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Using GIS and the RUSLE Model to Create an Index of Potential Soil Erosion at the Large Basin Scale and Discussing the Implications for Water Planning and Land Management in Morocco

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Using GIS and the RUSLE Model to Create an Index of Potential Soil Erosion at the Large Basin Scale and Discussing the Implications for Water Planning and Land Management in Morocco

by

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Dedication

To the next generation of researchers in Morocco, advocates for the Open Data and Transparency movements all over the world, and my family, both in blood and spirit.

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Abstract

Using GIS and the RUSLE Model to Create an Index of Potential Soil Erosion at the Large Basin Scale and Discussing the Implications for Water Planning and Land Management in Morocco

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The University of Texas at Austin, 2015

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Severe erosion rates endanger the drinking water and agroforestry sectors in Morocco. To determine ways to improve erosion mitigation in Morocco, this study examined the political landscape underpinning research and policy implementation nation-wide. It also conducted a case study for erosion modeling in the most important river basin for drinking water in Morocco, the Bouregreg Basin. In this case study, 15 erosion scenarios were constructed in ArcMap according to the Revised Universal Soil Loss Equation (RUSLE), the most commonly used tool to predict erosion in Morocco, to determine the effect of variation in data inputs on the quantity and severity of sheet and rill erosion. Results indicate that average annual erosion rates in the Basin are minimal to moderate, with localized areas experiencing severe rates over 25 tons/hectares/year, indicating that channel and gully erosion rather than sheet or interill erosion dominate in the basin. Increased DEM resolution from 30 to 90 meters amplified predicted erosion rates by a factor of 10, and variation in precipitation between the highest and lowest agricultural years yielded a difference in maximum erosion rates of nearly 60,000 tons/hectares/year.

These results indicate that the spatial resolution of datasets and variation in climatic factors produce substantial differences in model output and may bias policy-making in light of variation in data management practices and the potential effects of climate change. In order for Morocco to reach its goal of implementing Integrated Water Resource Management (IWRM), operators and researchers should collaborate at the basin level and establish best data management practices in the drinking water and agro-forestry sectors of Morocco. To achieve these changes, this study recommends that decision makers reexamine how they fund and support erosion research and mitigation, and that all stakeholders coordinate to both compile data to develop empirical and process-based erosion models fitted to Morocco and calibrate these models through investing in representative field studies.

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List of Abbreviations

IEA	L'institut International de l'eau et d'assainissement
ENSMR	Ecole Nationale Supérieure des Mines de Rabat (ENSMR)
ABH	Hydraulic Basin Agency
ABHBC	Hydraulic Basin Agency of Bouregreg and Chaouia
LASH	Laboratory for Hydraulic Systems Analysis
L'EMI	Mohammedia School for Engineers
FSR	Sciences Faculty at Rabat
HCEFLCD	High Commissariat for Water, Forests, and Desertification Control
CRF	Center for Forest Research
INRA	National Institute for Agronomic Research
IAV	Institut Agronomique et Vétérinaire Hassan II
RUSLE	Revised Universal Soil Loss Equation
MAPM	Ministry of Agriculture and Maritime Fisheries
USDA	United States Department of Agriculture
GDP	Gross Domestic Product
PNABV	National Plan for Watershed Management
INDH	Human Development Initiative
GIS	Geographic Information Systems
USAID	United State Agency for International Development

JICA	Japan International Cooperation Agency
PREM	Sustainability of Water Resources in Morocco project of USAID
NDVI	Normalized Difference Vegetative Index
ICOLD	International Commission on Large Dams
ENSO	El Niño-Southern Oscillation
UNDP	United Nations Development Program
HCP	High Commissariat of Planning
FAO	Food and Agriculture Organization
CSEC	Supreme Water and Climate Council
WUA	Local water user associations
PDAIRE	Master Plan for Integrated Resource Management
IWRM	Integrated Water Resource Management
MATEE	Ministry of Regional Development, Water and the Environment
L'ONEP	National Office for Potable Water Supply
ONEE-Branche Eau	National Office for Potable Water Supply
CIE	Inter-Ministerial Council of Water
MADRM	Rural Development and Sea Fishing
ORMVA	Agricultural Development Regional Office
MI	Ministry of the Interior
MOH	Ministry of Health
MF	Ministry of Finance
MAEG	Ministry of Economic and General

MFP	Ministry of Finance and Privatization
WRS	Water Resources Sustainability
DREF	Ministry of Water and Forests (DREF
MUSLE	Modified Universal Soil Loss Equation
DEM	Digital Elevation Model
EUROSEM	European Soil Erosion Model
WEPP	Water Erosion Prediction Project
ASTER	Advanced Spaceborne Thermal Emission and Reflection
UNEP	United Nation Environmental Program
GLASOD	Global Assessment of Human-Induced Soil Degradation
TM	Thematic Mapper
MSS	Multispectral Sensor
SMBA	Sidi Mohammad Ben Abdellah Dam
SIGMED	Approche Spatialisée de l'Impact des activités aGricoles au Maghreb sur les transports solides et les ressources en Eau De grands bassins versants
WOCAT	World Overview of Conservation Approaches and Technologies
LADA	Land Degradation Assessment in Drylands
DESIRE	Desertification Mitigation and Remediation
GRACE	Gravity Recovery and Climate Experiment
GLDAS	Global Land Data Assimilation Systems
TWS	Terrestrial Water Storage

MAD	Moroccan Dirhams
Article 19	Universal Declaration of Human Rights
RTI	Right to Information
TRIPS	Trade-Related Aspects of Intellectual Property
OCP	Cherifian Office of Phosphates

Executive Summary

Water-induced soil erosion directly threatens the national drinking water and agricultural sectors of Morocco and degrades an estimated 40 percent of its lands.[1] At baseline, Morocco's physical geography and climate render it vulnerable to high degrees of soil loss due to a co-occurrence of high precipitation and erodible soils, particularly in the northern Rif areas.[2] Morocco's rapid economic and urban development and vulnerability to climate change have intensified naturally high erosion rates. The Ministry of Agriculture and Maritime Fisheries (MAPM) estimates that Morocco loses a net 100 million tons of soil per year as of 1990, with annual rates per hectare ranging from 2.1 to 20 tons of soil per hectare per year, though rates in the Rif Mountains have reached 30 to 70 tons per hectare per year.[3] These rates exceed the tolerable soil loss of 5 tons/ha/year defined by the United States Department of Agriculture (USDA) 6-11 times over.[4]

High rates of soil loss and deposition contribute directly to sedimentation in dams, a concern for water sector operators and stakeholders, and the loss of fertile soils, a hazard for the agroforestry sector. Prior to 1988, 700 million meters cubed (Mm^3) were lost in dam storage capacity in Morocco.[5] Reservoir capacity has continued to diminish by 75 Mm^3 annually, which amounts to 0.5 percent of the total water storage capacity of all dams in Morocco.[6] Though this loss in water storage potential impacts all sectors, the HCEFLCD equates it to the amount of water necessary to irrigate 5,000-6,000 hectares of land per year, which is about one-half the area of the city of Rabat, Morocco's administrative capital.[7] Reliable water storage is also key to sustaining economic growth in Morocco, where the agricultural sector employs 39 percent of the country's registered workforce[8] and irrigated and rain-fed agriculture comprises 16 percent of Morocco's gross domestic product (GDP).[9] To this effect, high rates of erosion have depleted arable soils and intensified desertification.

The impacts of soil erosion demand intervention. However, accurately and proactively assessing the current and future extent of soil erosion demands a high short-term investment in land and soil surveys at a national level that the Moroccan government has not consistently prioritized. Though national surveys were conducted in the 1970s and again in the early 1990s, soil erosion research and mitigation is primarily supported in areas that have already reached or have exceeded a critical threshold of soil loss and replacement, such as the Rif, or areas of interest to investors and donors.

The Moroccan government has responded to the need to quantify and mitigate erosion, though follow-through remains limited. Legal and policy measures that support the creation of basin-level erosion management in the water and agroforestry sectors stem from the National Plan for Watershed Management (PNABV) in 2006 and the Water Law of 1995 or Loi de l'eau 10-95. Other national-level laws and initiatives treat socio-economic stressors on soils and include the Dahir of 10 October 1917, the Water Law of 1995, Human Development Initiative or Initiative Nationale de Développement Humain (INDH), and Plan Maroc Vert.

Though these legal and policy-based decisions build a framework for studying and combatting soil erosion, institutional and pragmatic factors limiting the on-the-ground effectiveness of this framework include:

- Medium to low coordination between actors in the administrative, scientific, and operational divisions of the water and agriculture sectors,
- Insufficient funding for carrying out research and projects,
- Conflicting incentives among citizens and private sector actors, and
- Increasing variability of precipitation, temperature, and vegetative cover due to climate change.

The resulting political and administrative climate renders this framework reactive rather than focused on sustainable, adaptive measures and thus unable to overcome complications posed by changing demographics and land use, demands of economic growth, and changes in physical parameters due to climate change. Land degradation through soil erosion may be imperceptible to stakeholders until it has already reached severe levels. This relative invisibility of erosion renders expensive short-term investments in large-scale erosion studies unpalatable to decision makers, despite the long-term benefits of averting irreplaceable soil loss.

Professionals in reservoir management, water supply planning, and agroforestry use empirical soil erosion models, including the Revised Universal Soil Loss Equation (RUSLE) to predict soil loss. These models may not always be appropriate, however, due to the inconsistent quality of data inputs, variation in climate trends, and complexity of erosion processes in Moroccan river basins. A mismatch between models used to predict erosion in a country severely affected by land degradation is a problem that requires immediate structural intervention. This study seeks to test methods to map erosion vulnerability using RUSLE and Geographic Information Systems (GIS) at the large basin scale in the Bouregreg River Basin, one of the most crucial basins in Morocco for drinking water. This study also describes and evaluates efforts to study erosion in Morocco and the Bouregreg Basin and discusses the outlook for resolving institutional barriers in research and the implementation of erosion mitigation policy.

This report consists of four sections. The first section of this study presents a review of the processes underlying soil erosion and soil erosion as it affects Morocco. The first section also reviews and evaluates methods used to study erosion in a global context, methods adapted to Morocco and specifically the Bouregreg Basin, and the institutional and legal framework supporting them. The second section of this study describes the study area, methods, and data used. The third section of this study presents the results of RUSLE factors and the RUSLE model scenarios constructed from them. The fourth and final section of this study discusses the results of the RUSLE scenarios for the Bouregreg Basin and the implications for the RUSLE model's appropriateness in the study area and in Morocco at large. This section also presents the RUSLE results in the context of previous research, and current governance regarding erosion research and mitigation in Morocco. This report concludes by presenting recommendations for policy makers to overcome institutional challenges identified for erosion prevention and mitigation.

Section I: Background

PHYSICAL PROCESSES DRIVING WATER-BASED SOIL EROSION

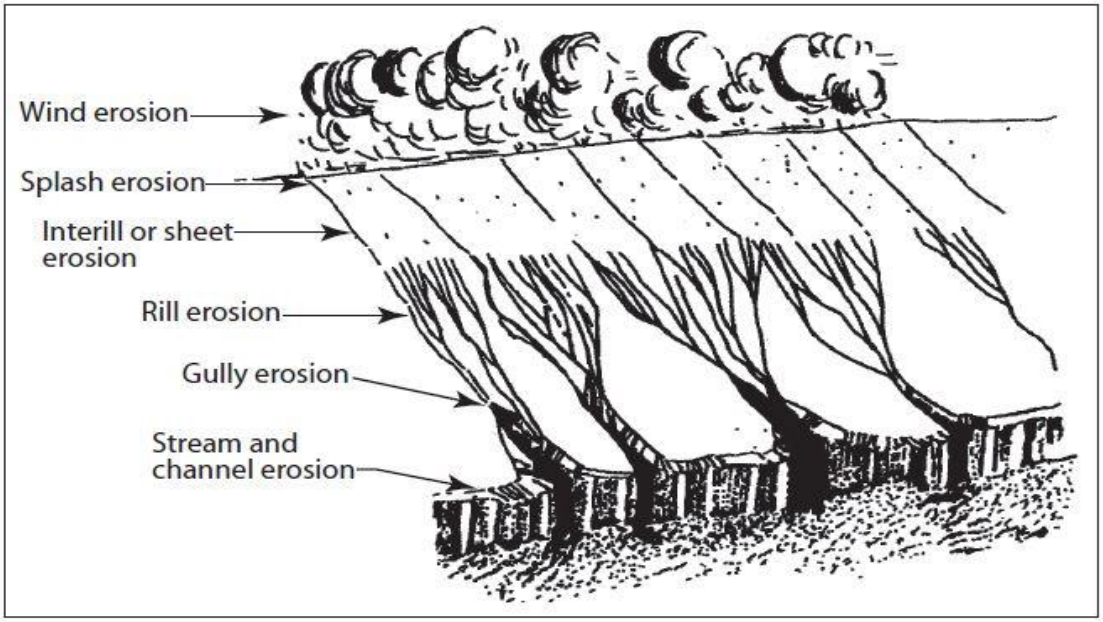
As the hydrological cycle affects soil in all of its steps, the USDA and US Forest and Land Management Bureau describe water-based erosion as interconnected and cumulative.[10] Water-based surface soil erosion follows the gradual or instantaneous breakdown and conveyance of soil and mineral particles due to the kinetic energy of raindrops and overland flow.[11] This interaction between land and water forms sheet or interrill, rill, gully, channel or fluvial, and seepage formations depending on local topographical and lithological conditions.[12]

By and large, the erosivity of rainfall and runoff drive erosion, which varies in the time it takes to manifest to the naked eye.[13] The degree of soil erodibility expresses a presence or lack of resistance to these forces.[14] Exposed soil surfaces may not visually reflect the amount of erosion-based land degradation at play due to the spectrum of rainfall intensity, and subsequent runoff.[15] Processes that may produce dramatic effects include intense storms, which erode large amounts of sediment in aggregate, and concentrated runoff, which carves out extensive rill and gully systems in a landscape.[16] In contrast, infrequent storms or constant low to mid intensity storms may produce light effects on a landscape.[17]

The first step of water-based erosion occurs through interrill or sheet erosion, which consists of the initial dislodging of soil particles by raindrops and shallow surface flows.[18] Untreated sheet erosion leaves soil unable to retain vegetation due to the depletion of essential nutrients.[19] Soil then erodes and loses stability, yielding rills or micro-channels.[20] Rill formation, the second step of water-based erosion, occurs when bare soil is in contact with concentrated flow long enough for micro-channels to form, and primarily appears on steeper slopes and areas with low clay content.[21] Gully-based erosion occurs if stakeholders do not treat rills, and takes on a U or V shape on hillsides where water flows periodically.[22] Gullies also occur in forested areas with a high ratio between slope length and steepness.[23] Channel or fluvial erosion, conversely, occurs in areas with shallower slopes and a low ratio of slope steepness to slope length.[24] Resulting channels are often larger than gullies, however, and linked to permanent flows of water like rivers and coastal interactions where salt water intrudes into fresh water flows.[25]

As both a naturally occurring and human-initiated phenomenon, soil erosion causes changes in topographical composition and stability, key factors leading to rates of soil loss above soil replacement and its consequences, which include the redirection of water flow and storage and changes in water and air quality and vegetative cover.[26] Figure 1 illustrates the formation of erosion features.

Figure 1: How Erosion Features Form



Source: Todd Rivas, *Erosion Control Treatment Selection Guide*, (Washington: USDA, 2006), 3.

Soil plays an important role in the water and carbon cycles. Essential ecosystem resources, including the "provision of food, water, and bioenergy; regulation of water quality; supporting nutrient cycling and primary production; . . . and biodiversity," begin to fail when soil health has reached a critical threshold.[27] Fertile soils are important to the sustainability of food and water security because they affect the amount of usable water available in an ecosystem through river flow and the infiltration of groundwater.[28] As a common pool resource, current soil reserves are finite and must be managed sustainably.[29] Sustainable management does not translate easily in implementation because the water, bioenergy, food, and housing and development sectors drain nutrients from the soil and cause irreversible topographical changes.[30] Diminishing soil quality in turn impedes economic activity, as rehabilitating destroyed soils can impose high costs on stakeholders.[31]

FACTORS CONTRIBUTING TO EROSION IN MOROCCO

The variable and intense storms, fragile soils, and the steep and long slopes characterizing Moroccan geography render it naturally vulnerable to high rates of erosion.[32] Climate change and population-boom induced increases in grazing and urban development further decrease vegetative cover in forested and agricultural areas and intensify erosion rates. Diminishing forest coverage has degraded soil stability and its resistance to erosion, which has in turn diminished the quality of water and soil carrying capacity, crucial for vegetation growth and the needs of the agriculture and livestock industries.[33]

For example, recent estimates indicate rates of forest loss stood at 30,000 hectares annually from Morocco's nine million acres of forest.[34] Droughts beginning in the late 1970's coincided with a northward shift of climatic zones and reduction in the suitable habitat of sturdier hardwood tree species.[35] Illicit tree harvesting, slash-and-burn clearing, and urban development magnify losses occurring due to this shift, though the activities of international donors, such as the United State Agency for International Development (USAID) and Japan International Cooperation Agency (JICA), have had positive effects to reduce dam sedimentation by increased vegetative cover. Erosion rates in the Rif Mountains in the north of Morocco, for example, peaked at 3,500 tons/km^2/year in 1970, but recent estimates of dam sedimentation indicate that projects, such as the 1996 Sustainability of Water Resources in Morocco or PREM (Pérennité des Ressources en Eau du Maroc) project of USAID in the Loukkos Basin, may have played a role in decreasing local sedimentation rates to the Idriss I Dam due to project components that advocated extensive orchard and vetiver shrub planting.[36]

Studies using GIS and the normalized difference vegetative index (NDVI) as a measure of changes in vegetative cover from 1981-2003 confirm the increases in vegetative cover (11 percent) in the Rif Mountains, areas adjacent to the Atlas Mountains, and in the Drâa River valley.[37] Significant decreases (3 percent) coincided with the urban areas on the northwestern coast of Morocco, including Rabat and Casablanca, Morocco's economic and political capitals, which developed extensively in the latter half of the twentieth century.[38] These areas, particularly the Maâmora Forest between Kénitra and Rabat, the largest cork oak forest in the world, suffered a 30 percent reduction in coverage from 1951 to 1992 due to real estate development and tree harvesting for local pulp mills and firewood.[39]

Declining forest and vegetative cover contribute to soil destabilization, erosion, and dam sedimentation in Moroccan watersheds, particularly since variable rainfall extends the maturity period of forests.[40] As of 2000, about 25 percent of watershed land in Morocco lost more than 25 tons/hectare/year, rates that exceed severe risk for erosion.[41] As of the last accessible national survey of dam sedimentation in Morocco in 1988, soil loss in watersheds has led to the loss of storage capacity in downstream reservoirs amounting to 75,000 meters cubed ($m^{3)}$ per year or 0.5 percent of annual storage capacity for all Moroccan dams.[42] Individual reservoirs such as the Ibn Batouta reservoir in the Rif Mountains have closed due to excess silting.[43] This survey also estimated that 40 Mm^3 of sediment deposits in reservoirs per year, resulting in the loss of enough water to irrigate 5,000 to 6,000 hectares of agricultural land, 60 kW h^{-1} of electricity generation, and approximately 10,000 jobs. [44]

Table 1 describes a survey of dam sedimentation in Morocco for years 1992, 1998, and 2000. Average sedimentation rates stand at 49 hectares/m^3/year according to these three measured points, which is higher than the rate recorded in the national survey in 1988.[45] Each entry reflects rates conducted for a different group of dams. Inconsistency in historical records does produce substantive variance in available dam sedimentation rates. Administrative reforms in data management and storage, and standardization of the models used to measure sediment loss and deposition in upstream watersheds and downstream reservoirs would address this source of error in current and future efforts to study and mitigate erosion in Morocco. Treating systemic issues in data management could provide a low-cost method for improving erosion mitigation in Morocco.

Table 1: Sedimentation in Moroccan Dams

Reservoirs Affected	**Year**	**Annual Loss of Capacity in Hectares/m³/year**	**Percent Annual Loss of Capacity**
78 Dams	1992	50	0.5
29 Dams	1998	38	0.4
25 Large Dams	2000	65	0.45

Source: Generated by Madeline Clark using data from Sediment Committee, "Sedimentation and Sustainable Use of Reservoirs and River Systems," (Draft Bulletin, ICOLD, 2009), 31.

