data for rainfall, water flows and dam levels
- Hydrological models for the main rivers
- Hydraulic models targeting the basin's primary flooding issues

The effectiveness of this platform could be further improved by incorporating the following key elements:

- Enhancing the hydrological and hydraulic models that support the existing platform
- Considering the potential closure of major roads in the forecasting system, to prevent community isolation and reduce human casualties from flooding
- Refine flood forecasts for small-sized catchments affected by local storms and improve rapid response

Improving Flood Management

Field surveys indicate that historical flooding in the area has frequently cut off access to several roads, with some rivers swelling unexpectedly fast. To improve flood management, the following measures could be implemented:

- Establish a regional oversight committee to manage and monitor flooding events, focusing on improving local crisis management systems and promoting resource sharing at the inter-municipal level.
- Conduct simulations of land accessibility during floods to identify areas with dynamic risks—i.e., areas made inaccessible by floods—and those with static risks such as hospitals or schools that may also be affected.

Organizing Flood Awareness Campaigns

Because rainfall episodes are few and far between, while droughts are typically frequent and long-lasting, flooding risks are often overlooked, resulting in inadequate preparedness for the population. Therefore, it is recommended to:

- Implement awareness campaigns to inform the community about the risks of flooding and promote preventive measures
- Conduct simulation exercises to prepare the population for potential flooding events

Water Awareness Programs

Conduct educational campaigns to promote water conservation practices among farmers, local communities and school students. These initiatives should be supported and amplified by the water branch of ONEE in major urban centers and villages and by the National Office of Agricultural Extension (ONCA) to target farmers. It is vital to incorporate lessons on water context, vulnerability to drought and water resource conservation into the curricula of primary and secondary schools. Establishing environmental clubs in high schools can further enhance knowledge dissemination. Educational materials can be developed based on the findings of this study and serve as valuable resources. Additionally, raising awareness on the importance and benefits of nature-based solutions (NbS) will encourage community support and active participation in their implementation.

Breakdown of the key elements for implementation:

- Assess the training needs of each partner, to ensure their involvement in the training and awareness-raising programs.
- Draft agreements with stakeholders to engage them in organizing the training workshops.
- Develop a schedule of meetings and workshops for all partners involved.
- Organize training sessions for Douar Associations responsible for water supply and sustainable development.
- Conduct training for communal technicians on managing water supply systems (SAEP) and sewerage networks, while creating management manuals for these systems.
- Set up training courses for farmers that focus on environmentally friendly agricultural practices, efficient water-saving irrigation technologies, irrigation management and maintenance of irrigation equipment.
- Develop training programs in water management and agricultural production management to enhance the skills of young farmers and increase agricultural productivity and water savings.
- Organize training sessions for public and private operators responsible for water infrastructure management (water supply, sanitation, irrigation etc.) to enhance their skills in water resource management.
- Create online training modules to allow remote access and accommodate individuals with geographical or time constraints.
- Implement a water education and awareness program for future generations, targeting schools:
 - Through the Regional Academy of Education and Training (AREF), raise teachers' awareness on the importance of disseminating knowledge on water resources and management in their training modules.
 - Provide increased support to environmental education clubs, to expand their focus on water resources and water management at the regional level.
 - Improve teachers' knowledge on water management.
 - Develop water-related educational tools, such as comic books for young schoolchildren.
 - Organize school competitions centered on water-related themes.
 - Arrange regular visits and exchanges centered on water and water-related jobs.

Policy and Governance:

Water governance reform: Drought management should be approached in a cross-cutting and participatory manner, involving various relevant sectors. Key stakeholders in this process include the Basin Agency of Bouregreg Chaouia (ABHBC), Water Management Directorates (DPAs), Regional Directorates of Water and Forests, the ONEE Water Branch and Environmental Services.

The Water Scarcity Management Plan (PGPE) is mandated by Water Law 36-15 and must be developed by the ABHBC. This plan should provide a comprehensive drought management roadmap within the basin and guide all stakeholders in their efforts.

Early warning systems: Develop and implement early warning systems for drought prediction and management, to enable timely responses and preparedness. Such systems could be derived from the PGPE.

Incentive programs: Provide incentives and subsidies to encourage the adoption of water-saving technologies and practices in agriculture and other sectors.

Water accounting and auditing: Establish a water accounting and auditing system within the Bouregreg Basin similar to the one developed for the Berrechid aquifer. This system will deliver timely and consistent data to support water management decisions, particularly regarding new dam projects and water transfer to and from the SMBA dam. In collaboration with the ABH of Souss Massa, IWMI has implemented the “Water Accounting Plus” system to deliver precise information on the status and productivity of water, which can serve as a model for replication in the Bouregreg watershed.

Collection and Sustainable Management of Rainwater

Managing rainwater is essential to preserve watersheds and reduce erosion. The following systems are particularly effective for stormwater management:

Water harvesting cisterns: Promote the installation of water harvesting cisterns in homes and buildings to collect rainwater for various uses, including garden irrigation, groundwater recharge and reducing runoff from impervious surfaces.

Rainwater harvesting systems in urban areas: Implement techniques such as green roofs and permeable sidewalks to integrate rainwater harvesting systems into urban planning. These systems help absorb and store rainwater to minimize runoff.

Retention basins: Establish retention basins in suitable locations, such as slopes or open spaces. These basins are designed to temporarily retain rainwater, reducing runoff speed and allowing for gradual soil infiltration.

Sedimentation ponds: Install sedimentation ponds to capture suspended particles in rainwater. By trapping sediment before it enters river systems, sedimentation ponds help prevent watercourse pollution and maintain water quality.

Sustainable drainage systems: Adopt sustainable drainage systems that promote water infiltration into the ground rather than rapid evacuation. This can include using vegetated ditches, swales and other green drainage solutions to minimize erosion.

Stormwater management landscaping: Incorporate stormwater management features into landscaping, such as vegetated retention areas and buffer strips, which help filter rainwater, reduce runoff and protect sensitive areas.

Agrifood System

Improved Irrigation Techniques

Promote efficient irrigation methods, such as drip irrigation, precision irrigation and other irrigation management and control techniques, particularly in the newly developed irrigated areas downstream of the Tiddas and Boukhmiss dams, which cover over 4,000 hectares (PDAIRE-ABHBC, 2019).

The implementation of localized irrigation should be accompanied by monitoring and guidance for farmers to maximize effectiveness and prevent it from unintentionally transforming into a gravity-fed irrigation system, as has occurred in several instances.

The adoption of new irrigation management technologies presents a significant opportunity for more efficient and sustainable use of water resources. Innovations such as soil moisture sensors, weather stations, water demand forecasting models and automated control systems enable farmers to manage their water resources more effectively, optimize irrigation practices, reduce costs and conserve available resources.

Here are the main recommendations for implementing this solution:

- Leverage previous experience, particularly lessons learned from the R3 perimeter in Al Haouz (ORMVAH-ABHT-LMI-TREMA) and the pilot project in the Souss Massa region
- Deploy irrigation management tools, such as automatic weather stat networks, soil moisture sensors and relevant software and applications
- Conduct studies to determine the water requirements of the region's cultivated crops, including evapotranspiration and adaptation coefficients for local conditions (e.g., irrigation crops coefficients and reduction coefficients)
- Establish an irrigation management information system (e.g., a mobile application or website), starting with a pilot zone and gradually expanding to other areas
- Organize training and awareness sessions for farmers to ensure they effectively master both the irrigation system and the associated information system.

Water Reuse and Recycling

Implement systems for treating and reusing wastewater in agriculture and other sectors to lessen dependence on freshwater sources. Establishing wastewater treatment and reuse systems in the major centers of the basin is essential. Currently, only Ain Aouda has a system for treating and reusing purified wastewater, resulting in an estimated loss of 6,51 Mm³/year within the basin. Table 17 shows an estimation of wastewater production volumes in the Bouregreg Basin.

Table 17. Volumes of wastewater produced in the Bouregreg Basin

		Average wastewater production (Mm ³)	
Basin	Environment	2020	2050
Bouregreg	Rural	3,3	7,74
	Urban	3,21	5,1
Total		6,51	12,84

Source: According to estimations made by RESING in 2023

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he success of a project to reuse treated water for agriculture and green spaces depends on several key prerequisites:

- It is essential to identify and evaluate feasible projects for reusing treated wastewater in the area
- An institutional and legal framework must be established, along with standard reuse agreements involving various stakeholders, including the Interior Ministry's Water and Liquid Sanitation Division of the DGCT, local authorities, farmers, institutions responsible for wastewater treatment, the ABHBC and local departments of the Ministry of Agriculture.
- Integrated pilot projects should be implemented to encompass the collection, transport, treatment and reuse of treated water in the region.
- Awareness and education programs must be conducted to inform users, especially farmers, about the benefits of reusing treated wastewater for irrigation.