International efforts to study erosion also pinpoint the gravity of dam sedimentation in Morocco. Of 28 countries surveyed by the International Commission on Large Dams (ICOLD) in 2009, Morocco ranks 5th in percent capacity lost to sedimentation.[46] ICOLD predicted that the country's dams will achieve critical sedimentation volumes by 2050.[47] Figure 2 demonstrates that average sedimentation in Moroccan dams reached 1.48 percent per year in 2006, which exceeded the global annual average of 0.96 percent.[48] At that rate Morocco will lose its storage capacity by 2050 if no future reservoirs are built and no further action is taken to mitigate soil erosion.[49]

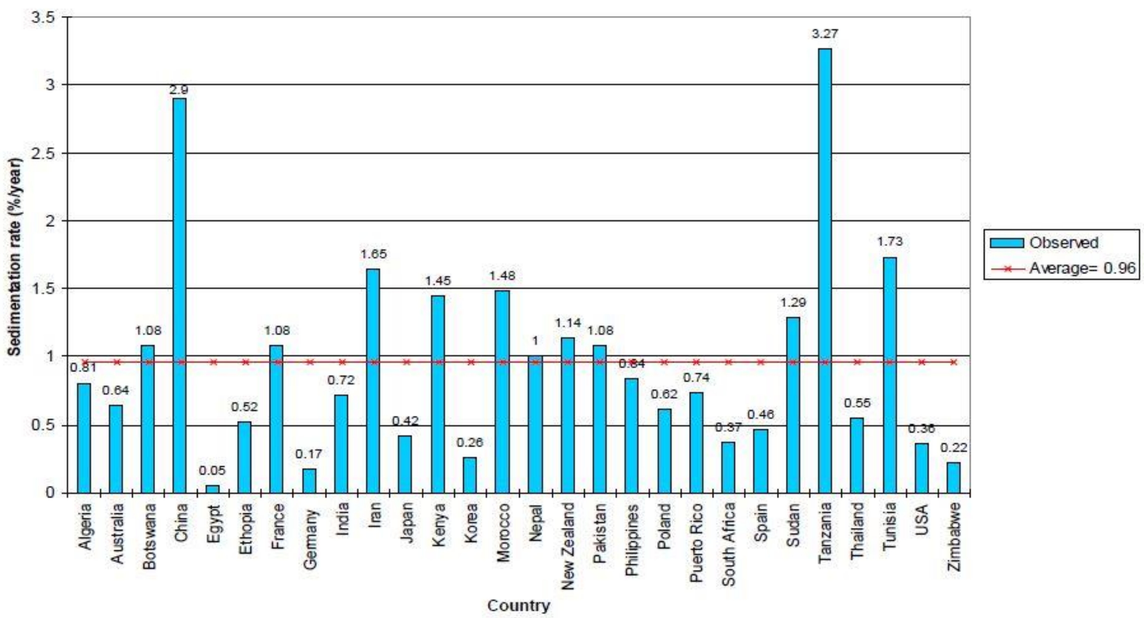


Figure 2: Observed Global Sedimentation Rates

Source: Sediment Committee, "Sedimentation and Sustainable Use of Reservoirs and River Systems," (Draft Bulletin, ICOLD, 2009), 36.

Though dam sedimentation appears to be increasing, the ratio of dam and water storage infrastructure construction in Morocco relative to dam sedimentation also remains high. Dam construction expanded under King Hassan II in 1967 with his goal of irrigating one million hectares before the year 2000 by increasing the dam capacity of

Morocco for water storage reserved for the drinking, irrigation, industry, and energy production sectors.[50] As a result, there were 84 large dams in operation as of 1996, with a total capacity of 1,000 million meters cubed, irrigating 772,000 hectares.[51] During the droughts of the beginning in the late 1970s and continuing well into the 1990s, the increased water storage obtained through dam construction protected Morocco's drinking water supply, and enabled it to meet the growing demands stemming from major population centers and users in its drinking water, agricultural, and industrial sectors.[52] As of 1996, water demand from all sectors increased at a rate of 8 percent per year, of which the dams supplied 64 percent of this increase in demand. This supply-side focus in water management continues to the present day, though environmental reforms such as Plan Maroc Vert are forcing Morocco to search for alternative demand-side policies to better combat uncertainty in water supply potential, such as rainwater harvesting.[53]

The Impacts of Climate Change on Morocco

Decreasing forest coverage and increasing dam sedimentation, as threats to water storage for the drinking water and agricultural sectors, will intensify Morocco's natural vulnerability to the effects of climate change. With a variable climate overlapping the contrasting Mediterranean and Sub-Saharan zones and influenced by the El Niño-Southern Oscillation (ENSO) and North Atlantic Oscillation, Morocco's rainfall distribution is uneven.[54] Coastal basins such as the upper Moulouya, Loukkos, Sebou, and Bouregreg-Chaouia bordering the Mediterranean and Atlantic to the north and northeast, experience an average of 750 millimeters (mm).[55] Basins in the arid south such as Tensift and Souss-Massa-Drâa bordering the Sahara Desert experience an average rainfall of 100 mm.[56] The majority of rainfall in all basins occurs between October and April, which gives rise to intense storms that encourage high erosion rates.[57]

Morocco has also historically been vulnerable to periods of drought that last between one and six years and that have been increasing in recent decades.[58] Average rates of evapotranspiration are also high, as only 29 billion of Morocco's total rainfall (150 billion m^3) replenishes surface and groundwater flow, with the rest returning to the atmosphere.[59] A comparative study of precipitation from 1945-2000 and 1975-2000 indicates that inputs to the hydrological cycle are decreasing, citing a 20 percent reduction in precipitation that reflects the frequent droughts occurring between the years of 1970 and 2000.[60]

Of Morocco's 22 billion m^3 of renewable freshwater resources, 17 billion m^3 are mobilized.[61] Though drinking water receives priority in water allocations in Moroccan Water Law, 80 percent of this mobilized potential is already allocated to existing demands from the agricultural sector. [62] Increased demand for water from all sectors resulting from Morocco's rapid economic development has also led to the exploitation of scarce groundwater resources, which directly conflicts with principles embedded in the Water Law of 1995.[63] Figures of the Secretariat of Water of Morocco indicate that as of 2004, per capita water resources only reached 700 m^3 per person per year, placing it well below the United Nations Development Program (UNDP) water scarcity criterion of 1,000 m^3 per person per year.[64] Predicted per-capita water allotments will decrease to below the absolute scarcity threshold of 500 cubic meters per person per year by 2025, rendering Morocco a chronically water stressed country.[65]

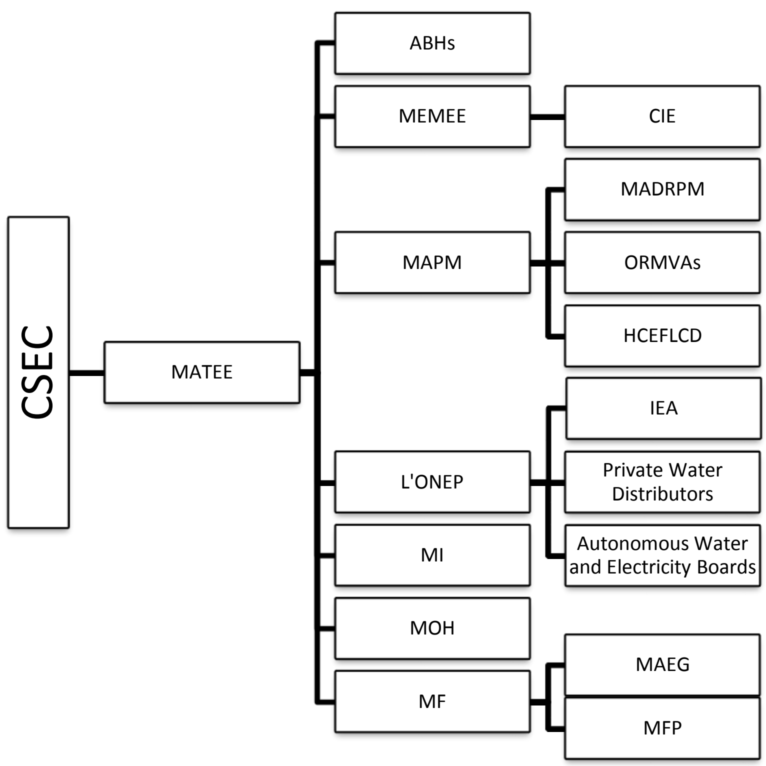
Relying on the export of water-intensive crops holds important impacts for Morocco's food security.[66] Though Morocco was listed as self-sufficient in terms of food production in the 1970's and 1980's, increasing drought frequency and population and urban growth ushered in increases in the import of cereals, oil-related products, and sugar to meet domestic demand in recent years.[67] As a result of the increased frequency of droughts, desertification in rural areas like the Souss region to the south catalyzed the mass migration of nomadic and agricultural communities to the cities in the 1980s.[68] Approximately half of Morocco's land area of 710,000 $kilometers^2$ (km^2) is currently classified as desert areas, which increases to 78 percent when dry zones are included.[69] Arable lands and permanent cropland, conversely, naturally occupy a small portion, or 12 percent of Morocco's total land area of 710,000 kilometers^2 (km^2).[70] Because 50 percent of Morocco's rainfall falls on 15 percent of its territory and the most intensely rain-fed areas possess fragile, infertile soils that are not conducive to agriculture, 12 percent of Morocco's permanent cropland is irrigated to support water-intensive crops such as barley, bread and durum wheat, maize, fava beans, chickpeas, lentils, and peas.[71]

Moroccan policy makers should not ignore the importance of demand-side management in soil and water conservation. Rapid population growth has magnified water demand in Moroccan coastal cities that are vulnerable to the effects of climate change, including Casablanca, Rabat, and Tangiers.[72] The total number of inhabitants in Morocco increased from approximately 19.8 million in 1980 to 31.6 million in 2010, with a projected jump to 42.9 million by 2050.[73] The growth of Morocco's urban areas in the last half century reflect this trend. More than 53 percent of its population lived in urban areas as of the 2004 National Census conducted by the High Commissariat of Planning, or Haute Commissariat au Plan (HCP), a 12 percent increase from 1980.[74] Morocco's urban population is projected to reach 78 percent by 2050.[75] Though population growth rates decreased from 2.36 percent in the period 1980-1985 to 0.98 percent in the period 2005-2010, they have increased to 1.41 percent for the period 2010-2015. [76]

INSTITUTIONAL FRAMEWORK OF EROSION MITIGATION IN MOROCCO

To combat erosion, forest loss, and flooding in the lower parts of watersheds, which often include cities, the Moroccan government has placed soil and forest conservation high on its list of national priorities.[77] However, its government, through the HCEFLCD and Hydraulic Basin Agencies, or Agences des Bassins (ABHs), does not always implement or enforce its erosion mitigation policy.[78] Figure 3 illustrates the interaction of entities within the water and agroforestry sectors of Morocco.

Figure 3: Landscape of Water and Agroforestry Management in Morocco



Source: Generated using data from A. Ouassou et al., "Application of the drought management guidelines in Morocco (Part 2. Examples of application)," in eds. A. Iglesias, M. Moneo, A. López-Francos, *Drought Management Guidelines Technical Annex*, (Zaragoza: CIHEAM / EC MEDA Water, 2007), 343-372.

The HCEFLCD has taken charge of forest management from the Ministry of Agriculture and Maritime Fisheries, or Le Ministère de l'Agriculture et de la Pêche Maritime (MAPM) and is responsible for enforcing national and local-level policies regarding forest use.[79] Under the Dahir or official declaration of October 10th, 1917, the HCEFLCD holds administrative and legal power for enforcing forest conservation because the Dahir defines forest resources as the property of the state, excluding land titles established previous to 1917.[80] The HCEFLCD also serves as the primary supervising institution for research on the state of forest, water, and soil resources, and conducts vulnerability studies regarding forest loss and erosion though its affiliate Center for Forest Research, or Centre de Recherche Forestière (CRF). After the HCEFLCD and CRF finish their investigation, the HCEFLCD develops erosion and forest degradation mitigation measures, including monitoring and early warning systems, in coordination with regional stakeholders such as the ABHs.[81] The HCEFLCD also implements soil, water, and forest conservation programs, and publishes strategic plans for soil, water, and forest resources in critical basins in coordination with the ABHs, the MAPM, the Ministry of Energy, Mines, Water, and the Environment or Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement (MEMEE), and international donors such as USAID and JICA.[82]

The HCEFLCD initiated the PNABV, the most powerful policy instrument driving erosion mitigation, in 1996 to ameliorate 1.5 million hectares of forest over 20 years and 10 million hectares of the 22 river basins most significantly altered by erosion damage.[83] To supplement the PNABV, the HCEFLCD created the National Forest

Management Program in 1998, which will serve as the guiding plan for forest management policy until 2020. This strategy places an emphasis on the management of forests as a national asset, harmonizing urban development with forest conservation, a participatory development approach, and the strengthening of partnerships between stakeholders.[84]

As it was developing the PNABV, the HCEFLCD aimed to develop and strengthen a model for predicting erosion in order to optimize soil conservation. In an agronomical study comparing land loss with runoff as a function of land cover, the HCEFLCD attempted, with help from the Food and Agriculture Organization (FAO), to adapt the RUSLE model to Moroccan conditions.[85] This effort did not succeed, however, because (a) Moroccan operators could not mobilize a statistically sound, reliable dataset comparable to that used to develop the Universal Soil Loss Equation (USLE) and RUSLE, and (b) because RUSLE is not suitable for predicting channel or gulley erosion.[86]

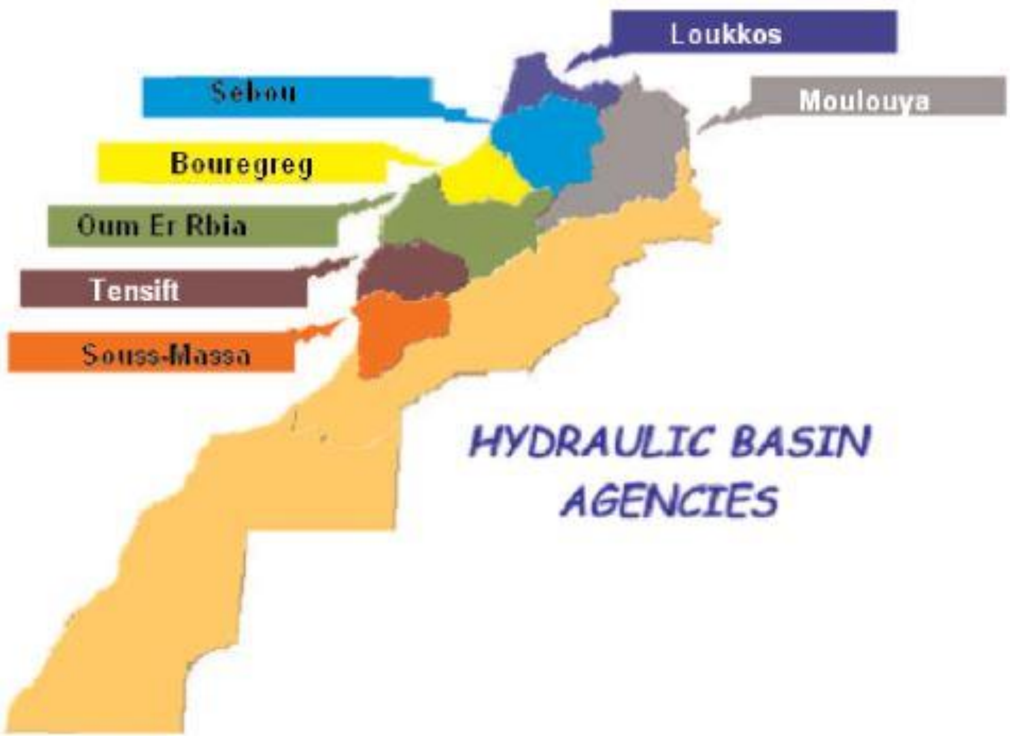
RUSLE still serves as the primary tool among water and agroforestry operators for predicting erosion, and HCEFLCD strategies for controlling erosion prioritize areas which have passed the threshold for preventing erosion.[87] This focus stems from deficits in financial and administrative support, which international development funding mechanisms provide to the Moroccan government, rending Morocco's land management paradigm reactive rather than proactive. For example, though the PNABV began in 1996, ABHs have only recently adopted the practice of simulating of flooding and erosion potential to minimize siltation in new dam sites prior to building a dam.[88] The HCEFLCD serves as a consultant in erosion and flood management studies for the ABHs as part of larger feasibility studies, but defers to the ABH in the actual implementation of erosion mitigation projects.[89]

Morocco's current water law began to take shape in the early 1990s and follows the framework of earlier laws passed during the French Protectorate and after Morocco's independence in 1956.[90] Before the nineteenth century, Morocco's naturally variable climate and reliance on surface water prompted the development of the Azerf or customary law of indigenous Amazigh or Berber groups and adoptability of Sharia law after the Islamic conquest of Morocco in the 9th century.[91] Morocco's current institutional and legal framework for governing water is encoded in Loi n° 10-95 sur l'eau, or the Water Law of 1995, which was ratified in the Bulletin Officiel de Maroc on August 16th, 1995.[92] The Water Law of 1995 established that the Supreme Water and Climate Council or Conseil Supérieur de l'Eau et du Climat (CSEC), which is headed by the King of Morocco, sets forth overarching goals for national water and climate policy.

The Water Law of 1995 also created the ABHs, which are responsible for managing water resources at the river basin-level in coordination with local water user associations (WUAs) and water distributors.[93] Implementation of the annual ABH Master Plans for Integrated Resource Management (PDAIREs) began in 1997, through ten agencies for the Loukkos, Tangiers and coasts, Moulouya, Sebou, Bouregreg-Chaouia, Oum Er-Rbia, Tensift, Souss-Massa-Drâa, Atlas South, and Sahara River Basin Systems.[94] On the ground, the ABHs create and enforce targeted local regulation and uphold integrated water resources management (IWRM), including erosion mitigation.[95]

Though the PNABV stipulates that the HCEFLCD and ABHs work closely together to optimize erosion mitigation, erosion in principle receives brief mention as of the PDAIREs published in 2012 and primarily through its relation to flood mitigation.[96] Tangible mention of information specific to erosion from the HCEFLCD began only in ABH PDAIREs published in 2013, despite the fact that the PNABV began nearly a decade earlier.[97] Figure 4 illustrates the division of Moroccan according to the boundaries of the ABHs.

Figure 4: Hydraulic Basin Agencies in Morocco



Source: A. Ouassou et al., "Application of the drought management guidelines in Morocco (Part 2. Examples of application)," in eds. A. Iglesias, M. Moneo, A. López-Francos, *Drought Management Guidelines Technical Annex*, (Zaragoza: CIHEAM / EC MEDA Water, 2007), 353.

Though the ABHs drive water and land management policy-making at the basin-level, governance at the national, commune, and municipality levels involves sectoral planning by ministries and operation between stakeholders that include public and private companies and local water user associations. These stakeholders include the Ministry of Regional Development, Water and the Environment (MATEE), which is the direct technical supervisor of L'ONEP, now called ONEE-Branche Eau and henceforth referred to as L'ONEP.[98] L'ONEP relies on the IEA as its premier vehicle for research on issues bridging the technical, social, and economic aspects of water planning and reservoir management.[99] L'ONEP is responsible for water sanitation and water distribution in rural areas.[100] The departments of water and the environment within the MEMEE, the MOH, the MI, and the MAPM, in addition to the ABHs, communicate their needs to L'ONEP, so that L'ONEP produces enough water according to these needs.[101] Local municipalities vote to either continue using L'ONEP, hire a private water company such as Redal, Lydec, or Veolia, or create an autonomous water and electricity distribution board for providing services regarding the delivery and distribution of water.[102] Redal, Lydec, and Veolia govern Rabat, Casablanca, and Tangiers and Tetouan, respectively.[103] Autonomous water and electricity boards include RADEEC in Settat-Chaouia), RADEEF in Fes, RADEEJ in El Jadida, RADEEL in Larache, RADEEM in Meknes, RADEEMA in Marrakech, RADEEO in Oujda, RADDES in Safi, RADEET in Beni-Mellal-Tadla, RADEETA in Taza, RAK in Kénitra, RAMSA in Agadir.[104] Table 2 lists other sectoral leaders in water planning.

Table 2: Sectoral Leaders in Water Planning and Management

Organization	Abbreviation	Role
Ministry of Energy, Mines, Water, and the Environment	MEMEE	Coordinates the management and monitoring of environmental resources.
Inter-Ministerial Council of Water	CIE	Headed by the Prime Minister and facilitates communication between government ministries in the water sector.
Ministry of Agriculture and Maritime Fisheries' Department of Rural Development and Sea Fishing	MAPM; MADRPM	Manages irrigation water through its Agricultural Development Regional Offices (ORMVAs).
Ministry of the Interior	MI	Supervises water distribution, sanitation, and the operations of utilities through its Department of Utilities and Services.
Ministry of Health	MOH	Monitors and controls drinking water quality output at gage points and educates the public about the linkage between water and health.
Ministry of Finance's Ministry of Economic and General Affairs	MOH; MAEG	Chairs the inter-ministerial tariffs committee and regulates drinking water and sanitation tariffs, excluding contractual tariffs where there are cases of historic rights or delegated management.
Ministry of Finance's Ministry of Finance and Privatization	MF; MFP	Directs and coordinates the economic and financial planning of the water, forestry, and agricultural sectors.

Source: Generated by Madeline Clark using data from Ahmed Wagdy and Khaled AbuZeid, “Challenges of Implementing IWRM in the Arab Region.” (Proceedings of WWF4, Mexico City, 2006).

Erosion mitigation currently taxes the resources of the HCEFLCD and ABHs because institutional support primarily exists for coordination between the water and agroforestry sectors where irrigation is concerned.[105] The ABHs, MEMEE, and MI comprise the primary operators of large water infrastructure projects like reservoirs and L’ONEP infrastructure and resources pump water from the reservoirs to its treatment centers, which are then subject to distribution.[106] Local and regional water planning and management authorities including L'ONEP are not responsible for mitigating and studying erosion even though they suffer from the water storage deficits created by dam sedimentation as water producers and distributors.[107] Public entities like L'ONEP do however include soil and water conservation as guiding principles in the environmental impact assessments that they complete for new infrastructure projects.[108]

As mentioned previously, soil and water conservation are treated differently under Moroccan law. In the same way that the Dahir of October 10, 1917 delimits and protects forest resources from the conflicting interests of stakeholders, the Water Law 10-95 defines water as property of the state, elevates the sustainability of water resources through conservation and adaptation measures as a national priority, and seeks to wean stakeholders away from the supply-driven approaches to generating new water resources.[109] The funding and economic incentives necessary to properly enforce both legal instruments does not exist consistently, though both the HCEFLCD and ABHs publish a detailed schedule of tariffs and fees, and punishments for violating conservation and permit procedures. Table 3 compares the treatment of soil and water in Moroccan Law.