Agricultural Strategies

Drought-resistant crops: Encourage the cultivation of drought-resistant crops, such as sorghum and specific wheat varieties, which require less water. In rainfed areas, supporting farmers in adopting these new drought-resistant cereal varieties is essential to strengthen their resilience to climate change, particularly in the mountainous regions of Khouribga and Khénifra. In irrigated areas served by large-scale modern hydraulic projects and private irrigation – especially in regions to be developed downstream of the Tiddas and Boukhmiss dams (see Map 2) – it is vital to promote crops that are both water-efficient and of high-value.

Crop diversification and rotation: Promote crop diversification and rotation to reduce the risks associated with relying on a single crop and to adapt to changing climatic conditions. This strategy of diversification should mainly focus on areas being developed downstream of the Tiddas and Boukhmiss dams. Additionally, encouraging permaculture practices is advisable, especially considering the growing demand for its products in both domestic and global markets.

Conservation agriculture: Advocate for conservational agriculture practices that minimize soil disturbance, retain moisture and improve soil health to enhance resilience against droughts.

Community Engagement and Education

Capacity building: Deliver comprehensive training and support to farmers on sustainable agricultural practices, water-efficient techniques and crop management during droughts, with ONCA responsible for delivering this essential support. Additionally, capacity-building efforts should target water, agriculture and forestry institutions' staff, to equip them with the tools and knowledge necessary for effective drought management within the basin.

Participatory conservation: Encourage participatory management by engaging users in designing and implementing policies and measures. Involving local communities in nature-based solutions (NbS) initiatives, fosters a sense of stewardship and promotes sustainable management of natural resources.

Control and Monitoring of Agricultural Productivity and Control of Irrigation Water Abstraction Using Satellite Imagery

This project seeks to create an IT platform for the Bouregreg Basin that uses satellite imagery to monitor agricultural productivity and efficiency of irrigation water use. By leveraging satellite images and remote sensing-generated evapotranspiration data, the platform can track water irrigation water withdrawals and evaluate crop growth. The high-resolution platform will provide precise information on water consumption in specific areas, mainly on privately irrigated regions of the Bouregreg Basin. This recommendation complements the earlier suggestion regarding "Improved irrigation techniques".

Setting Up a Program to Rationalize the Use of Fertilizers and Pesticides

Implementing a program to rationalize using fertilizers and pesticides is crucial for promoting sustainable, environmentally friendly agriculture. The program will include:

- Surveying to assess the use of organic and inorganic fertilizers and pesticides to identify particularly vulnerable areas. This survey will enhance the understanding of current chemical usage in agricultural regions and the associated environmental risks, enabling targeted actions in the most at-risk areas.
- Developing farm advisory sheets and guidelines for the responsible use of inorganic fertilizers and pesticides tailored to the region's specific agronomic and environmental contexts.

Because engaging farmers in this rationalization process is essential, awareness campaigns will be created to encourage them to adopt more sustainable and responsible practices in using fertilizers and pesticides.

Land System

Environmental Conservation

Ecosystem restoration: Focus on restoring degraded lands, promoting afforestation and protecting watersheds to maintain ecological balance and enhance water retention capacities. These efforts directly address the interconnections between drought, erosion and flooding. Effective reforestation and watershed management efforts are necessary for reducing erosion and strengthening the resilience of local communities and biodiversity against drought. By improving water retention, creating microclimates and enhancing ecosystem health, these initiatives significantly reinforce resilience against drought.

Soil and water conservation: Implement soil conservation methods such as terracing, contour plowing and agroforestry to reduce erosion and enhance water retention. Nature-based solutions (NbS) offer promising strategies to mitigate the impacts of drought:

- Planting native trees and vegetation helps restore degraded watersheds, enhances water infiltration and reduces runoff, replenishing groundwater during dry spells
- Establishing green belts around agricultural areas and communities, serves as windbreaks, decreasing evapotranspiration and improving soil water retention
- Promoting sustainable land management through agroforestry systems that combine trees or shrubs with crops or livestock, conserves soil moisture, provides shade and diversifies agricultural production
- Constructing terraces and contour plowing techniques help retain water on slopes, minimizing erosion and conserving soil moisture
- Establishing riparian buffer zones along rivers and streams with native vegetation, prevents erosion, maintains streamflow and improves water quality

By implementing NbS, we can mitigate drought effects while supporting biodiversity conservation, ecosystem restoration and overall climate resilience. Integrating NbS with traditional water management practices, offers a sustainable and holistic approach to addressing impacts of drought in semi-arid regions.