Table 3: Legal Definitions of Soil and Water in Moroccan Law

Law	Moroccan Forest Law and the Dahir of October 10th, 1917	Water Law of 1995
Definition and Ownership	Forest and water resources, and any exploitable natural resource, are defined as being property of the state; Exceptions to state ownership are limited to contracts drawn before 1917 including individual, tribal, and grazing lands;	Water is a public good, which means it is guaranteed for consumption by all and owned by the state; Exceptions limited to traditional water rights protected under customary law or Azerf dating before the French colonial period.
Priority Use	Strengthened through establishment of National Parks in 1934. State determines priority use;	Water management is centered on hydrological boundaries at the basin level, and drinking water takes priority, followed by agriculture and then industry;
Enforcing Punishments for Violations	Tariffs are imposed on use of forest resources, and on violators of public space by HCEFLCD;	Tariffs are imposed by the ABHs, and violators are punished by ABH water police in theory; Water possesses economic value, which strengthens the enforceability of the "user-pays" and "polluter-pays" principle;
Planning	Strengthened by the PNABV and National Forest Program in 1996 and 1998;	The National Water Plan serves as a long-term strategy for integrated water resources management, currently until the year 2020;
Regime Establishment	The Ministry of Agriculture, and then HCEFLCD in 2003 grant contracts and coordinate with local development authorities and private users;	Decentralized decision making and increased stakeholder participation realized, bottom-up, through the establishment of WUAs, ABHs, and the CSEC
System of Rewards	Rural development given priority in international development projects, otherwise no incentive for complying;	Economic incentives for water allocation decisions exist through rational tariffs and cost recovery, though prices have increased;
Capacity Building	HCEFLCD responsible for mobilizing resources, and where overlap occurs, calls on other concerned stakeholders, such as the ABHs regarding flood mitigation;	All stakeholders engage in capacity-building to meet challenges that occur in the management of water resources- the water sector is organized with actors among the private and public sectors;
Monitoring	The HCEFLCD is the sole actor responsible for enforcing Moroccan Forest Law, including erosion mitigation and bio-diversity rehabilitation.	Responsibility for monitoring and controlling water quality is delegated to the ABHs to mitigate environmental degradation.

Sources: Generated by Madeline Clark using data from Institution," Haut-Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification, 2009, http://www.eauxetforets.gov.ma/fr/institution.aspx, paragraphs 2-3; A. Ouassou et al., "Application of the drought management guidelines in Morocco (Part 2. Examples of application)," in eds. A. Iglesias, M. Moneo, A. López-Francos, *Drought Management Guidelines Technical Annex*, (Zaragoza: CIHEAM / EC MEDA Water, 2007), 343-348.

Though land use and ownership conflicts are regulated by the Dahir of 10 October 1917 and subsequent Dahirs, decision makers have not streamlined the Moroccan Forest Law as they have the Water Law of 1995, as illustrated in Table 3. The greatest challenge to erosion mitigation rests in the fact that erosion in Moroccan watersheds primarily occur in severely degraded areas, or badlands, and along river networks, which have limited economic exploitation potential and non-existent or ambiguous returns to stakeholders.[110]

Three other strategies and decisions initiated by the current King of Morocco, Mohammed IV have shaped environmental policy-making in Morocco. The Green Morocco Plan, or Plan Maroc Vert, was initiated in 2008 in response to a crisis in global food prices from 2006-2008. [111] This initiative aimed to increase investment and efficiency in the agricultural and water sectors and promote sustainable, environmentally-friendly rural development.[112] This plan has now infiltrates all new projects initiated in Morocco, and has led to innovation in the energy, environmental, agricultural, and water sectors.[113] The Environmental Impact Studies Law 12-03, or Loi n° 12-03 Relative aux Études d'Impact sur l'Environnement, dictates that an assessment of potential environmental impact must precede any new industrial or infrastructure project, and the public should be informed of the study's contents.[114] Regarding the human consequences of new projects, the INDH, which was ratified in 2005, plays an important role in linking the economic and social realities of a basin with environmental objectives.[115] The HCEFLCD and ABHs support the activities of the INDH through rural development strategies. The INDH, in the same vein as the PNABV and Water Law of 1995, has been primarily supported by the framework and momentum of international projects.

International Involvement in Morocco

Though the Moroccan government has passed soil, forest, and water resource management reforms, the support needed to implement and enforce these reforms has primarily comes through international funding. Pressure from donors has also influenced evaluation methods within the field of natural and environmental resource management, particularly regarding environmental impact assessment protocol.[116] Stakeholders such as L'ONEP that have worked extensively with donors like the World Bank now promote the principles of environmental impact assessment and project evaluation, which echoes a greater awareness of accountability in Moroccan administrative culture.[117] Unfortunately, the uneven implementation of these principles neuter the sustainability of accountability on the ground and limit the legal mechanisms necessary to implement and enforce it.

In the mid-1990s, national and FAO experts formulated a large-scale water management project for Morocco under the supervision of FAO's Forestry Department.[118] The goal of the project was to promote participatory water management under the framework of IWRM.[119] Watershed areas ranged from small 1,000 km^2 catchments to large 50,000 km^2 basins and specific sediment yields between 300 to 3,000 tons/km^2/year.[120] The project rested in assessing potential influence of land conservation practices on reservoir sedimentation rates in the large dams of Morocco, and assigning value to the benefits of project interventions. The study found that proposed land conservation practices would have a negligible impact on reservoir sedimentation regardless of the land area covered because only a fraction of each watershed would benefit economically from erosion control measures.[121] To overcome the challenges identified in the study, FAO officials recommended implementing a uniform, decentralized form of water management with clear incentives and penalties for complying with national and local policies, allowing local water board authorities and users to report to their respective ABH.[122]

USAID participated in the development of the Moroccan PNABV through the Morocco Watershed Protection and Management project, which ran from 1996-2002 and aimed to improve water resources management by promoting the efficient and sustainable use of forest, soil, and water resources in two different basins in the Souss-Massa and Nakhla Watersheds in the south and north, respectively.[123] In the Nakhla Watershed, the aim of the project included expanding successful water resources sustainability (WRS) pilot projects and supporting agroforestry and soil conservation activities in the entire watershed to reduce the siltation of the Nakhla River.[124] Project objectives in the Souss-Massa-Drâa Basin consisted of identifying, designing, and implementing new watershed protection activities to control soil erosion, reduce the spread of desertification, and protect water quality.[125] Other goals of the project focused on establishing best practices using local resources.[126] Project partners included the MEMEE, MAPM, the Directorate of Hydraulics, the Ministry of Water and Forests (DREF), L'ONEP, and the Agency for the Development of Northern Morocco (Agence du Nord), the Wilaya of Tetouan, the Wilaya of Agadir, and the Souss-Massa-Drâa River Basin Agency.[127]

USAID observed that successful strategies for implementing projects in the Nakhla Watershed included: adjusting administrative and decision making mechanisms, which diminished bureaucratic rigidity; enhancing coordination of stakeholders across sectors; and decentralizing decision making.[128] Issues limiting the full success of the project included differences in the ability of participants to comprehend both the benefit of the project and the negative consequences of no action due to economic status and education level.[129] Well-off participants perceived the benefit of participating at a small investment, in return for improved ecosystem services over time.[130] Some small-scale farmers did not understand the program, and undermined project components seeking to promote new farming practices in mixed farmland and orchards by uprooting trees planted for soil stability and plowing vertically along steep slope gradients, practices which intensify sheet erosion.[131] Focusing on participatory management did not solve this problem, and was exacerbated by the absence of structure in negotiation norms.[132] The USAID team also highlighted that the wide dispersion of responsibilities among ministries and agencies and an absence of a central authority for monitoring and enforcement the ability the project to inspire the adoption of IWRM.[133]

JICA also participated in the National Plan for Watershed Management from April 2007 to December 2013 by partnering with the Moroccan government under the PNABV.[134] With the HCEFLCD as an implementing partner, the project took place in the Oued El Mellah Watershed (Provinces of Settat, Khouribgha, and Ben Slimane), which is ranked fifth among the twenty-two critical watersheds identified by the PNABV, and the Allal El Fassi Dam Upper Watershed (provinces of Sefrou and Boulemane).[135] The project components that focused on alleviating poverty in rural areas also supported the INDH.[136] Project objectives include afforestation, improvement of the living conditions of local residents, forest conservation, and the integration of forest conservation in local economic development.[137] Project actions manifested through afforestation, small-scale buffer dams, and activities for livelihood development in the framework of the Village Action Plan or Plan de Development des Douars (PDD).[138] Two years after project implementation in 2015, 1,200 of 3,400 hectares targeted were successfully afforested, with planting survival rates of 60 percent and 70 percent, and eight dams that were constructed as of 2013.[139] Tables 4.1 and 4.2 summarize important measures that Morocco has taken to address erosion.

Table 4.1: Establishing Law for Erosion Mitigation in Morocco, 1917-1996

Action Taken	Date	Description
Legal intervention in Forest Conservation begins	1917-1951	Dahir 1917 creates Moroccan Forest Law. Forest conservation measures like combatting clearing for farmland begin.
Dahir on Creation of National Parks	1934	National protection of forests recognized, as national park areas declared off-limits for economic exploitation, including wood-gathering and grazing.
Erosion mitigation defined by preventative measures	1945-1970	Erosion damages recognized in decreased soil productivity, gullies, landslides, floods, and dam sedimentation. Measures to combat manifest sparsely through research, mechanical interventions like terraces, earth banks, and sills, and biological interventions like reforestation.
National Interest Program Implemented	1952-1969	National Interest Program sets up legislation and inspires public action to combat soil erosion though contracts with communities and landowners.
Quantitative Study of Erosion Begins	1965-1985	B. Heusch develops runoff plots for Moroccan catchments, demonstrating that: 1. Sheet erosion is less important than river erosion, 2. Exceptional rainstorms induce more erosion damages by saturation of the topsoil than averaged rainfall, 3. Agricultural land use type incurs most erosion.
National Survey of Erosion	1970	Study of erosion nation-wide, including water mobilization policies, leads to draft of plan of action.
Dahir on the Organization of Public Participation in the Forest Economy	1976	Further delineation of responsibilities and rights of stationary and nomadic users in forest-dependent economies.
FAO conducts feasibility studies on IWRM	Early 1990s	The FAO forestry department partners with stakeholders in the Loukkos Watershed to determine the impact of IWRM management strategies and participatory mechanisms on dam sedimentation.
Water Law of 1995	1995	This law provides a legal framework for water resources planning and management for the first time.
Establishment of CSEC	November 1996	Headed by the King, this council gathers data from the hydrologic basin agencies, sets water policy, and issues a National Water Plan every five years.
Creation of PNABV	1996	Adoption of National Watershed Management Plan (PNABV) as the strategic framework for integrating small scale, local level planning and long-term participatory IWRM. The adoption of the PNABV encouraged by other reforms, including the Water Law of 1995.

Source: Generated by Madeline Clark using data from A. Omerani, “Watershed management,” in “Institutional implications of participatory approaches.” *Decentralization and Rural Development* 20 (Rome, FAO, 2002).

Table 4.2: Strengthening Erosion Mitigation in Morocco, 1997-2008

Action Taken	Date	Description
USAID declares support for PNABV	**1996-2002**	USAID begins series of projects in the Nakhla Watershed as part of PNABV.
Establishment of the first Hydraulic Basin Agency of Oum Er-Rbia	1997	Hydrologic Basin Agencies take over basin-level management of water resources and become key drivers of policy in the water sector.
Official decision to review master plans for water resources and their integrated management, or PDAIREs (Plans directeurs d'aménagement integré des ressources en eau)	October 1997	Established the legal tradition of the PDAIRE, the PNABV, and the establishment of fixed regulations for reservoir allocations.
Use of public water use defined	February 1998	Established a system of authorizations of the use of public water resources and new rules and limitations for changes to river bed morphology including the extraction of material, created district water commissions, defined water quality standards, carried out an inventory of water pollution levels, defined standards for wastewater recycling, and delimited areas for the protection of water aquifers.
HCEFLCD Enacts National Forest Management Plan	1998	Strategy places an emphasis on management of forests as a national asset, harmonizing urban development with forest conservation, a participatory development approach, and the strengthening of partnerships between stakeholders
HCEFLCD takes over forest management from the Ministry of Agriculture	2003	HCEFLCD transforms from technical agency to multi-purpose management authority.
JICA begins involvement in PNABV in Chaouia basin	2007-2017	JICA partnered with the HCEFLCD to stage mechanical and institutional interventions in the Oued El Mellah Watershed, which experienced flash floods in 2005.
Plan Maroc Vert initiated	2008	This strategy originated in the agricultural sector, but has had important impacts for all aspects of Moroccan policy-making.

Source: Generated by Madeline Clark using data from A. Omerani, “Watershed management,” in “Institutional implications of participatory approaches.” *Decentralization and Rural Development* 20 (Rome, FAO, 2002).

METHODS TO PREDICT AND QUANTIFY EROSION

Despite the serious and accumulating consequences that dam sedimentation, point source pollution, and the loss of arable soil perpetuate on water quality and storage capacity, there is still a lack of consensus on how to directly measure and quantify sediment transport and yield, particularly within watersheds.[140] Soil erosion models presented to policy makers sort into two categories. The first category is that of quantitative studies that rely on empirical and physical models. These studies are more technical, and yield discrete estimates of soil loss, land loss, and rates of soil and land loss.[141] Within this spectrum, there are also engineering studies that describe sediment yield and delivery. The second category is that of qualitative studies, which rely on empirical models and describe risk.[142] Qualitative models represent the majority of input presented to decision makers and stakeholders because they do not rely on an extensive expertise to interpret.[143]

Empirical and process-based soil erosion models can help decision makers in three ways: choosing suitable conservation methods; undertaking erosion surveys for regional and longitudinal planning; and regulating conservation compliance.[144] Regardless of their purpose, stakeholders optimize model choice based on the objective of the study, the nature of the study site and erosion present, and the availability and quality of data and technological resources available.[145] Table 5 provides a summary of USDA-produced erosion methods discussed in this section.

Table 5: Methods Developed for Soil Erosion Modeling by the USDA

Method	Type	Input and Output	Conditions	Benefits	Limits
USLE	Empirical, multiplicative	Interaction of 7 factors yields average annual soil loss over plot area in agricultural field or forest.	20 years of precipitation data, majority agricultural land use, minimal plot curvature	Quick and not data-intensive, roughly generalizable and reliable	Does not predict channel/gully erosion, sediment yield, or sediment delivery model
MUSLE	Empirical, multiplicative	Interaction of 5 factors yields average annual soil loss over defined area in drainage network.	20 years of runoff data, majority agricultural land use	Same benefits as USLE, but can be used to derive sediment delivery model and predict rates of gully erosion	Does not predict sheet/interrill erosion
RUSLE	Empirical, multiplicative	Interaction of 5 factors yields average annual soil loss over plot area in agricultural, mixed-use, and forested areas.	20 years of precipitation data, majority agricultural land use	Same benefits as USLE and can be implemented using computer	Similar limitations as USLE
WEPP	Process-based and non-multiplicative, interaction of infinite factors	USLE and RUSLE inputs and parameters like evaporation, canopy moisture, and soil moisture yield on-site soil loss and off-site sediment delivery.	Depends on factor	More comprehensive sediment yield information, modeling	Extensive data requirements and high model uncertainty due to parameter interactions

Source: Adapted by Madeline Clark using data from K.G. Renard et al., *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Equation (RUSLE)* (Washington: USDA, 1997), 11-19.

Soil loss equations were developed to render soil conservation accessible to the layman as well as technicians and scientists, particularly with regards to interpolating limited erosion data to unstudied areas.[146] Efforts to develop the first method for predicting soil erosion began in 1936 in the United States and continued through the 1940's and 1950's as state and local-level scientists, engineers, and decision makers met to develop rational soil loss equations relative to local conditions.[147] The success of official state and regional equations inspired soil conservation leaders to call for the development of a national equation.[148] To achieve this aim, the Agricultural Research Service established National Runoff and Soil Loss Data Center at Purdue University in 1954.[149] This data center took on the responsibility for consolidating and examining all available data from runoff and erosion studies throughout the continental United States.[150] During the next two years, federal and state research entities at 49 U.S. locations contributed a collective 10,000 years of basic runoff and soil loss data to the data center at Purdue for summarization and statistical analysis.[151]

At a conference in 1956 held at Purdue, key researchers and users reconciled differences among existing soil loss equations and made attempts to develop an equation for extending technology where no measurements of erosion by rainstorms had been made.[152] Discussion between experts at this conference set the maximum permissible loss for any soil as 5 tons/acre/year, or 2 tons/hectare/year.[153] During this period, Wirschmeier, Smith and other researchers developed the six-factor Universal Soil Loss Equation (USLE) based on data at the Purdue center.[154] The goal of this equation was to make erosion potential representable by single number, applicable across all contexts, and not demanding in terms of data needed to construct it.[155] After a period of participatory calibration and input, the updated USLE was published in USDA's Agriculture Handbook 537 in 1978. USLE reduced a very complex phenomenon to a simple model, and it has become the most widely-used soil conservation planning tool, both in the United States and internationally.[156]

Additional research that has occurred since the USLE was officially adopted in Handbook 537 and provided the basis for RUSLE.[157] Though RUSLE and the Modified Universal Soil Loss Equation (MUSLE) incorporate the original USLE equation and use the same empirical principles and basic database, several of the factors have been elaborated due to new advances in technology and new data not available when USLE was published in 1965 and 1978.[158] RUSLE is similar to USLE, though many factors are process-based and the model is implemented in a computer-based environment.[159] RUSLE is designed to predict the longterm average annual soil loss carried by runoff from specific field slopes in cropping and management systems as well as rangeland, some forest conditions, and construction sites.[160] MUSLE is similar to RUSLE, though it replaces precipitation with runoff for the R-Factor of erosivity, and is used to predict fluvial erosion along channel networks.[161] Of interest to this study, developments in the LS factor are particularly extensive in RUSLE. A simpler, continuous form of the computation of the LS factor at a single point or cell in a GIS was developed by Mitasova and Mitas in 1996, and better accommodates pixel-based datasets like digital elevation models (DEMs).[162]

Research since the publication of RUSLE has focused on developing process-based methods for predicting and controlling erosion.[163] Process-based and physical models that have been developed to replace empirical models like USLE and RUSLE include the European Soil Erosion Model (EUROSEM), European Union; GUEST, Australia; and the Water Erosion Prediction Project (WEPP), United States.[164] The WEPP model is comprised of seven factors that include precipitation infiltration, water balance, plant growth, residue decomposition, and surface runoff.[165] Interactions between factors continue infinitely, which requires large amounts of data and increases the opportunity for uncertainty to enter the model.[166] Unlike USLE and RUSLE, WEPP provides onsite soil loss and off-site sediment delivery, including ephemeral gully erosion, and sediment delivery by particle size, which is important for chemical transport by sediment.[167] WEPP also provides more detailed local and catchment-wide information on the spatial and temporal distributions of soil loss, deposition, and sediment yields.[168]

Though empirical and process-based models do not replace or provide the granularity and reliability of soil erosion field studies or surveys, they do not require the same degree of financial resources and time to conduct.[169] Empirical models can be used to inform coordination of more intensive field studies and broad policy measures, but not to determine with a high degree of confidence and accuracy the erosion rate on a particular area of ungaged land.

Influence of Data Resolution on RUSLE Output

The resolution of datasets available for free or minimal cost to decision-makers and researchers in developing areas and countries does not exceed the maximum resolution available publically, or 30 meters (m). Studies such as those conducted by Gardner et al. indicate that course, variable pixel resolution of elevation, soil type, and land use datasets effects variance in RUSLE model output.[170] To this effect, Gardner et al. investigated limits and variability in the resolution of national DEM, soil, and land cover datasets available to decision makers in the United States and their influence on the magnitude and variability of erosion and sedimentation estimates derived through RUSLE modeling in a GIS in the Upper Little Tennessee River Basin in Macon County, North Carolina.[171] The results of the study indicated that (a) simultaneous coarsening of data leads to lower model predictions; (b) model results for coarser soil erodibility data increased with resolution; (c) unexplained variance occurred in simulations when compared to the reference model.[172] These results suggest that model estimates of sedimentation in a particular catchment do not compare well with each other when using different source data, and that the resolution of data used determines the precision of RUSLE results obtained in a GIS.[173] Gardner et al. recommended this modeling be used in decision making when supported by local observations and field measurements of local conditions and processes, watershed land use, and management practices.[174]

It is important to note that RUSLE and USLE only predict sheet/interrill and rill erosion, and not channel or gully erosion, which is a more typical feature of Moroccan watersheds.[175] RUSLE and USLE also do not predict sediment yield or derive sediment transport models, and both predict average annual soil loss, not for storms of individual years.[176] This quality does not negate the utility of RUSLE and USLE. Though erosion yields tend to change based on random fluctuations in factors, the annual and storm variation in R and seasonal variation in C average out as the length of the time series increases.[177] Sediment yield should not be confused with erosion; it is the amount eroded that is transported to a point in the watershed distant from the origin of the detached soil particles.[178]

EROSION RESEARCH IN MOROCCO

Serious efforts to study erosion in Morocco began in the 1960s and 70s, which coincides with the spike in dam building activity that occurred during the same period.[179] A survey of available literature also indicates that concerns about limiting dam sedimentation and the degradation of agricultural lands has driven erosion research in Morocco. These studies, which were primarily driven by international scientists, reflect a general trend in North Africa to study erosion, sediment transport, and reservoir sedimentation, though the interests of each research unit's sponsoring organization have traditionally defined its respective scope and objectives, limiting the comparability and transferability of results.