Planting Native Trees, Shrubs and Plants

Soil stabilization: Cultivating native plant species along streams and hillsides helps stabilize the soil. The roots of these plants create a natural net, enhancing soil cohesion and reducing the risk of erosion.

Reduced runoff: Trees and native plants develop a dense canopy that intercepts raindrops, minimizing their direct impact on the soil. This process reduces runoff and decreases the risk of gullies forming.

Biodiversity: Promoting native species fosters local biodiversity. These plants are well-adapted to the region's specific conditions, strengthening the ecosystem's resilience to climatic variations and environmental changes.

Restoration of degraded areas: Implementing reforestation techniques is essential for restoring degraded areas. This includes planting trees on land deforested or damaged by human activities or natural events.

Improved soil quality: The roots of newly planted trees enhance soil structure, promoting stability and fertility. This not only aids in soil conservation but also supports local farming activities.

Protection against water erosion: Trees planted in suitable locations serve as natural barriers against water erosion. They slow down runoff, allowing for more effective water infiltration into the soil.

Limiting Risk Factors (mainly anthropogenic factors)

Several factors can exacerbate erosion and soil loss in the basin, including deforestation and non-compliance by mining companies. The leading solutions proposed during the workshops to mitigate the anthropogenic causes of erosion include:

- Mandate that mining companies implement closure and site restoration plans where such measures are not in place, along with ongoing monitoring and sanctions for non-compliance
- Promote effective management of cultivated land by assisting farmers in adopting soil conservation practices

Continuing and Ensuring the Success of Solutions Already Undertaken

This section focuses on conventional solutions implemented or underway in the basin, including physical and biological watershed management. We recommend adopting an integrated approach for reforestation projects involving fruit trees, such as carob. One effective strategy is to establish cooperatives at the planning stage, to support the project from inception through implementation. Future initiatives should prioritize the sub-basins most affected by erosion.

Raising Awareness of Sustainable Soil Management Practices

Education and awareness-raising are crucial for promoting sustainable soil management practices in local communities. The following strategies can enhance these efforts:

Educational workshops: Organize workshops to educate residents about the importance of sustainable soil management. Topics can include erosion prevention, water conservation, and the benefits of revegetation.

Information campaigns: Launch local information campaigns that utilize visuals, brochures and social media to explain the consequences of erosion and the advantages of sustainable practices. Emphasize the links between soil health, food security and water quality.

Involve schools: Integrate educational programs on soil management into local school curricula. One can cultivate a lasting commitment to sustainability by raising awareness among youth.

Participatory meetings: Hold community meetings to discuss soil management issues. Encourage participants to share their experiences and propose ideas for implementing sustainable practices, fostering a sense of responsibility and commitment.

Preserve Flood Zones and Limit their Occupation

To enhance flood prevention and expedite the implementation of law 36-15, two key areas can be strengthened:

- Develop and regularly update maps of flood-prone areas. Focus on urban centers and larger localities – to help anticipate encroachment into these vulnerable zones. This proactive approach can save lives, minimize potential flood damage and maintain flood flow and expansion capacity.
- Establish Flood Risk Prevention Plans (PPRI): The ABHBC is Morocco's first water basin agency to implement a PPRI. Its experience will be invaluable for the Bouregreg area, which includes several growing towns and urban centers, in integrating flood risk considerations into land-use planning.

Transversal Recommendations: Research and Innovation

Investment in Research

Support research initiatives that focus on developing drought-resistant crop varieties, improving water management technologies, understanding groundwater dynamics and on formulating climate adaptation strategies.

Additionally, support should extend to scientific research that explores and validates innovative erosion control techniques, such as bioengineering, ecological engineering and nature-based solutions.

Establishing partnerships with Moroccan academic institutions is essential to leverage and test the findings of these studies, ultimately enhancing resilience and adaptation for local populations.

Technological Innovation

Encourage developing and adopting innovative technologies, such as weather forecasting tools and drought-tolerant seed varieties.

Addressing drought in semi-arid regions like the Bouregreg Basin, necessitates a comprehensive approach that integrates water conservation, agricultural adaptation, community engagement, policy reforms, environmental conservation and technological innovation. Such an integrated strategy is crucial for building resilience and ensuring sustainable water management in changing climatic conditions.

Planning and Responsibility

Table 18 below outlines the planning horizons—short, medium and long term—as well as the stakeholders who may be involved in implementing these solutions.