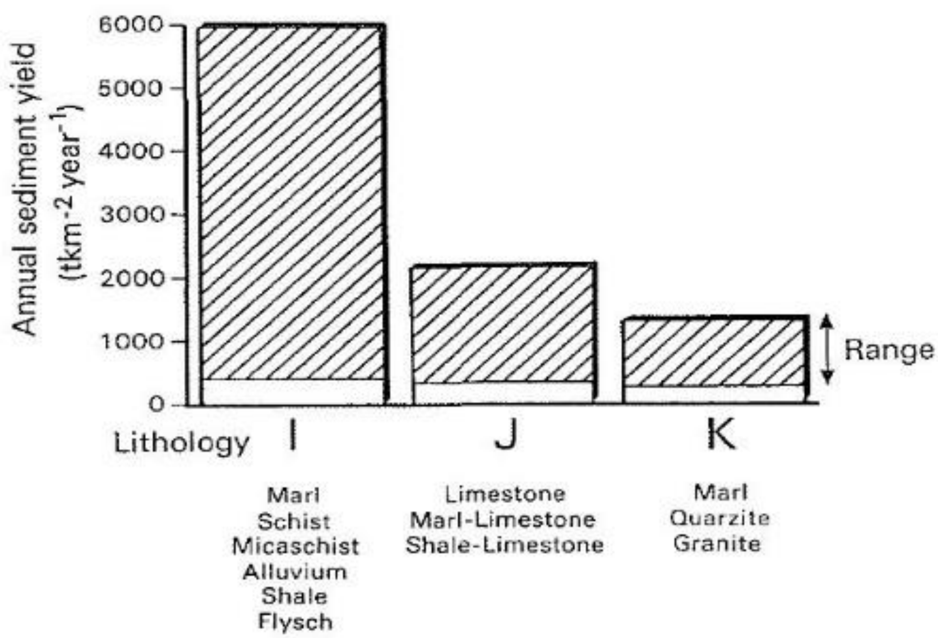
In 1970, B. Heusch, a project director at the Station for Forestry Research in Rabat, conducted a study that examined the relationship between rainfall and runoff to derive an erosion and sediment transport model for the northern Rif and Central-Massif areas of the country.[180] Examining basins with a total area greater than 500 km^2, Heusch used relationships between total surface area, annual precipitation in millimeters, and annual runoff to predict soil erosion rates in tons per km^2 per year, and found that erosion rates ranged from 25 tons/km^2/year in the Anti-Atlas, Sahara, Souss, and Moulouya plains, to 3,500 in the western Rif areas, which exceed the tolerable soil loss established by the USDA by a factor of 5 to 700.[181] Heusch predicted erosion rates were: 700 tons/km^2/year in the Middle Atlas; 1,700 tons/km^2/year in the Mediterranean areas bordering the Rif; and 3,500 in the Western Rif.[182] Of interest to this study, Heusch's rates in areas bordering the Atlantic coast-Oum Er Rbia, Bouregreg, Tensift, and Sebou amounted to approximately 150 tons/km^2/year.[183] Though areas in the northern mountainous Rif, neighboring Mediterranean coast, and Middle Atlas Mountains compose only 6 percent of Morocco's total surface area, they had the highest soil erosion rates, and were responsible for 40 percent of total land lost.[184] Heusch also explored the effect of intense storms on erosion rates in several Riffian sub-basins by measuring discharge and found that both net erosion and erosion rates were influenced significantly by rainfall intensity.[185]

The next major effort to study soil erosion occurred as part of a FAO soil study in 1977. H.M.J Arnoldus examined the applicability of using the Fournier Index, or ratio of average monthly precipitation of the wettest months to annual precipitation, as a replacement for the R Factor in the USLE to map erosion vulnerability in West Africa and Morocco. [186] Arnoldus used the Fournier Index due to the lack of the 30-minute intervals of precipitation data necessary to use the original R-Factor equation developed by Wirschmeier and Smith in 1979.[187] Through a series of regressions of the Fournier Index with known R-Factor values, Arnoldus found that Fournier's Index had a poor low correlation of R=0.55with R-factor values at 164 US stations and 14 West African Stations.[188] Arnoldus then modified the index to include the average monthly precipitation of all months in a year rather than the average monthly precipitation of the wettest months, which improved the correlation to R=0.83 and may be attributed to the fact that rainfall fluctuations are ignored in the original Fournier Index.[189] Based on the improved performance of regressions for pre-divided climatic zones, Arnoldus concluded that the Modified Fournier Index applies best to locations within homogenous climatic regions.[190]

Regarding the results of his 1977 survey of predicted soil erosion rates in Morocco, Arnoldus found that average soil loss in Morocco ranged between 0 and 2,000 tons/hectare/year, with areas in the northern Rif and in the High Moulouya plains having the highest rates of soil loss.[191] In addition, the topographical factors of slope length and steepness were found to have the most significant effect on potential soil loss, followed by rain erosivity and soil erodibility.[192] Arnoldus used precipitation measurements in mm to calculate R, and R factor units are in metric ton meters centimeters per hectare per hour per year (t-m/cm/ha^{-1}/h^{-1}/yr^{-1}).[193]

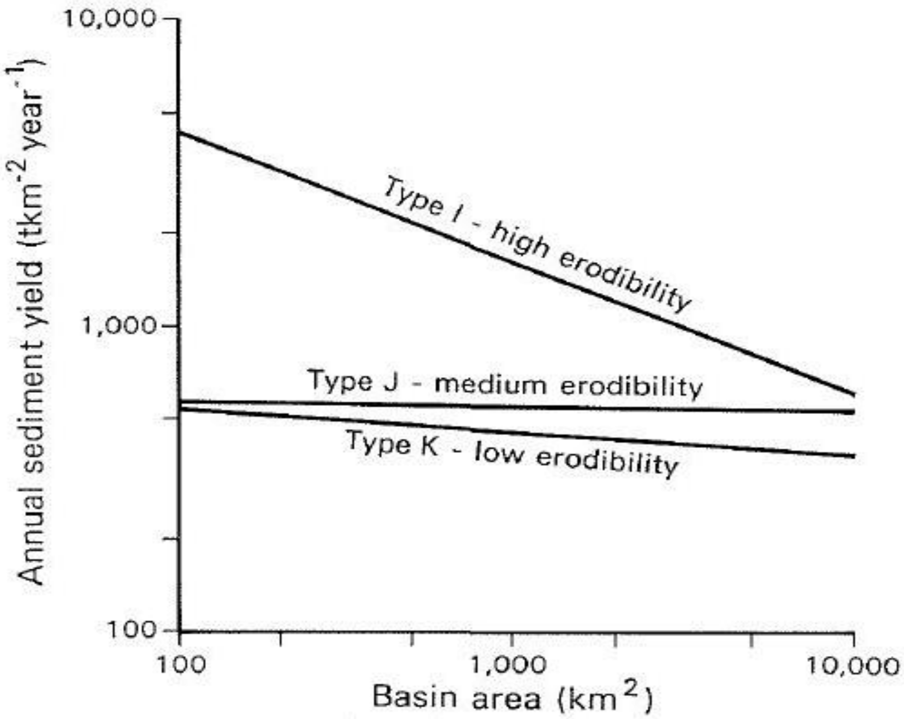
A full-scale initiative to assess erosion as it pertained to dam sedimentation occurred in the late 1970s, and 1980s. In 1988 and 1992, Abdelhadi Lahlou, then working at the Hydraulic Administration in Rabat, described the state of the sedimentation of dams and methods used to quantify sedimentation and mitigate sedimentation in Morocco.[194] Though regional efforts to update Lahlou's work have occurred, they have not been replicated in aggregate according to publically available records. Lahlou used data on sediment yields from 15 monitoring stations and sedimentation rates for 23 dams to calculate total sedimentation and land degradation for 38 drainage basins.[195] Lithology or soil and geological typology varied the most between these basins, which made it possible to derive a relationship between lithology and specific sediment yield, in conjunction with basin area and annual runoff.[196] Government entities such as the MAPM, Office of Water and Forests, MI, and Department of Geology applied this relationship as of Lahlou's 1992 study for planning roads, ports, and drinking water.[197] The Directorate of Hydrological Development also used this relationship as of 1988 to predict silting in future dam sites. This relationship between soil lithology, basin area, and annual sediment yield is described in Figures 5 and 6. Lahlou reports a positive relationship between dominant lithologies I, J, and K and average annual sediment yield, as indicated by Figure 5. As described by Figure 6, basins with a small area have high rates of soil loss if soils are highly erodible.[198] This relationship is insignificant for soils of low erodibility, with no relationship observed for soils of moderate erodibility. [199]

Figure 5: Lithology and Mean Annual Sediment Yields in Morocco



Source: Lahlou, Abdelhadi. "The Silting of Moroccan Dams." Sediment Budgets IAHS 174 (1988): 74.

Figure 6: Annual Sediment Yield, Basin Area, and Lithology in Morocco



Source: Lahlou, Abdelhadi. "The Silting of Moroccan Dams." Sediment Budgets IAHS 174 (1988): 76.

Figure 7 lists metrics for dam sedimentation in Morocco as of 1996 for 16 reservoirs. Many of the largest principle dams, particularly in northern watersheds such as the El Kansera and Nakhla Dams in the Sebou and Loukkos Basins, experienced sedimentation rates that substantially decreased their storage capacity.[200] Supporting the relationship described in Figures 6 and 7, the Nakhla Dam, though having one of the smallest areas of the basins listed, has the highest rate of lost capacity. The El Kansera Dam has the fourth highest rate of lost capacity, but like the Mohammed V Dam, has a high initial capacity, indicating its importance as a water resource. The Mohammed V and El Kansera Dams also have the fourth and eighth largest dead zones, respectively.

Many of the largest dams, including Mohammed V and El Kansera, have dead zones that are completely filled by sediment, and will require expensive measures like dredging to recover.

Figure 7: Sedimentation of Principle Moroccan Large Dams

Dams	Watershed area (km^2)	Initial capacity (10^6 m^3)	Last bathymetric survey date	Total sedimentation since the construction of the dam (10^6 m^3)	Average annual silting-up (10^6 m^3)	"Dead zone" (10^6 m^3)	Lost capacity (in %)	Actual capacity (10^6 m^3)
Nakhla	107	13	1987	6.08	0.23	1.5	46.80	6.92
Mohamed V	49 920	725	1990	256.91	11.17	60.0	35.44	468.09
Lalla Takerkoust	1 710	96	1988	26.50	0.50	4.0	33.97	51.50
El Kansera	4 540	330	1989	64.66	1.22	21.5	22.30	225.34
M. B. E. A. Khattabi	780	43	1989	6.96	0.87	4.5	16.19	36.04
Ibn Batouta	178	43.6	1989	5.60	0.56	2.51	12.84	38.00
My Youssef	1 440	198	1990	22.00	1.10	24.0	11.11	176.00
Mansour Eddahbi	15 000	592	1988	62.88	3.93	24.0	11.09	504.12
Bin El Ouidane	6 400	1 484	-	99.82	3.22	324.0	6.73	1384.18
Hassan Eddakhil	4 570	369	1990	20.96	1.31	20.0	5.68	348.04
Y. B. Tachfine	3 780	320	1989	16.49	0.97	20.0	5.15	303.51
S. M. Ben Abdellah	9 800	509	1985	22.97	1.77	100.0	4.51	486.03
Oued El Makhazine	1 820	807	1990	33.99	3.09	20.0	4.21	773.01
Hassan I	1 670	272	1990	10.00	3.33	40.0	3.70	260.01
Al Massira	28 500	2 724	1987	82.94	7.54	480.0	3.04	2641.06
Idriss I	3 680	1 217	1986	30.94	2.21	180.0	2.54	1186.06
Abdelmoumen	1 300	216	1987	1.38	0.23	10.0	0.64	214.62

– The regression obtained between mean annual silting-up (E) (10^6 m^3 $year^{-1}$), the watershed areas S (km^2) and the ratio [reservoir capacity (C)]/[inflow (A)] is as follows: $E = 10^{-2.228} . S^{0.699} . (C/A)^{-0.259}$. The regression coefficient is 0.758.

– The "dead zone" of the following large dams: Mohamed Ben Abdelkrim Al Khattabi, Ibn Batouta, Hassan Eddakhil, Mansour Eddahbi, El Kansera and Mohamed V, is already full of sediment.

Source: Source: Lahlou, Abdelhadi. "The Silting of Moroccan Dams." Sediment Budgets IAHS 174 (1988): 75.

As of 1996, methods to measure sedimentation in addition to the bathymetric method included sediment monitoring, aerial surveys, and the use of degradation prediction relationships for upstream basins.[201] Other methods included the measurement of fluvial sediment at gaging stations including bed load and suspended sediment, and Radioisotope methods.[202] Table 6 summaries and describes these methods, which are mentioned in this review because they pre-date the incorporation of GIS in modeling and indicate that USLE and RUSLE were not in use before 1996 among most decision makers and scientists in Morocco. Lahlou also mentioned issues in the calibration and validation of models because of differences between measurements and model prediction.[203]

Table 6: Methods to Quantify Dam Sedimentation

Method	Description
Bathymetry	Bathymetric methods measure a reservoir's bottom morphology in cross-sections divided according to position and elevation. These cross-sections are then used to construct elevation-volume curves and a digital model of the reservoir bottom. The difference between model measurements above and below the dam spillway level estimate sedimentation volume. Bathymetric modeling is expensive and time consuming relative to other methods.
Sediment Monitoring	Sediment monitoring involves taking water level measurements during floods at the reservoir gaging station and the level of water computed by the station calibration curve for discharge or instantaneous flow, and multiplying it by the concentration of suspended sediment to derive the sediment hydrograph, and the area under this curve yields the total suspended sediment load. Bed load formulae, including Myer-Peter and Einstein-Brown, are used to compute bed transport rates.
Aerial Stereophotography	Aerial stereophotography is one of the best methods for computing dam sedimentation due to its low error (0.10 meters), and ability to be used during dry periods like the drought that Morocco experienced between 1980 and 1985.
Degradation Prediction Relationship Models	Degradation prediction relationship are a set of tools most widely used by engineers, and have become more applicable with the increasing availability of data.[204]

Source: Generated by Madeline Clark using data from Lahlou, Abdelhadi, "Environmental and Socioeconomic Impacts on Erosion and Sedimentation in North Africa," 492-495.

Lahlou listed methods used in Morocco to mitigate dam sedimentation as of 1996, which are listed in Table 7.[205] These methods have not changed significantly, and have focused on curative methods. The Hydrologic Basin Agencies are currently considering preventative interventions, however that include the protection of river channels, a responsibility bestowed on the Hydrologic Basin Agencies according to the Water Law of 1995, with the help of the HCEFLCD.[206] Available literature does not address whether water and agroforestry operators reuse sediment extracted through the process of dredging reservoir bottoms.[207] Though this strategy may impose heavy costs on individual operators, it could present a sustainable, low-cost strategy relative to other forms of soil rehabilitation that may benefit Morocco in the future if stakeholders collectively mobilized labor and funding.

Table 7: Erosion Mitigation Methods in Morocco

Type	Description
Preventative	Watershed management, Maintenance of river banks, Reservoir management, Sediment transport diversion, Water supply management, Legislative and regulation control;
Curative	Evacuation of sediments by appropriate management, Flushing at lower reservoir levels, Allocation of dead zone for sediment storage, Dredging of sediment, Raising of dams and establishment of new sites.[208]

Source: Adapted by Madeline Clark from Lahlou, Abdelhadi, "Environmental and Socioeconomic Impacts on Erosion and Sedimentation in North Africa," 495-496.

Beginning in the early 2000s, IAV began publishing studies on the use of spectral indices to infer information about soil qualities, including stability.[209] Chikhaoui and Naimi completed a study in the Loukkos of the Rif using DEMs produced by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) dataset to determine the extent of land degradation as inferred by soil characteristics according to the United Nation Environmental Program's (UNEP) Global Assessment of Human-Induced Soil Degradation (GLASOD) classification.[210] They found that the 15 meter band provided a reliable index of terrain roughness, which can be used to determine soil type.[211] Student work from IAV has also used spectral indices from remote sensing images produced by the Landsat Thematic Mapper (TM) and Multispectral Sensor (MSS) to discriminate between different classes of land degradation between 1978 and 2010 in the Tleta Watershed in the western Rif of Morocco using the GLASOD classification.[212] The results of these studies indicate that land degradation is increasing in the Tleta Watershed in the western Rif of Morocco, where measured stable areas decreased from 30 percent in 1991 to 16 percent in 2010, whereas very degraded soil increased from 11 percent to 30 percent during the same period.[213]

In 2014, researchers from L'EMI completed a study implementing the USLE model in a GIS and a qualitative susceptibility analysis in the Oued Beht Watershed of the Sebou Basin to quantify the susceptibility and risk of the watershed to erosion, and determine its contribution to dam sedimentation for the El Kansra Dam.[214] Average annual soil loss was 8,356,468.18 tons/year for a 4,307 km^2 basin.[215] Areas of homogeneous soil loss were grouped and aggregated to form estimates of risk for flooding and high erosion according to the return period of the storm of greatest magnitude.[216] These results were compared to estimates of socio-economic characteristics and activities in the basin to determine the total damage caused by erosion and flooding.[217]

Methods Used to Study Erosion in the Bouregreg Basin

The Approche Spatialisée de l'Impact des activités aGricoles au Maghreb sur les transports solides et les ressources en Eau De grands bassins versants (SIGMED) project was a 36-month research initiative that ran from 2010-2013 and involved the partnership of universities, scientific institutions, governance authorities in water and land management, and international organizations based in Morocco, Algeria and France.[218] SIGMED partners sought to create an inventory of knowledge and data regarding the state of soil erodibility, the interaction of anthropological, climatic, and biome-level factors in land degradation, and the process of soil transport, deposition, and sedimentation in the Bouregreg Basin, particularly with regard to the Sidi Mohammed Ben Abdellah (SMBA) Dam.[219] This project implemented principles in line with the vision of 2005 Plan Blue for sustainable development in the Mediterranean.[220] Among the studies produced by this project, Mahé et al. found that increasing annual and seasonal variability of precipitation and temperature, particularly for "rare [climatic] events" in the Bouregreg Basin over the past 80 years, corresponded to a notable decrease in vegetative cover, in conjunction with various socio-economic factors including land development.[221] Using remote sensing imagery derived from the Medalus satellite, the study determined that sedimentation reached levels of 150-250 tons/km^2/year in localized areas, which agreed with changes in Bouregreg River flows, temperature, and rainfall patterns over the past 80 years.[222] These sediment yields are equivalent to 15,000-25,000 tons/hectare/year.

Other projects within the SIGMED project also supported this finding linking increased rare events of precipitation, flows, and rainfall with erosion, and further explored causes, such as topographical morphology. For example, Maleval used remote sensing images and GPS data point registers to derive topographical characteristics, river and ravine extents and volumes in six ravines surrounding the SMBA Dam.[223] Results derived from two study sites in the northern areas of the basin near the Bouregreg River junction near Salé indicate that erosion in ravines with large areas and slopes less than 15 degrees had a moderate net soil loss of 100 m/ha^{-3} on average.[224] However, two study sites with slopes greater than or equal to 15 degrees near the Korifla and Grou junctions at the SMBA lake witnessed net soil losses that were much greater, and even reached more than 5,000 m^3/hectare. These areas near the Grou and Korifla Rivers were also dominated by brush vegetation, soft soil deposits, and intense storm episodes. These results suggest that erosion around the dam occurs locally and where topographic morphology exhibits slopes with large drop gradients and surface areas. [225] These findings are consistent with results of previous studies, such as those of Heusch and Arnoldus that link steep slope gradients with increasingly severe rates of soil loss.

Within another project affiliated with the SIGMED consortium, Karkouri et al. used the World Overview of Conservation Approaches and Technologies-Land Degradation Assessment in Drylands-Desertification Mitigation and Remediation Project (WOCAT-LADA-DESIRE) model to create an inventory of physical and anthropological factors contributing to erosion.[226] Specifically, the WOCAT questionnaire enabled researchers to conduct field work concerning topographical, climatic, geologic, lithological, vegetative, and land-management practices in the Sehoul Sub-Basin in areas near the northern areas of the Bouregreg River Basin near the Rabat-Salé-Zemmour-Zaër province and the SMBA Dam.[227] The WOCAT model produced a longitudinal, qualitative assessment of the severity of land degradation, and quantified the increase of land degradation in hectares.[228] Rain-fed agriculture led to the greatest density of land degradation, whereas uncultivated land yielded the most intense rates of land degradation.[229] Net land degradation for the Sehoul Sub-Basin amounted to 16,027 hectares for all land-use types included in the study for the temporal period of 2003-2005.[230] Chaker et al. conducted a follow-up study in the Sehoul Basin to analyze attitudes and perceptions of erosion in Sehoul, and found that 72 percent of residents were not aware of, nor concerned with the issue of soil erosion due to their inability to perceive it.[231] Laouina et al. investigated ravine erosion in the Sidi-Azzouz Catchment of the Sehoul Sub-Basin through the models WOCAT-LADA-DESIRE, PESERA, and DESMICE, and suggested techniques and conservation practices to manage land degradation.[232] Areas vulnerable to erosion center around the Grou and Bouregreg River beds are characterized by slopes that are equal to or greater than 30 percent, soils that are coarse and highly erodible, low infiltration and high runoff, and land management and cover that encourage the destabilization of soil.[233] Laouina et al.'s study, which consisted of field experiments and surveys in the Hannanat Catchment of the Sehoul Sub-Basin, also advocated for the greater involvement of the Moroccan government in promoting sustainable land management through afforestation and vegetation rehabilitation.[234]

In 2008, Bensalah divided the Bouregreg Basin into homogenous areas according to soil type and land use, and studied the hydrologic behaviors of soils in 18 sites, using simulated rainfall of high intensity in 30 minute intervals.[235] Measured parameters included the kinetic energy of rainfall, final infiltration rate in mm/hour, runoff recoverable after end of a rainfall period, runoff coefficient, and soil detachability.[236] Results indicated that in the Bouregreg Basin, soil surface features and related land cover are key to the hydrologic behaviors of soils.[237] Study results also supported that converting forests to cropland increases erosion risk, and forest vegetation improves the quality of water that flows to the SMBA Dam.[238] These results support the conclusions posited by Heusch in the 1970s, and have been echoed by multiple studies, with mixed uptake by the Moroccan government in large basins aside from internationally-funded projects.

Using the MUSLE model, a study was conducted by Yassin et al. in 2011 for the Sidi or Ain Sbaa Micro-Watershed in the Oued El Mellah Sub-Basin of the greater Chaouia River Basin.[239] The results of the MUSLE model were compared to measured points of sedimentation in this micro-catchment, and MUSLE results were 18.5 tons/hectare/year compared to the measured loss of 17.8 tons/hectare/ year, indicating that the model is suitable for this catchment.[240] As mentioned previously, RUSLE is the dominant model used in Moroccan soil modeling, but this study demonstrates that it is not always the best nor most informative model to use because it only predicts erosion from sheet or interill erosion, which does not contribute to dam siltation and is based on empirical studies conducted in the United States.[241]

In 2009, Yassin et al. attempted to test the suitability of the RUSLE model for two sets of Wirschmeier-type plots in the Central Plateau of Morocco in the Lalla Regrega and Ain Guemouch forest stations, which are located approximately 50 and 100 kilometers from Rabat, respectively.[242] These areas are characterized by a semi-arid climate, gully formation, and sandy soils and deciduous forests at Ain Guemouch and clay-based soils and coniferous forests at Lalla Regrega.[243] In this study, the RUSLE model underestimated soil loss by a factor of 4, or a difference in interval of 10 to 200 kg/hectare/year versus 50 to 840 kg/hectare/year measured by field measurements.[244]

This dry period coincided with little runoff and minimal erosion rates.[245] The actors expect that the RUSLE model may underestimate erosion rates due to the fact that it does not address channel erosion, and that a more suitable period would have been one with intense erosion, at least 10 years of data, and greater runoff.[246]

In a study commissioned by the HCEFLCD in 2008, qualitative methods and the RUSLE model were applied to the upper Bouregreg River to both determine priority zones for intervention and infer net erosion loss in the upper Bouregreg Basin and their contribution to SMBA Dam sedimentation.[247] The upper Bouregreg Basin was found to have an average erosion potential of 260 tons/ km^2/year that contributed 1.7 tons/ km^2/year to the sedimentation of the SMBA Dam, and contributing a loss of 260 Millions of Moroccan Dirhams per year.[248] Table 8 includes a comparative inventory of the studies discussed in this section of erosion research in Morocco.

As displayed in Table 8, most research conducted on erosion in Morocco has used empirical methods developed by researchers in the United States or European countries with data from a geographical context external to Morocco. The studies of Heusch, Arnoldus, and Yassin et al. present an exception to this rule because they adjusted existing models and relationships to Moroccan conditions, but the basic model assumptions did not change. Model choice appears to have been driven by the preferences of international donors and researchers, which have composed an essential part of Morocco's portfolio to erosion mitigation as demonstrated in previous sections. This reliance on internationally-derived empirical methods results from a lack of granular, reliable historical data in developing economies like Morocco, where the technological and institutional capacities necessary to develop empirical models and process-based models specific to Moroccan physical, climatic, and social parameters do not exist.

The research results resulting from this sample are not comparable due to differences in methods, instruments, scope, and assumptions in application. The geographical scope of this research on erosion prevention and control has focused on single micro-catchments and sub-basins. Arnoldus' national survey of soil erosion presents an exception, though it relies on coarse-scale surveys that have not been updated since the late 1970s.

National estimates of the extent and impact of erosion, including efforts to survey land cover, use, and soil typology, are limited. This stands in contrast with the principles outlined by the PNABV, which has asked stakeholders to work toward basin-level integrated water and land management to prevent and control erosion. Accurate, consistent, and scalable methods for predicting and verifying erosion and sedimentation rates must be developed before Moroccan researchers are able to derive current, reliable national estimates of erosion, sediment yield, and sediment transport. Scaling up the methods produced by local studies and updating national studies and surveys on soil, land cover, and land use would help water and land management professionals collaborate more effectively and adopt an integrated approach for understanding the impact of sediment loss and deposition on biomes and human activities downstream, a stated priority in major projects including SIGMED.[249]

For example, in the Bouregreg Basin, the geographical scope of previous studies focuses primarily on the Upper Bouregreg and select micro-catchments. The Grou and Bouregreg Rivers converge upstream of the SMBA Dam, creating an erosion potential for the entire basin based on natural sediment yield and transport. Information for the Grou and Korifla Rivers' contribution to sedimentation at the outlet of the Bouregreg Basin has not been consistently collected. As a result, the Agence du Bassin de Bouregreg et de la Chaouia (ABHBC), which is responsible for maintaining and generating information on the Bouregreg Basin, does not have the information it needs to coordinate with actors ranging from the CSEC to the HCEFLCD to address social consequences of severe erosion like dam sedimentation.

This research develops an erosion assessment method based on GIS software, which water planning and land management professionals in Morocco already use in varying degrees. Methods using GIS can help researchers and professionals incorporate this systems-level approach in natural resource planning and management and separate the effects of climate change on increasing systemic variability. This can be helpful when examining contributing factors to erosion dynamically in space and time. Unfortunately, decision makers do not provide the support, investment, or incentives necessary for acquiring software, developing databases, and training employees in best practices.[250] These methods require access to climatic, land cover, and land use data from multiple years and at a high spatial resolution, and many developing economies do not possess the financial or the administrative means to produce and maintain these datasets.[251]

To conclude, water-based erosion in Morocco endangers the country's agricultural and urban centers and limits its progress toward its goals in water, food, and energy security. This trend should incentivize the Moroccan government to increase its support of the agroforestry and water sectors by establishing autonomous funding mechanisms and legal conventions that promote collaboration. Reforms such as these may improve the administrative climate for implementing IWRM, where erosion mitigation and other pivotal issues including irrigation optimization can be implemented in tandem, as part of a systems-level solution for protecting Morocco's natural resources.

Table 8: Inventory of Erosion Research in Morocco

Source and Date	Study Area Coverage	Method	Results	Benefits	Limits
B. Heusch, 1970	Morocco	Rainfall-runoff plots	Average 25 tons/km^2/year	First substantive survey of erosion in Morocco	Insensitive to other parameters
H.M.J. Arnoldus and FAO, 1977	Morocco	USLE and Modified Fournier Index	0-2,000 tons/hectare/year	First fitted equation for the R-factor for West Africa and Morocco	Used coarse resolution datasets
Lahlou, 1988 and 1996	Morocco	Evaluation of Sedimentation for Reservoirs Using Metrics from Dams	1.38-256.91 Mm^3 total sedimentation, 0.97-11.17 Mm^3 rate of sedimentation	First substantive survey of dam siltation in Morocco	Has not been replicated since 1988
HCEFLCD, 2008	Bouregreg Basin, Upper and Mid Bouregreg River	RUSLE	260 tons/km^2/year or 1.7 million tons/year	Comprehensive application of RUSLE, field studies of physical and bio-climatic characteristics	Only focuses on one-third of the watershed
Yassin et al., 2009	Micro-catchments in the Chaouia and Bouregreg Basins	RUSLE, MUSLE, rainfall simulation	17.8-18.5 tons/hectare/year in Oued El Mellah	Rigorous application of methods, important insights in model selection for Moroccan watersheds	Plot-specific
SIGMED, 2010-2013	Bouregreg Basin	WOCAT, Remote Sensing Time-Series Modeling	150-250 tons/km^2/year	Comprehensive study of Bouregreg Basin	Focus is on using qualitative methods
IAV Hassan II, 2011-present	Loukkos Basin, Oued Tleta Watershed	Spectral Indices to Measure Soil Degradation	Nearly two-fold increase in degraded lands between 1972 and 2010.	Innovative and Rapid Way to assess soil type and land degradation	Not verified by field studies
L'EMI, 2014	Sebou Basin, Oued Beht Watershed	USLE	0-8,356,468.18 tons/hectare/year	Rapid and Comprehensive Study of Risk in Sebou Watershed	Not verified by field studies, Not clear where some data sources originate

Sources: Generated by Madeline Clark using data from B. Heusch, 39-63; H.M.J. Arnoldus, 39-51; Abdehadi Lahlou. "The Silting of Moroccan Dams," 71-77; "Etude d'aménagement du bassin versant du l'oued Bouregreg en amont du Barrage Sidi Mohammed Ben Abdellah : Notre méthodologique," 1-3; M. Yassin, S. El Bahi, K. Renard, and M. El Wartiti. "Application du modèle universel de perte en terre révisé (RUSLE) aux terrains forestiers du plateau central." 50-64 ; M. Yassin, Y. Pépin, S. El Bahi, and P. Zante. "Evaluation de l'érosion au Microbassin de Sidi Sbaa : Application du Modèle MUSLE." 171-181; Abdellah Laouina and Gil Mahé, 21-113; M. Chikhaoui and M. Naimi. 56-60; Rabii El Gaatib and Abdelkader Larabi, 677-689.

Section II: Study Area and Methods

PROBLEM STATEMENT

This study seeks to construct an erosion vulnerability index for the Bouregreg River Basin through a GIS implementation of the RUSLE model. Using basic tools in ESRI's ArcGIS Desktop's Hydrology toolbox and Raster Calculator, this study will estimate or interill and rill formations from water-based erosion, which is the type of erosion that the RUSLE model detects in a variety of catchment sizes. This approach is consistent with the Moroccan use of RUSLE as a primary method for erosion modeling, so this study will implement it in the context of the Bouregreg Basin to test its effectiveness.[252] In addition, this study also tests whether GIS can model over geospatial space and time and examine the relative contribution of both random, climate-based factors and human-influenced factors such as vegetative cover at various DEM resolutions. Understanding variable inputs affect output can inform future studies seeking to model basin-level erosion.

RUSLE is appropriate for this study because it one of least data-intensive methods for modeling erosion in a GIS, and has evolved into a standard practice for conducting rapid regional assessments of water based soil erosion. The study area and data available for constructing the index also meet the RUSLE model's basic conditions. In the Bouregreg Basin, there are at least 20 years of rainfall data. The primary land use of the basin is also agricultural.

However, there are some factors that limit the generalizability of this study. For example, the RUSLE model requires detailed, verified information on land cover and erosion management practices to produce the most accurate, actionable results. The large scale of the basin may affect the quality of results, as RUSLE is traditionally applied at the plot-level. Factors falling outside the scope of RUSLE, such as the extent of land and sediment loss by channel or fluvial erosion, will also not be included in this study, though these processes are important for describing erosion patterns in Moroccan watersheds. These issues will be addressed in discussing the output from this study, which can help inform the development of future methods to more fully study and measure river basin erosion.

STUDY AREA

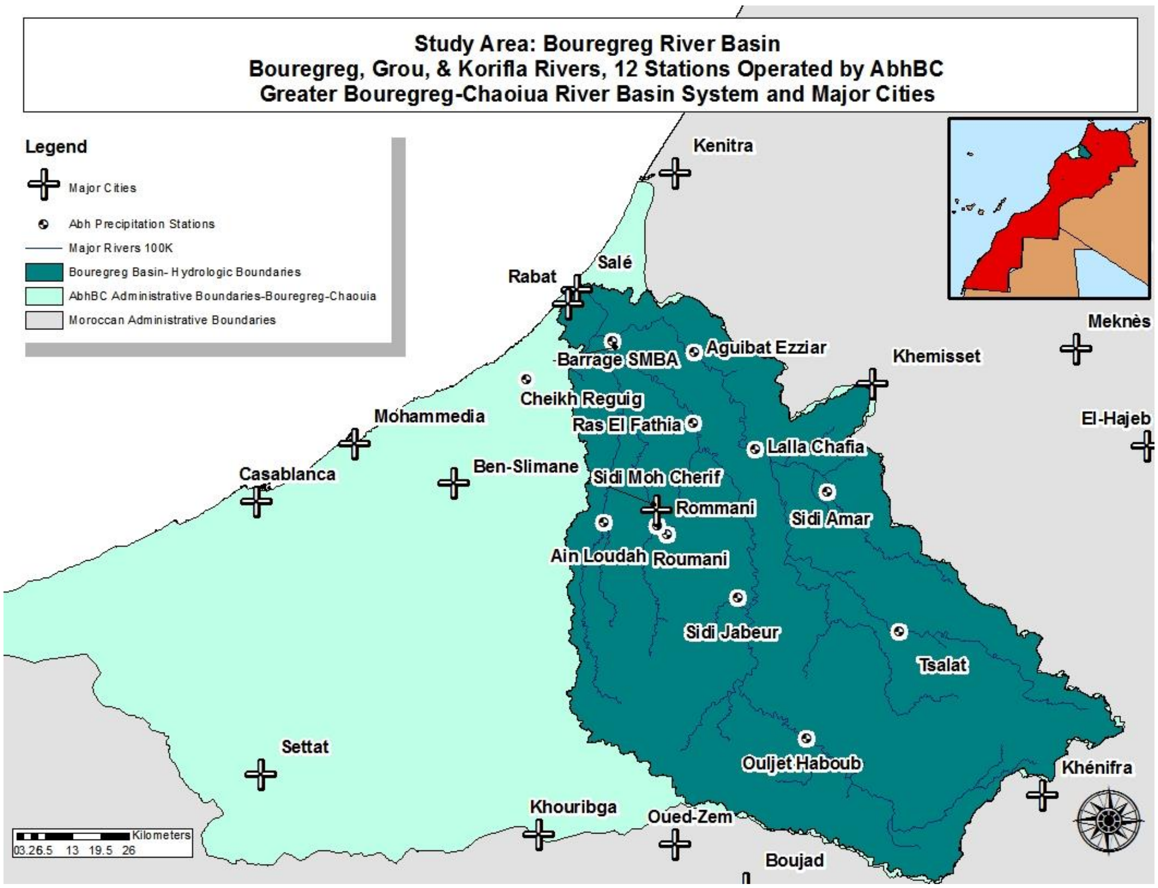
Geographic and Administrative Location

The Bouregreg River Basin, hereafter called the Basin, rests between the greater river basins of Sebou and Oum-Er-Rbia on western Morocco's north-central coastline. The Basin's geographic extent ranges from 34° 18' North, 9° 11' West; 34° 18' North, 4° 51' West; 32° 42' North, 5° 31' West; and 32° 45' North, 8° 10' West.[253] Though the administratively-defined basin outlet rests about 15 kilometers from the Atlantic Ocean at the SMBA Dam near the administrative capital Rabat, this study will use the outlet at the sea.[254] The Basin has a total area of 9,795.37 kilometers squared, a perimeter of 686,276 km, and equates to roughly 50 percent of the total area governed by the ABHBC.[255] The area of the entire Bouregreg-Chaouia River Basin system is 20,470 km^2 and comprises about three percent of Morocco's territory.[256] Administrative areas covered by the Basin include the Khoribgha and Khenifra provinces to the southwest and east, and the Rabat-Salé-Zemmour-Zaër province to the north, which contains the administrative capital of Morocco, Rabat.[257]

Governance

Water allocations between sectors and users reflect a formal consensus reached among the CSEC, ABHBC, governmental and non-governmental stakeholders, and WUAs.[258] As a result of this planning process, stakeholders have collectively decided that water captured within the Basin supply primarily the drinking and municipal water sectors, rather than agriculture or industry.[259] Neighboring river basins Chaouia, Sebou, and Oum-Er-Rbia primarily allocate water to agricultural users.[260] Figure 8 illustrates the administrative boundaries of the ABHBC, the hydrologic boundaries of the Bouregreg Basin, relevant major cities, and the major rivers of the Bouregreg Basin within the context of Morocco's national territory.

Figure 8: Study Area in the Context of Morocco and ABHBC Governance



Source: Map created by Madeline Clark using data from Administrative Boundaries of Bouregreg-Chaouia. Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015; Administrative Boundaries of Morocco, Obtained in person from the GIS Department of L'office Nationale de l'eau Potable, Morocco, October 11, 2014; Major Cities of Morocco, Obtained in person from the GIS Department of L'office Nationale de l'eau Potable, Morocco, October 11, 2014. Rivers and Bouregreg hydrological boundaries created using 30 meter Digital Elevation Model, Shuttle Radar Topography Mission, accessed August 25, 2014 and February 15, 2015, http://earthexplorer.usgs.gov/.

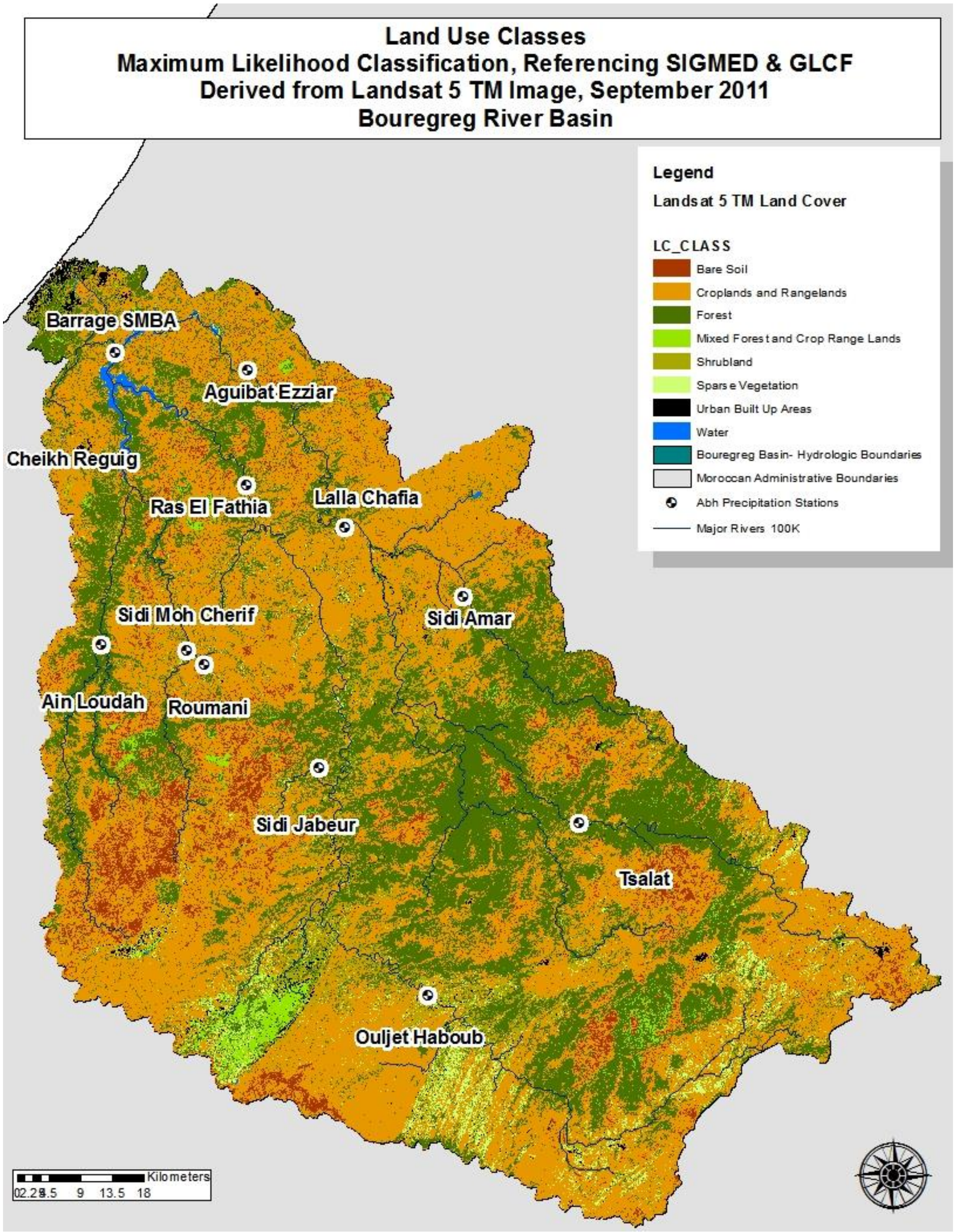
Population

As of 2004, the greater Bouregreg-Chaouia River Basin held the greatest population density in Morocco by hydrological basin due to the concentration of 7.3 million inhabitants in the 250 kilometer strip of the northwestern coast of Morocco stretching from Rabat-Salé to Casablanca, the administrative and economic capitals, respectively.[261] The population distribution of the Basin is influenced by its geomorphological features.[262] Mountainous areas in the southwest of the Basin have a weak population density compared to coastal areas near the Basin's outlet.[263] Approximately 2,366,494 inhabitants live within the boundaries of the Basin, and 1.89 million of them (80 percent) are urban residents living in Rabat, Salé, and Khemisset.[264] The other 20 percent live in rural areas, small communes, or in the douars of Ait Belkacem and Moulay Driss Aghbal.[265] Due to the concentration of water demand within cities, the Basin has been identified as a critical and highly-stressed watershed, with per-capita water withdrawal allotments low in comparison with other basins (303.8 m^3/year).[266] This average allotment is below the minimum per capita requirements to avoid water stress (1,700 m^3/year).[267]