Table 18. Planning horizons (short, medium and long term) and the stakeholders who may be involved in the solutions

Categories	Solutions	Horizon Planning	Responsible Stakeholders
Water system	Deepen the understanding of the hydrological system	Medium to long-term	DRPE, ABHBC
	Enhance the flood forecasting system	Medium-term	DMN, ABHBC, Ministry of Equipment and Water
	Improving flood management practices	Short-term	Interior Ministry, Ministry of Equipment and Water, Royal Gendarmerie, Local Authorities, Civil Protection, ABHBC
	Organize flood awareness campaigns to educate the community	Short-term	ABHBC, Provinces, Communes
	Develop water storage infrastructure	Medium to long-term	DRAs, DPAs, ABHBC, Water Department, Provinces
	Implement water awareness programs	Short-term	ONCA, ONEE-Water, Ministry of National Education
	Expand policy and governance, including water governance reform, early warning systems, incentive programs, water accounting and auditing	Medium to long-term	ABHBC, DRA, ONEE-Water, DRE
	Improving knowledge of groundwater resources	Medium to long-term	ABHBC, Province, Communes, Local Authorities
	Mandate the installation of meters at groundwater abstraction points	Medium-term	DRPE, ABHBC, Province, Local Authorities, DRAs, DPAs
	Increase the efficiency of drinking water distribution networks	Medium to long-term	ONEE-Water, Water department, Provinces, Communes
	Substitute surface water for groundwater as a drinking water source	Medium to long-term	DRPE, ABHBC, ONEE Water, Water department, Provinces, Communes
	Collect and sustainably manage rainwater with retention basins, water harvesting cisterns, rainwater harvesting systems in urban areas, sedimentation ponds, sustainable drainage systems and stormwater management landscaping	Medium to long-term	ANEF, Provinces, Water department, ABHBC
Agrifood system	Improve irrigation techniques	Medium-term	DRAs, DPAs, ABHBC, ONCA, Agriculture Chamber, INRA, Regional Council, farmers
	Promote water reuse and recycling	Medium-term	ABHBC, ONEE-water, Water department, Region Council, Provinces, Communes, INGOs (IWMI, GIZ, FAO)
	Implement agricultural strategies, with a focus on the following approaches: • Cultivation of drought-resistant crops • Promote crop diversification • Adopt conservation agriculture	Medium to long term	DRAs, DPAs, farmers

Continued...

Categories	Solutions	Horizon Planning	Responsible Stakeholders
	Engage communities through education: enhance capacity building and promote participatory conservation efforts	Short-term	ONCA, DRA, farmers
	Monitor agricultural productivity and control irrigation water abstraction using satellite imagery	Medium to long-term	ABHBC, DRA, DPA, International Organizations (IWMI, FAO, GIZ, etc.), Universities (FST Mohammedia, UM6P, IAV Hassan II), Project SCO_IRRISAT of the Royal Center of Remote Sensing (CRTS)
	Implement a program to rationalize the use of fertilizers and pesticides	Medium to long-term	ONCA, DRA, DPA, DRE, ABHBC
Land system	Preserve flood zones and limit their encroachment/development	Medium to long-term	ABHBC, AU, Provinces
	Focus on environmental conservation, especially ecosystem restoration and soil and water conservation	Medium to long-term	ANEF, DRA, DPA, Provinces
	Promote the planting of native trees, shrubs and plants for enhanced soil stabilization, reduced runoff, biodiversity protection, restoration of degraded areas, improved soil quality and buffer against water erosion	Medium to long-term	ANEF, Provinces
	Address and limit risk factors—particularly anthropogenic factors—by promoting sustainable management practices, engaging mining companies and tackling deforestation	Short-term medium-term	ANEF, ABHBC, Provinces Local Authorities, Ministry of Equipment and Water
	Build on the success of already existing solutions, such as physical and biological watershed management, using an integrated and sustainable approach	Short-term	ANEF, Provinces
	Raise awareness on sustainable soil management practices educational workshops, participatory meetings, information campaigns and involvement of schools	Short-term	ANEF, ABHBC, DRA, Ministry of National Education
Transversal recommendations	Invest in research	Medium to long-term	All stakeholders: Research Units (Universities, Institutes), INRA, ABHBC, CRTS etc.
	Support technological innovation	Medium to long-term	DRA (Green Generation), Ministry of Equipment and Water, Universities, Institutes, INRA, ANEF

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