Land Use

The Basin's primary land use classes are forest and agriculture, which make up 40-50 percent and 20-30 percent of the Basin, respectively, depending on season.[268] Table 9 in the Appendices section of this report lists the eight land use classes used in this study and the percentage of the basin they compose, and Figure 9 illustrates their pattern in the Basin. Most farms are characterized by small-scale vegetable growing and arboriculture, though cereal culture farming occurs in areas such as the Zaër plain.[269] Shrublands increase in density with elevation.[270] Forests such as the Maâmora Forest characterize the coastal plains and piedmont of the Middle Atlas at Bouaâza and Khemisset.[271]

Figure 9: Land Use Classes in the Bouregreg Basin



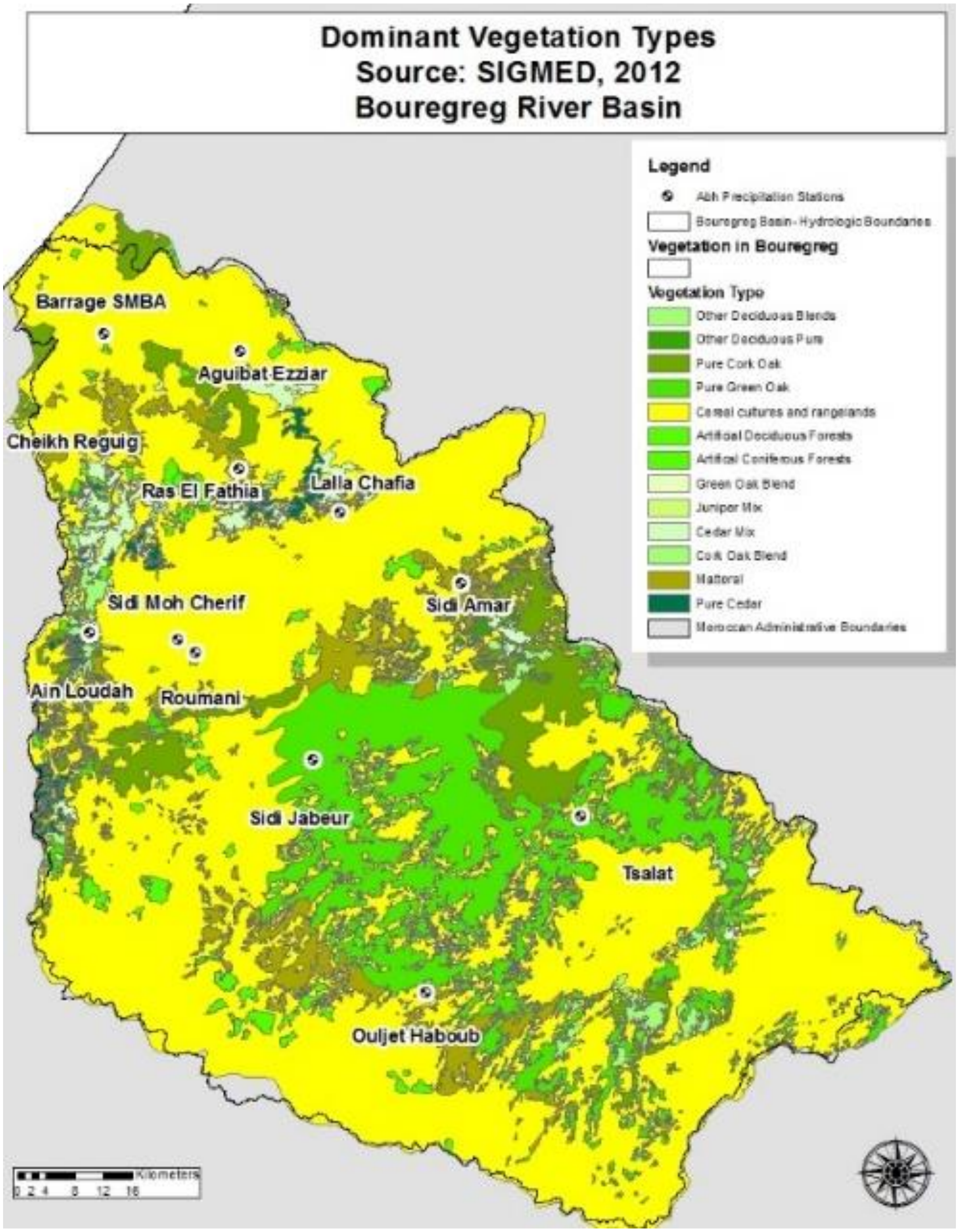
Source: Map created by Madeline Clark using data from Landsat 5 TM Images 2021037, 2022036, 2022037, September 5 and 14, 2011, Shuttle Radar Topography Mission, accessed May 23, 2015, http://earthexplorer.usgs.gov/; Rivers and Bouregreg hydrological boundaries created using 30 meter STRM DEM.

Land Cover

Figure 10 illustrates the distribution of vegetation cover trends in the Basin. To create Figure 10, the SIGMED Vegetation Dataset derived from national maps was used.[272] Cereal cultures and rangelands are dominant land cover classes in the Basin, followed by forests.[273] Approximately 26 percent of the Basin is composed of forests which have been reduced by the exploitation of its wood for making charcoal and clearing pastureland.[274]

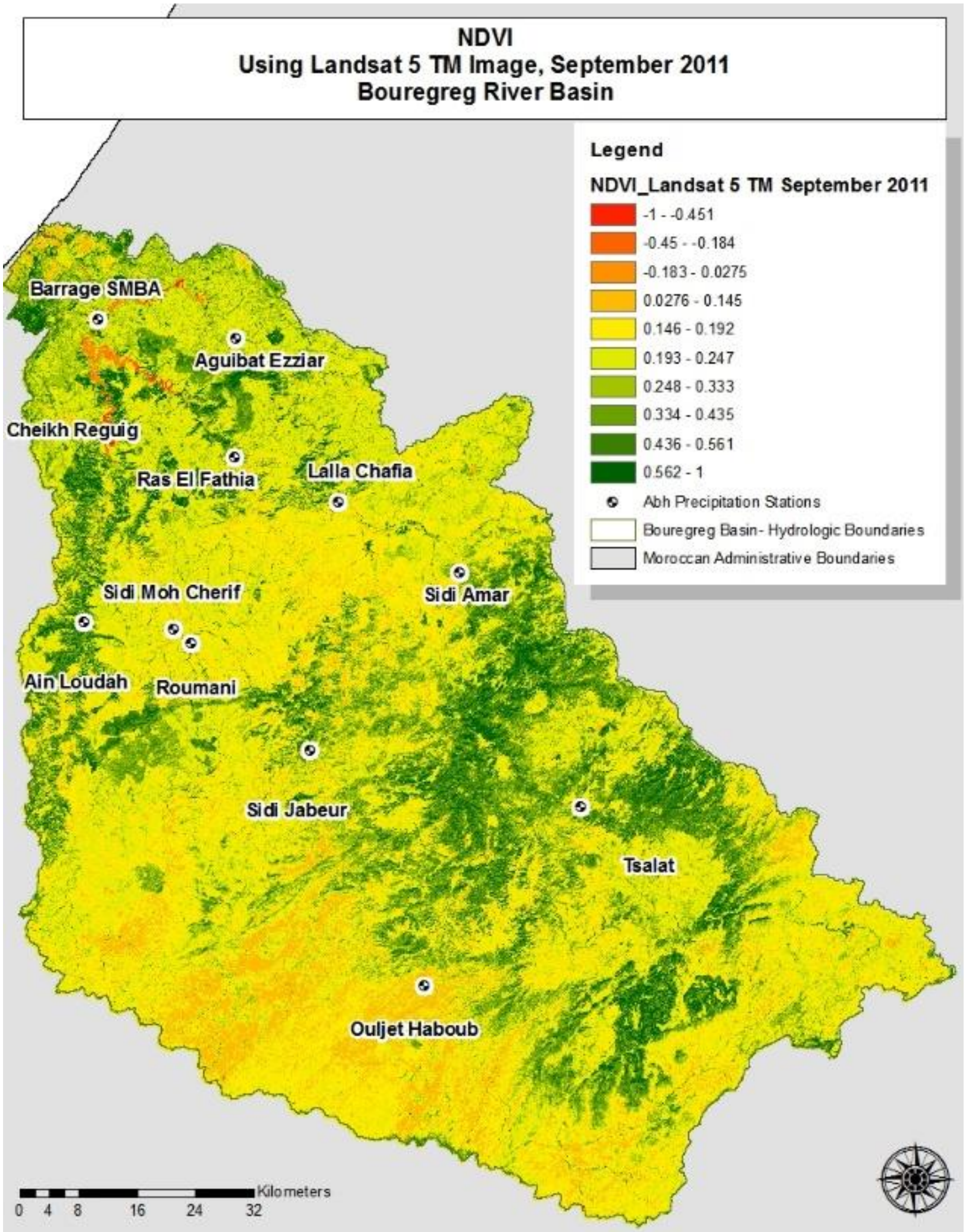
Though the Basin possesses areas rich in biodiversity, such as the El Harcha Forest in the Maâmora Plains, the mountains of the Middle Atlas to the southwest, and Ment Plateau, it has lost much of its wealth in wetlands and flora due to extensive urban development.[275] Dominant species are green and cork oak, in the sub-humid and semi-arid regions.[276] In the arid regions, cedar and Oleastre species dominate.[277] NDVI values, as illustrated in Figure 11, are highest for forested areas and lowest for urban areas and bare soil.

Figure 10: Dominant Vegetation Types in the Bouregreg Basin



Source: Map created by Madeline Clark using data from O. Berkat and M. Tazi, Ministère de l'Agriculture et de la Réforme Agraire, 1992, in A. Laouina, "Le Bassin Versant du Bouregreg, Caractéristiques Géographiques," in eds. Abdellah Laouina and Gil Mahé, "Gestion Durable des Terres," (Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg. CERGéo, 2013), 11-12; Rivers and Bouregreg hydrological boundaries created using 30 meter STRM DEM.

Figure 11: NDVI values for the Bouregreg Basin in September 2011



Source: Map created by Madeline Clark using data from Landsat 5 TM Images 2021037, 2022036, 2022037, September 5 and 14, 2011, Shuttle Radar Topography Mission, accessed May 23, 2015, http://earthexplorer.usgs.gov/; Rivers and Bouregreg hydrological boundaries created using 30 meter STRM DEM.

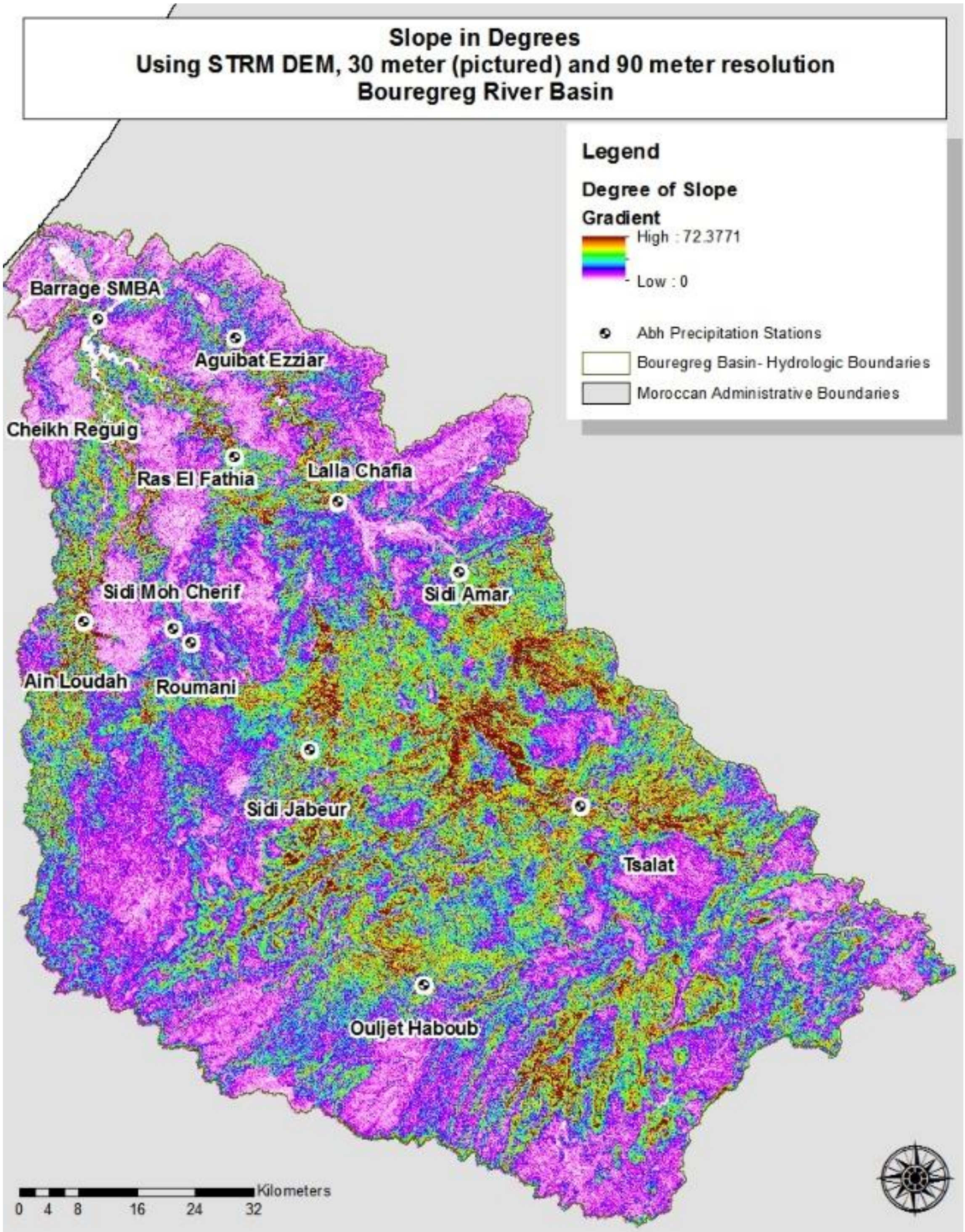
Elevation

Figures 12 and 13, respectively, visually illustrate elevation and slope in the Basin. Elevation in the watershed ranges from 59 meters above sea level at the SMBA Dam to 1621 meters in the southeast near the beginning of the Middle Atlas range.[278] Geomorphologically, the Basin is split into 2 zones: (a) the high mountains that ease into varied pastoral steppes of the High Bouregreg; and (b) the Zaër plateau with furrowed plains and deep valleys.[279] The average slope of the Basin is 0.6 percent.[280] Steep slopes of more than 15 degrees primarily occur in the mountainous areas of Oulmes, along riverbeds near Ain Loudah, Sidi Moh Cherif, and Ras El Fatiha in the north-central areas of the Basin, and Sidi Jabeur and Tsalat in the southern parts of the Basin.[281] The slope of the Basin drainage network splits it into two parts: (a) the northeast, which corresponds to the Lower Bouregreg River Basin; and (b) the southwest, which corresponds to the Upper Bouregreg River, Grou River, and its tributaries Korifla and Akreuch.[282]

Figure 12: Elevation in the Bouregreg Basin

Source: Map created by Madeline Clark using data from 30 meter Digital Elevation Model, Shuttle Radar Topography Mission, accessed August 25, 2014 and February 15, 2015, http://earthexplorer.usgs.gov/.

Figure 13: Slope in the Bouregreg Basin



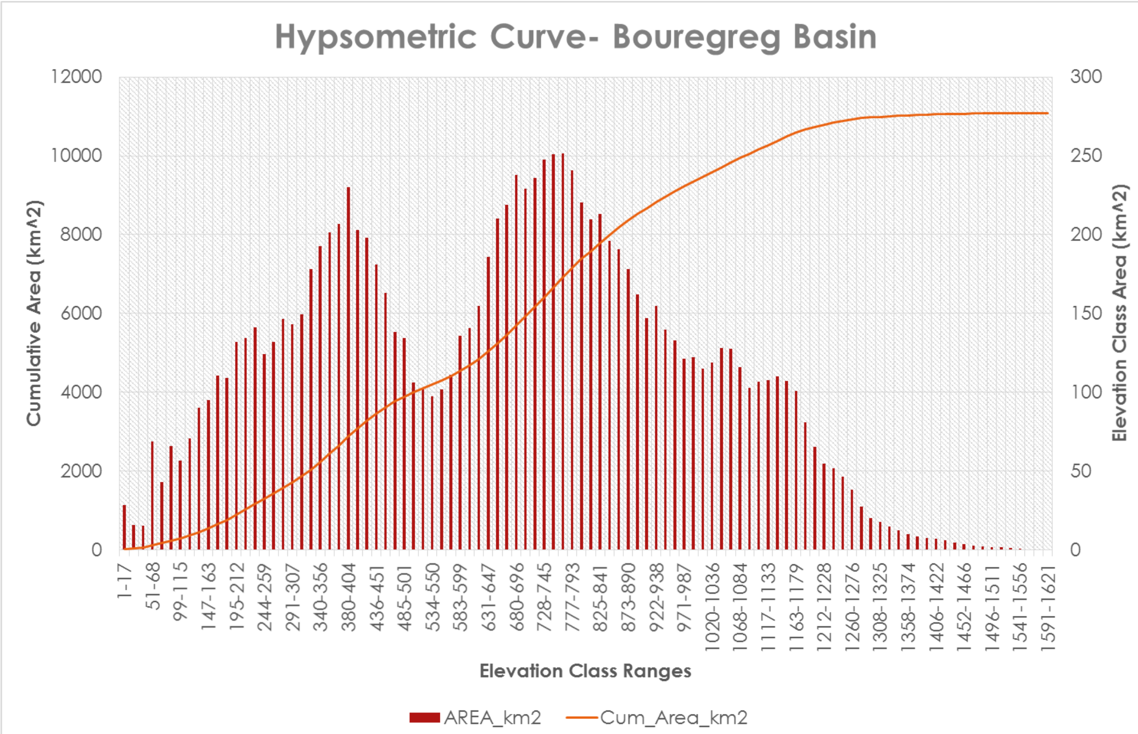
Source: Map created by Madeline Clark using data from 30 meter Digital Elevation Model, Shuttle Radar Topography Mission, accessed August 25, 2014 and February 15, 2015, http://earthexplorer.usgs.gov/.

Hypsometry

The field of geomorphology, developed by W.M. Davis, uses hypsometry to infer to the degree to which a catchment area or basin's drainage network have contributed to the erosion of its features.[283] Elevation with a basin is divided into 100 classes, and the area of each class is determined.[284] The elevation, relative area, and cumulative area of each class is plotted to derive the hypsometric curve, and provides insight on a basin's topography. Figure 14 contains a plot of the hypsometric curve derived from a subset of the STRM 30 meter DEM dataset in the Basin.

Another commonly used metric is that of the hypsometric index, which a ratio of maximum elevation over minimum elevation.[285] The hypsometric index of the Basin is 0.4987, which is below 0.5. Willgoose and Hancock interpret basins below this threshold as being of a mature age, relatively stable, and dominated by fluvial erosion in a drainage network.[286] This principle is consistent with the conclusions of Heusch and Yassin et al. that channel erosion plays a dominant role in shaping the topology of Moroccan watersheds.[287]

Figure 14: Hypsometric Curve for the Bouregreg Basin



Source: Generated by Madeline Clark with data from 30 meter Digital Elevation Model, Shuttle Radar Topography Mission, accessed August 25, 2014 and February 15, 2015, http://earthexplorer.usgs.gov/.

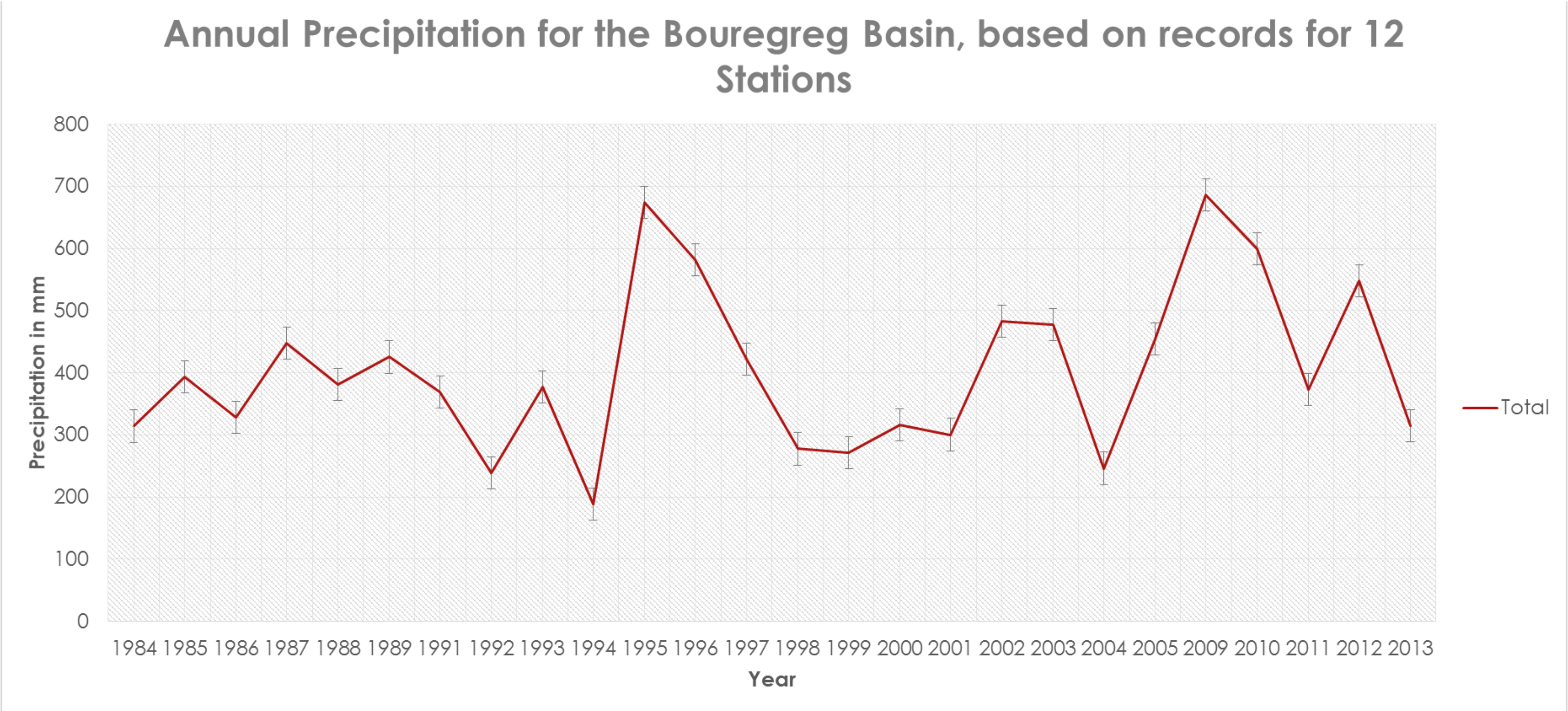
Climate and Rainfall

The climate of the Basin is guided by the three geographical characteristics of altitude, latitude, and the Atlantic coast.[288] Altitude peaks in the northeast at Mount Mtourzgane, and the surrounding mountainous areas experience frequent and intense precipitation compared to the plains and steppes to the west.[289] As latitude decreases from the northeast Atlantic coast to the south west, the climate becomes more humid with moderate temperatures, because of the influence of the dry, hot continental air originating from the Sahara and the humid and unstable air from the Acores in the southwest.[290]

During a rainy season, floods occur, whereas low water levels to drought occur during the dry season.[291] The dry, hot season corresponds to the period of April to October, and the wet, cold season November to March.[292] The mountainous zone registers temperatures that exceed 33.8° Celsius in the summer and 3° in the winter. The temperatures of the coastal zones range from 12° Celsius in the winter and 24° in the summer.[293] During a wet season, from October to April, 86 to 92 percent of annual precipitation occurs, though maximum rainfall is in February. Annual maximum flows decrease to the southwest. During a dry season, from May to September, eight to 14 percent of annual rainfall occurs. The Gregorian years of 1995 and 1996 were the driest and wettest on record in Morocco for the twentieth century, respectively.[294] Figure 15 illustrates Basin precipitation trends and reflects that precipitation was low in 1994 and high in 1995 for the agricultural years of 1984-2013, though data also indicate that 2009 exceeded 1995 in terms of total rainfall recorded.

In the middle of the 19th century, the Basin's climate shifted from humid to semi-arid, reflective of a nation-wide change in climatic zones.[295] Trends in temperature, precipitation, and evaporation fall between the humid basins in the north and Rif and arid basins in the south.[296] Average air temperature ranges from a low of 11° Celsius to 22° Celsius.[297] Basin-wide precipitation yields average between 400 and 800 millimeters annually.[298] The number of rainy days oscillates between 60 and 75 for the mountainous and coastal zones, and 75 to 100 for the highest elevations in the mountains.[299] Within the Basin, rainfall yields diminish weakly with latitude and elevation gradient.[300] Average rainfall and temperature range between: 480-500 millimeters per year and 18° Celsius near Rabat in the north; 400 millimeters per year and 17° Celsius in the arid central steppes; 370-400 millimeters per year and 15° Celsius in the south west; and 760 millimeters per year in the mountains. Average values for evaporation are 1,600 millimeters for Rabat-Sale and 800 mm/year for the high Bouregreg.[301]

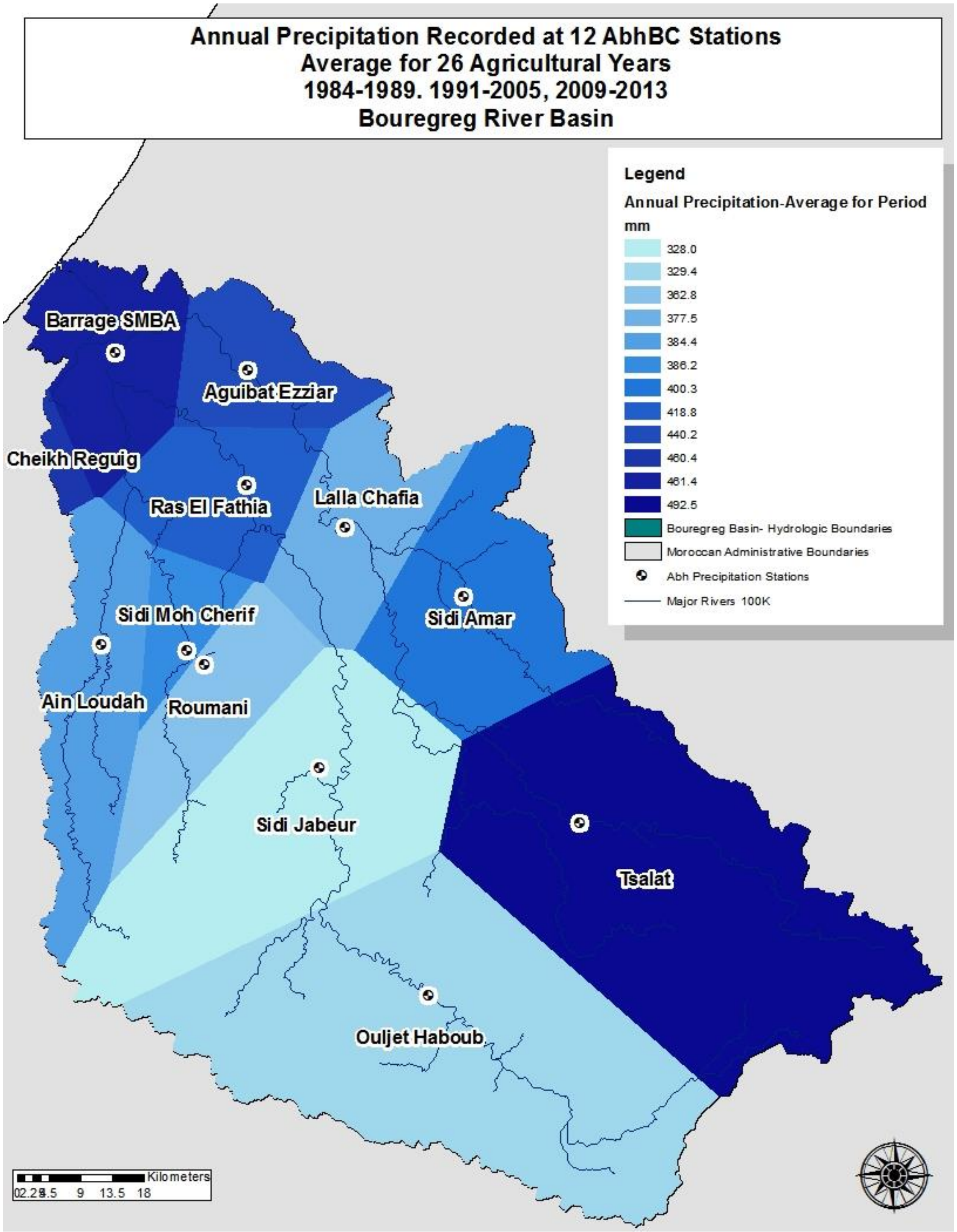
Figure 15: Annual Precipitation during 1984-2013 in the Bouregreg Basin



Source: Generated by Madeline Clark with data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 16 displays average annual rainfall in the Basin as interpolated by the Thiessen polygon method. According to data provided by the ABHBC for the agricultural years of 1984-2013 for 12 stations, annual precipitation averaged between 328 and 492 millimeters annually, with a mean of 403.5 millimeters annually, a minimum of 116 millimeters annually at Ouljet Haboub for 1994, and a maximum of 868.7 millimeters annually at Tsalat for 2009.[302] Precipitation yields are higher near the coastal and mountainous areas near the Sidi Mohammad Ben Abdellah Dam, Cheikh Reguig, Ain Loudah, and Ras El Fatiha stations and Tsalat and Oulmes, respectively. Rainfall rates are lower in the plains in the central areas of the Basin. Table 10 in the Appendices section of this report lists average annual rainfall, and maximum, and minimum monthly rainfall for each station.

Figure 16: Average Annual Precipitation- Bouregreg Basin (1984-2013)



Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015; Rivers and Bouregreg hydrological boundaries created using 30 meter STRM DEM.

Water Resources and Infrastructure

The entire Bouregreg-Chaouia Basin depends on surface water to replenish its water resources, and this trend is intensified in the Bouregreg Basin. Every year, the ABHBC, which is headquartered in the city of Benslimane in the Chaouia Basin, produces a PDAIRE, which also contains a summary of the state of affairs within the Bouregreg-Chaouia Basin. The latest PDAIRE available, produced in March 2012, indicates that the total water potential of the Bouregreg-Chaouia Basin system is 927 million m^3, with surface water resources contributing 852 million m^3 and groundwater resources contributing 75 million meters cubed.[303] The Bouregreg Basin alone contributes 80 percent of the Basin system's surface water, though it comprises only 50 percent of total ABHBC territory.[304]

There are five water delivery zones in the Basin, and transfers from Bouregreg and the Oum Er Rbia Basins are key to supplying major urban, industrial, and agricultural centers in the Chaouia Basin.[305] The Rabat-Salé-Zemmour-Zaër province is supplied solely by the SMBA Dam.[306] SMBA also supplies the Grand Casablanca area with 38 percent of its water, along with the Daourat and Sidi Maâchou reservoir complexes fed by sources in the Oum Er Rbia Basin.[307] Daourat also supplies the area of Settat and Berrechid in the Chaouia Basin. Local water resources, including aquifers, springs, and local dams, supply the interior areas of the Bouregreg Basin, which includes centers specific to Khemisset and Khenifra.[308]

The SMBA Dam provides 245 Mm^3 of water to Morocco's drinking water supply, of which 80 Mm^3 is reserved for Rabat-Salé.[309] Average inflows to the SMBA Dam from

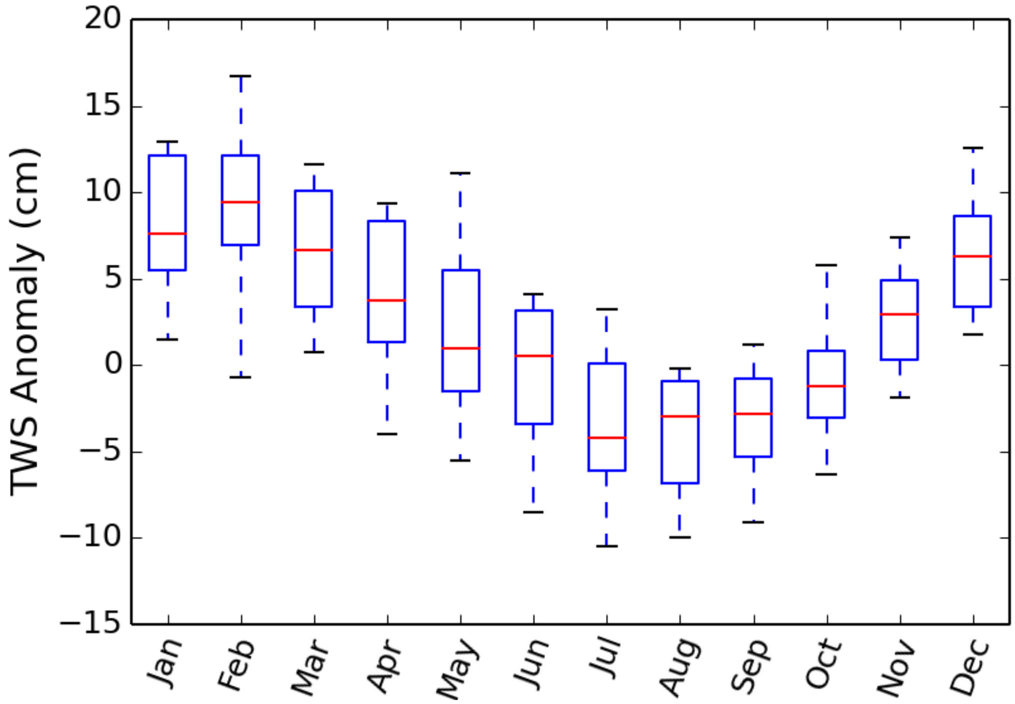
1939-2000 were approximately 850 Mm^3/year, of which 675 Mm^3 were reserved for Bouregreg Basin users.[310] Inflows to the SMBA Dam vary greatly, ranging from a low of 67.2 to 2,570.25 million meters cubed.[311] Average inflows during the period of 1972-2005 were 25 percent less than those for the period of 1939-2005, a trend also observed for Oum Er Rbia.[312]

Though rich in surface water resource potential, the Bouregreg River Basin does not contain extensive groundwater resources and thus relies on variable rainwater to replenish the Bouregreg and Grou Rivers and their tributaries.[313] In a series of simulations using 2003-2013 data from the Gravity Recovery and Climate Experiment (GRACE) and Global Land Data Assimilation Systems (GLDAS), rainfall plays an important role in the water balance of the Basin and in Morocco in general.[314] GLDAS data contain values for frozen and unfrozen precipitation, evapotranspiration, and runoff as recorded by NOAA satellites.[315] GRACE data describe net changes in the earth's gravity field as inferred by changes in the earth's surface density, which can be used to determine changes in terrestrial water storage (TWS) or the "thickness" of water in centimeters (cm).[316] Together, GRACE and GLDAS data provide a triangulation of water balance.

For the Basin, GRACE data were extracted for 2003-2014. The resulting trends reflect a seasonality in water storage that mirrors the seasonal distribution of rainfall described by ABHBC collected data and are illustrated in Figures 17 and 18.[317] Variability peaks in February, where maximum rainfall occurs, and drops in May and July, where the lowest rainfall is recorded. Water storage increases and decreases for

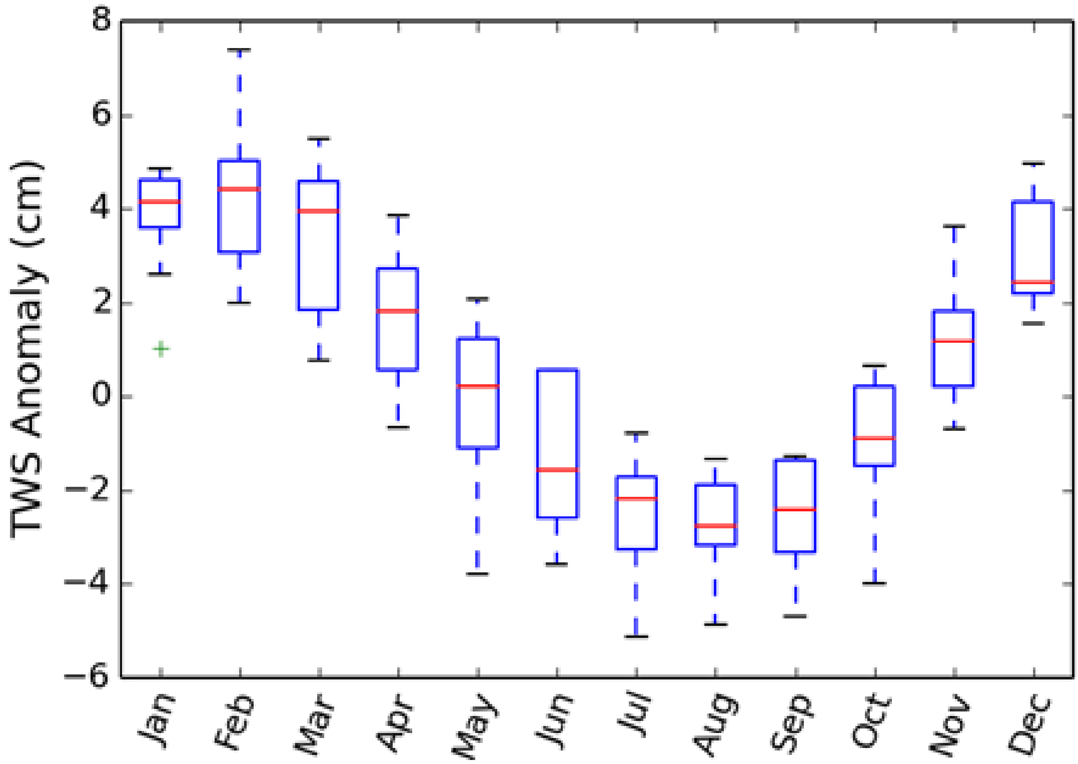
Bouregreg are more than twice that of those for all of Morocco on average, where maximum water storage in Bouregreg on average peaks in February at 17 centimeters, and a little more than seven centimeters for all of Morocco during the same month. Average decreases in water storage are a little more than ten centimeters for the Bouregreg Basin and five centimeters for all of Morocco. These results also reflect the more humid, homogenous climate of the Bouregreg Basin relative to Morocco.

Figure 17: Total Water Storage Changes by Season for Bouregreg



Source: Generated by Madeline Clark using tool developed by Arthur C. Ryzak, "Hydrologic Trend Analysis Tool," Center for Research in Water Resources, The University of Texas at Austin, 2015, accessed at http://tools.crwr.utexas.edu/HTAT/index.html; Data from 2003-2013 using Matthew Rodell and Hiroko Kato Beaudoing, NASA/GSFC/HSL, GLDAS Noah Land Surface Model L4 monthly 0.25 x 0.25 degree Version 2.0 (Greenbelt, Maryland, USA: Goddard Earth Sciences Data and Information Services Center (GES DISC), 2013), accessed February 15, 2015 at doi:10.5067/9SQ1B3ZXP2C5; F.W. Landerer and S. C. Swenson, "Accuracy of scaled GRACE terrestrial water storage estimates," Water Resources Research, 48, W04531, 11 (2012), accessed February 15, 2015 at doi:10.1029/2011WR011453.

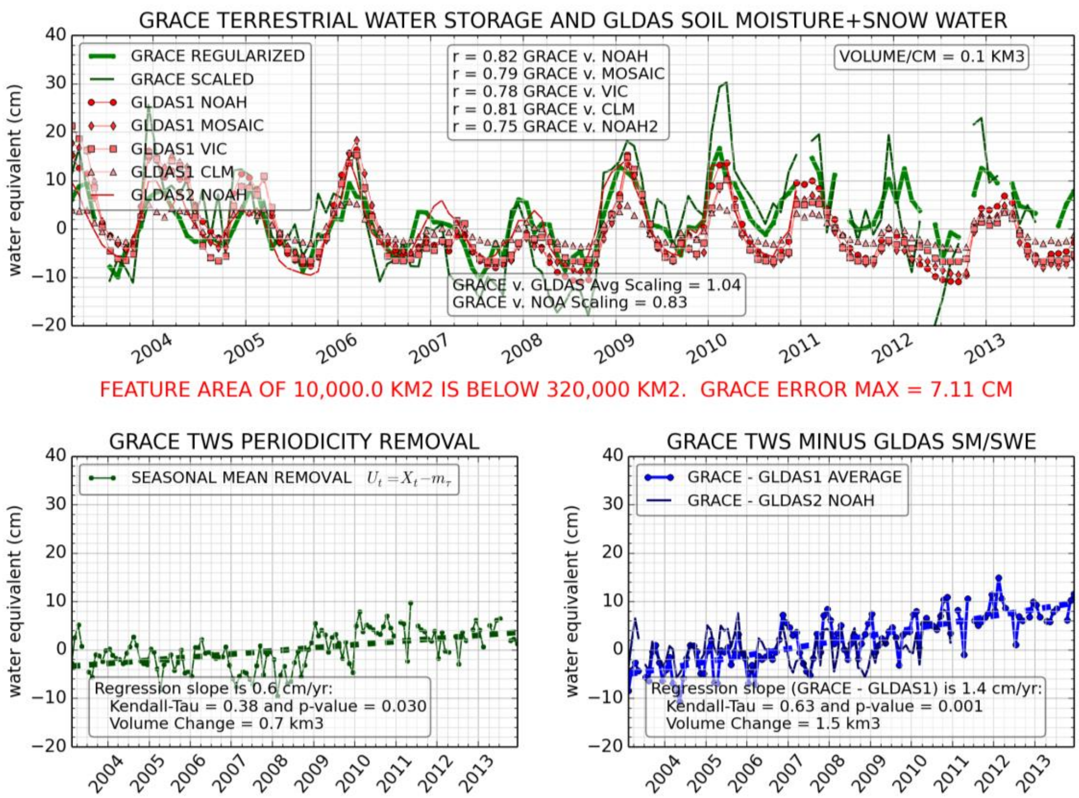
Figure 18: Total Water Storage Changes by Season for Morocco



Source: Generated by Madeline Clark using tool developed by Arthur C. Ryzak, "Hydrologic Trend Analysis Tool," Center for Research in Water Resources, The University of Texas at Austin, 2015, accessed at http://tools.crwr.utexas.edu/HTAT/index.html; Data from 2003-2013 using Matthew Rodell and Hiroko Kato Beaudoing, NASA/GSFC/HSL, GLDAS Noah Land Surface Model L4 monthly 0.25 x 0.25 degree Version 2.0 (Greenbelt, Maryland, USA: Goddard Earth Sciences Data and Information Services Center (GES DISC), 2013), accessed February 15, 2015 at doi:10.5067/9SQ1B3ZXP2C5; F.W. Landerer and S. C. Swenson, "Accuracy of scaled GRACE terrestrial water storage estimates," Water Resources Research, 48, W04531, 11 (2012), accessed February 15, 2015 at doi:10.1029/2011WR011453.

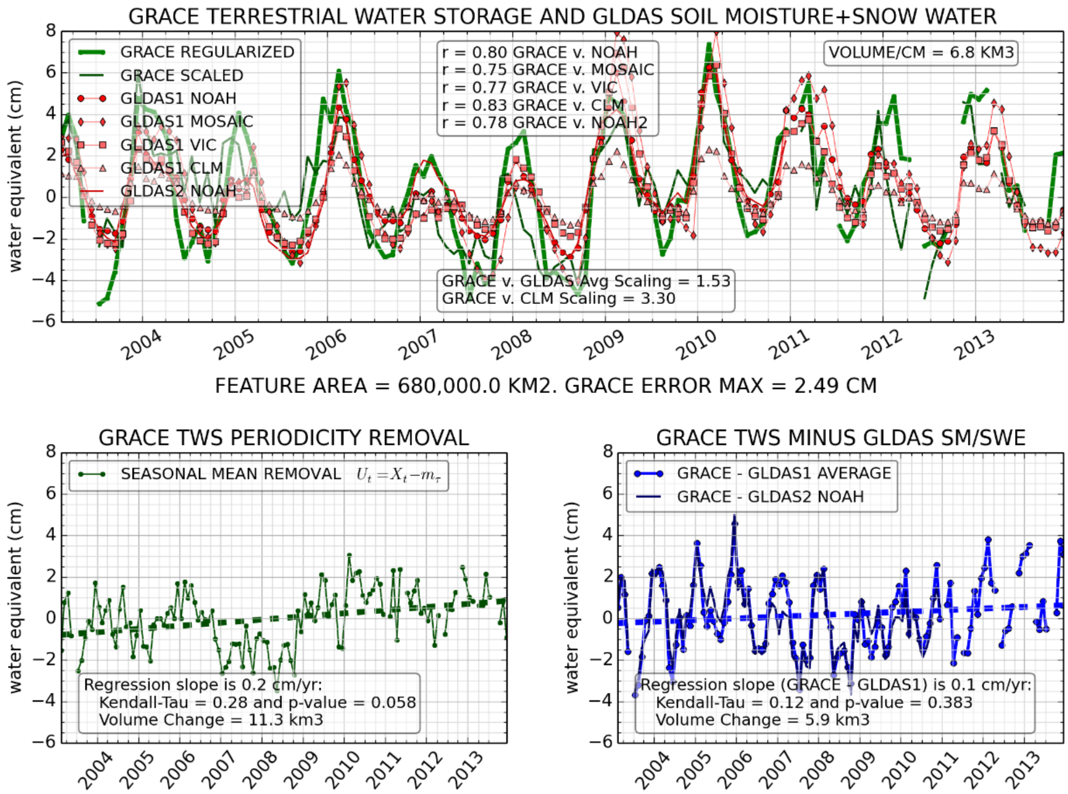
Figures 19 and 20 illustrate GRACE and GLDAS water budget trends for the Bouregreg Basin and the entirety of Morocco, respectively. Water availability according to the plots of GRACE and GLDAS data reflect trends in rainfall recorded by ABHBC for the period of 2003-2014. GLDAS recorded soil moisture peaks in the wet periods observed for 2009, 2010, and 2011. This finding of a close temporal link between rainfall and soil moisture supports that the Bouregreg Basin, and Morocco more generally, rely on surface water resources for water supply. GRACE data demonstrate a lag that may reflect the time necessary for rainwater to infiltrate into aquifers, however. In 2006, an isolated wet year, there is not the same degree of water storage as observed for 2009-2011.[318] The Basin is a subset of the total area of Morocco, so the error of these results is also higher and may impact their generalizability, as indicated in Figure 19 in the red text.

Figure 19: Water Budget Trends for Bouregreg



Source: Generated by Madeline Clark using tool developed by Ryzak, Arthur C. "Hydrologic Trend Analysis Tool." Center for Research in Water Resources, The University of Texas at Austin. 2015. http://tools.crwr.utexas.edu/HTAT/index.html; Data from 2003-2013 using Matthew Rodell and Hiroko Kato Beaudoing, NASA/GSFC/HSL, GLDAS Noah Land Surface Model L4 monthly 0.25 x 0.25 degree Version 2.0 (Greenbelt, Maryland, USA: Goddard Earth Sciences Data and Information Services Center (GES DISC), 2013), accessed February 15, 2015 at doi:10.5067/9SQ1B3ZXP2C5; F.W. Landerer and S. C. Swenson, "Accuracy of scaled GRACE terrestrial water storage estimates," Water Resources Research, 48, W04531, 11 (2012), accessed February 15, 2015 at doi:10.1029/2011WR011453.

Figure 20: Water Budget Trends for Morocco



Source: Generated by Madeline Clark using tool developed by Ryzak, Arthur C. "Hydrologic Trend Analysis Tool." Center for Research in Water Resources, The University of Texas at Austin. 2015. http://tools.crwr.utexas.edu/HTAT/index.html; Data from 2003-2013 using Matthew Rodell and Hiroko Kato Beaudoing, NASA/GSFC/HSL, GLDAS Noah Land Surface Model L4 monthly 0.25 x 0.25 degree Version 2.0 (Greenbelt, Maryland, USA: Goddard Earth Sciences Data and Information Services Center (GES DISC), 2013), accessed February 15, 2015 at doi:10.5067/9SQ1B3ZXP2C5; F.W. Landerer and S. C. Swenson, "Accuracy of scaled GRACE terrestrial water storage estimates," Water Resources Research, 48, W04531, 11 (2012), accessed February 15, 2015 at doi:10.1029/2011WR011453.

Water and agroforestry professionals and researchers in Morocco can benefit from the GRACE and GLDAS datasets if they use them to supplement data. Though the spatial resolution of these datasets is still coarse, or one kilometer, they can be used by experts to approximate water and climate trends where data points are scarce, missing, or unreliable. The ABHBC, for example, records rainfall data at 19 stations in the Greater Bouregreg-Chaouia Basin, yielding a low station density. Free, publically available datasets like the

GRACE and GLDAS may improve the robustness of the ABHBC's results at no additional cost. Using these datasets may also incentivize researchers to collaborate with NOAA to improve the quality of GRACE, GLDAS, and other datasets over time.

Surface Water Resources

The Bouregreg River, including the Bouregreg, Grou, and Korifla Rivers, demonstrates moderate flows averaging 23 meters/second (m/s), though 1,500 m/s was registered during the highest Basin flood on record. The source of water for the Basin lies in in the eastern depression of the Central plateau at the piedmont of the Middle Atlas, from a non-karstic source, endowing it with a more regular flow. The Bouregreg River flows over the Meseta Plateau in the direction of the Atlantic coastline, fed by runoff and seepages from small local aquifers with sedimentary, granite, and metamorphic formations.[319]

The dense river network stemming from the Bouregreg and Grou Rivers drives the behavior of surface water in the Bouregreg, and river flow in the Basin decreases from the northeast to the south-west.[320] The Bouregreg River has a total drainage area of 3,830 km^2 within the Basin. Subterranean water sources contained within basin boundaries include the Maâmora, Temara, and Sehoul aquifers.[321] The Grou River contains two major tributaries, Korifla and Akreuch, and lies in the southwest with a total drainage area of 5,760 km^2.[322] Typical stream flow is regular and strong, and metrics are listed in Table 11. Recorded streamflow for the Bouregreg River at Lalla Chafia is 2.17 liters/second/km^2 (l/s/km^2); for the Grou River at Sidi Jabeur, 1.97 l/s/km^2; and for the Korifla River at Ain Loudah, 1.79 l/s/km^2.[323]

Table 11: Average Stream Flow in the Bouregreg Basin

Stream gauge station	Surface area in km^2	Total production in Mm^3	Rate in $l/s/km^2$
SMBA	9,590	660	2.2
Lalla Chafia	3,230	220	2.2
Sidi Jabeur	3,110	194	2.0
Ain Loudah	636	36	1.8

Source: Agence du Bassin Hydraulique du Bouregreg Et De La Chaouia, "Le Plan Directeur d'Aménagement Intégré des Ressources en eau Du Bassin Hydraulique Du Bouregreg et de La Chaouia, Rapport De Synthèse" (2012): 20.

Groundwater Resources

The Bouregreg- Chaouia Basin lacks geologic formations conducive to the formation of aquifers, as nearly 85 percent of the Basin contains soils with a texture and structure that does not allow for the infiltration of water.[324] Groundwater contributes 30 million m^3 total to the Basin's water potential.[325] Though the 1995 Water Law protects aquifers from overexploitation by prohibiting their use as a primary water resource, the ABHBC issues individual permits on a case-by-case basis within the Maâmora, Temara, and Sehoul aquifers for municipal water supply and urban garden irrigation.[326] These aquifers are limited compared to groundwater resources in other basins.[327]

Reservoirs

The reservoir serving the outlet of the Basin at the SMBA Dam provides service to approximately 6 million people in and outside of the Basin.[328] The dam, which is the principal hydrologic infrastructure serving the Western Region of Morocco for surface water, was built in 1974 to regulate and treat water for drinking water and industrial use in the area including Rabat and Casablanca and is reserved only for this purpose.[329]

Reserving SMBA primarily for drinking water reflects the Basins' high population density, which is concentrated in the Rabat-Salé-Zemmour-Zaër province. Because the Basin through the reservoir also supplies Casablanca, Morocco's economic capital and largest city, with 38 percent of its water needs, the SMBA Dam produces 31.5 percent of Morocco's drinking water.[330]

Nationally, Bouregreg, Sidi Said Maâchou, Daourat and Faourat are the biggest reservoir complexes in Morocco.[331] The Bouregreg complex capacity is 1,025 million meters cubed and was created in stages from 1969, 1975, and 1983.[332] The SMBA Dam's elevation was increased by more than 100 percent in 2008 to increase the reservoir's storage capacity from 480 Mm^3 to 1,025 Mm^3 due to increases in urban water demand.[333] The SMBA Dam currently utilizes 974 Mm^3 per year of this capacity, with a working volume of 875 Mm^3.[334] In an analysis of the SMBA Dam conducted by ABHBC in 2012, the dam's average working volume was 800 Mm^3, contribution of Oum Er Rbia was 120 Mm^3, and average evaporation was 35 million meters cubed.[335] The dam's pump station and gallery bring raw water to a chloration treatment plant operated by ONEP 2.8 kilometers downstream to produce water for consumption by the drinking and municipal water sectors.[336] Annual production of water using ONEP complexes is about 262 Mm^3 and costs about 1.1 million Moroccan Dirhams (MAD), or $114,486.36 USD as of August 2015.[337]

The dam experiences moderate to severe rates of sedimentation that range from one to three Mm^3 per year and average at 2.8 Mm^3/year according to data collected for 1985, 1995, 2000, and 2003.[338] Dam sedimentation is thus a serious issue for the

Bouregreg Basin because it decreases water storage capacity through the increase of dead storage. Sedimentation also diminishes the quality of its water, which could affect Morocco's major urban centers if water deficits increase.[339] Excess sedimentation also degrades biodiversity up and downstream and impacts the health of the Basin's ecosystem.[340]

The second dam is Ain Koreima on the Akreuch tributary near Rabat- Salé, with an inflow volume of 5.7 Mm^3, of which 1.3 Mm^3 is reserved for irrigation and livestock.[341] In addition to SMBA and Ain Koreima, there are 6 small dams for livestock and irrigation, which are listed in Table 12.[342]

Table 12: Small to Mid-size Dams in the Bouregreg Basin

Name/Prefect or Province	Date built	Capacity in Mm^3	Use
Arid	1985	0.70	Irrigation
Ait Lamrabtia	1985	0.20	Livestock
El Ghoulam	2002	0.90	Livestock
Khemisset/Bouknadel	2001	1.04	Livestock
Khenifra/ Ain Tourtoute	1987	0.85	Irrigation and Livestock
Tskrame	1989	0.03	Irrigation and Livestock

Source: Agence du Bassin Hydraulique du Bouregreg Et De La Chaouia, "Le Plan Directeur d'Aménagement Intégré des Ressources en eau Du Bassin Hydraulique Du Bouregreg et de La Chaouia, Rapport De Synthèse" (2012) : 33.

Flood Mitigation

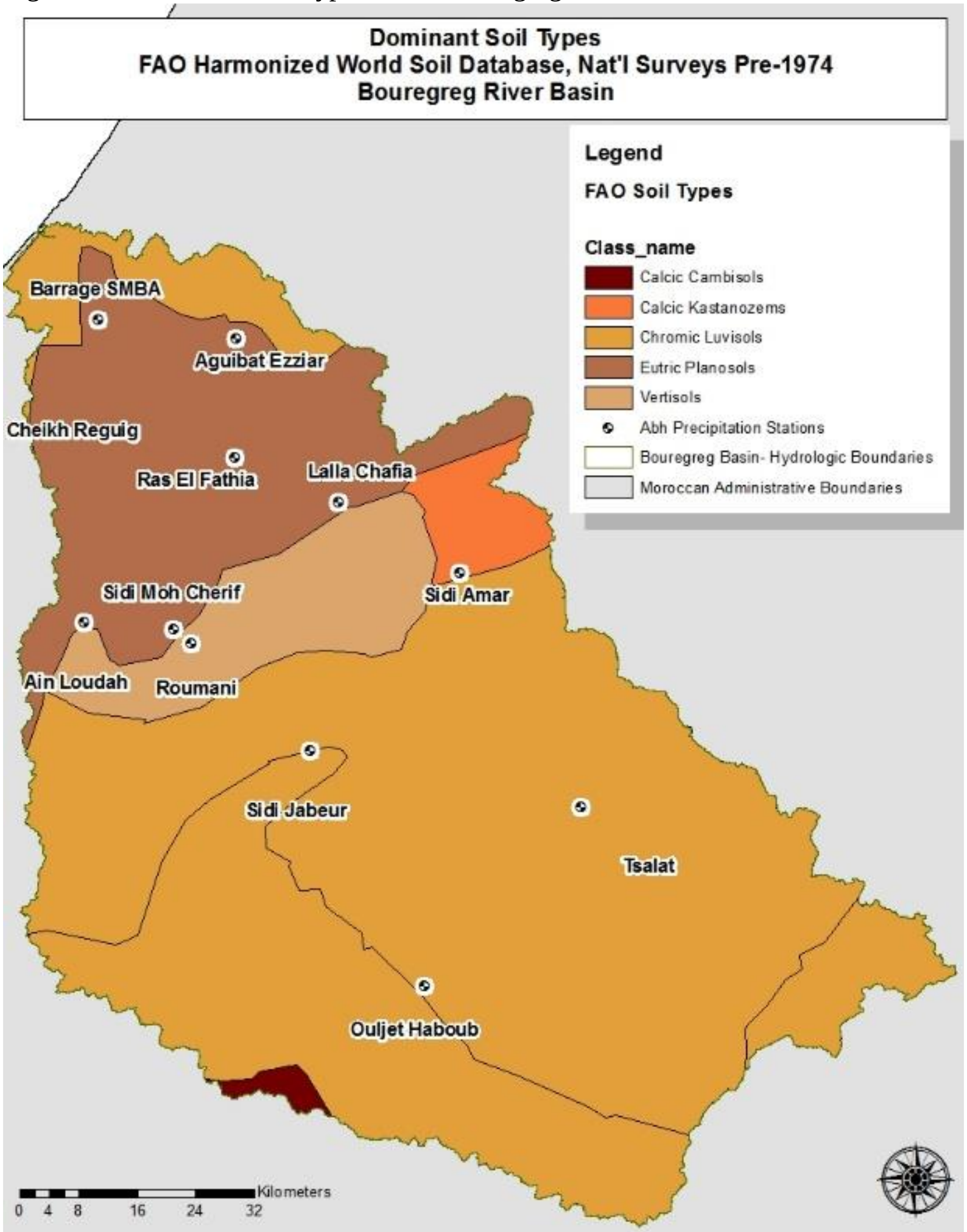
The ABHBC's priority is the Oued Malleh Watershed of the Chaouia Basin within the scope of its ongoing and planned flood mitigation measures.[343] There is currently a pilot study to combat erosion as part of the partnership between JICA and the HCEFLCD under the PNABV.[344] The ABHBC also is undertaking structural flood control measures on rivers and dams, and non-structural measures such as improving the ABHBC's early warning system for floods.[345]

Soil Characteristics

As visually represented by Figure 21, the major soil types in the Basin according to FAO Classification include: Chromic Luvisols; Calcic Kastanozems; Eutric Planosols; Chromic Luvisols; Vertisols; Calcic Cambisols; and Vertisols.[346] These soils are characterized by a loamy or light clay nature. Table 13 in the Appendices section lists the coverage of the five FAO soil types as a percentage of the Basin.

The lithological composition of the Bouregreg's drainage basin is dominated by schistic, flyschic, and calcic formations.[347] This typology covers about 79 percent of the Basin’s area.[348] Outcroppings consisting of schistic and flyschic formations cover 40 percent of the Basin.[349] Resistant lithological types include calcic, greys, granites, micrograniites, and granulites, and cover 10 percent of the Basin.[350]

Figure 21: Dominant Soil Types in the Bouregreg Basin



Source: Generated by Madeline Clark using data from Harmonized World Soil Database v1.2 in G. Fischer, F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, and D. Wiberg, "Global Agro-ecological Zones Assessment for Agriculture" (Laxenburg: IIASA and FAO, 2008), accessed August 20, 2015 at http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/#jfmulticontent_c284128-2.

Erosion

Areas at high risk for erosion in the Loukkos Basin in the north-west Rif and the Haute Moulouya Basin in greater Moulouya Basin complex have been studied extensively for ways to quantify erosion potential and sediment transport; in these cases soil loss has reached a threshold limiting its full recovery. Though it is historically and holistically less at risk for soil loss due to water erosion, the Bouregreg River Basin does show the potential for significant soil loss in localized areas.

The PNABV identified the Bouregreg Basin as 13th of 22 basins at critical risk for erosion, a decision based on the degree of erosion witnessed and the intensity of its effects on inhabitants.[351] The ABHBC uses bathymetric studies to model sediment transport; they have been conducted approximately every 10 years.[352] Specific degradation is 265 m^3/ km^2/year for the Basin, which translates to about a 2.5 percent decrease in the capacity of the SMBA Dam.[353] Within the Basin, there are 2 priority zones, as listed in Table 14.

Table 14: Erosion and Flood Mitigation Zones in the Bouregreg Basin

Zone	Period of Realization	Location
1	Short term	The watersheds of the Lower Bouregreg, Middle Bouregreg, Tabahhart, and a part of the sub basin of Ksikssou. This zone contributes to 90 percent of water inflows to the SMBA dam.
2	Medium to long term	The sub basin of the Aguiennour River and a part of the Ksikssou Sub-Basin. Management of these basins is under study.[354]

Source: Adapted by Madeline Clark using data from Agence du Bassin Hydraulique du Bouregreg Et De La Chaouia, "Le Plan Directeur d’Aménagement Intégré des Ressources en eau Du Bassin Hydraulique Du Bouregreg et de La Chaouia, Rapport De Synthèse" (2012) : 33.

Laouini et al. evaluated erosion in the Hannanat Watershed, which is near the Aguibat Ezziar station in the northwest of the Basin sitting at the intersection of the Bouregreg and Grou Rivers.[355] Erosion by superficial runoff affects more than 80 percent of slopes but contributes only weakly to soil loss in semi-arid conditions.[356] Laouini et al. determined that highly erodible soils combined with reduced organic matter and vegetation cover result in soil compaction and higher overland flow.[357] These conditions usually occur in grazing areas due to slash and burn clearing and the load of animals on the soil.[358] Traditional land management systems, involving agriculture, animal husbandry, and forestry, degrade soils to the point of producing moderate overland flow and erosion rates.[359] Poverty and the absence of resource protection traditions have not encouraged adaptive management strategies.[360]

To conclude, the rate of sedimentation in SMBA has increased in recent years; its reservoir capacity was expanded in 2008 to increase storage in part due to sedimentation. This study focused on the Bouregreg Basin because the irrecoverable siltation of the SMBA Reservoir is an outcome that should be avoided, regardless of the potential magnitude of erosion rates. Prevention of soil erosion in a basin can help save Morocco the high costs of building new water storage infrastructure and rehabilitating damaged soils in the future.

METHODS

Potential erosion rates and sediment yields basin-wide are modeled using the modified RUSLE through ESRI's ArcGIS ArcMap Graphic User Interface (GUI). The RUSLE equation and its terms A, R, LS, K, C, and P are listed and described below in Equation 1.[361]

Equation 1: RUSLE Equation, Renard, 1991

$$A = R * LS * K * C * P$$

RUSLE is a multiplicative index that estimates soil loss in metric tons/hectare/year through the interaction of the five parameters A, R, LS, K, C, and P.[362] Average annual soil loss (A) manifests in the units used to describe soil erodibility, or tons/hectare/year, for the period of precipitation data used to calculate rainfall erosivity (R).[363] The first parameter R measures the kinetic energy of rainfall as it hits the ground in Mega joules (MJ) per mm/ hectares$^{-1/}$hour$^{-1/}$ yr^{-1}, or the erosivity of raindrops in MJ mm/ hectares$^{-1/}$hour$^{-1/}$ yr^{-1}.[364] The term LS measures the contribution of slope length (L) and steepness (S) to the ratio of soil loss and is unitless.[365] K measures the erodibility of soil types in tons/ hectare/ hour/ hectare^{-1}/MJ^{-1}/mm^{-1}.[366] C measures the contribution of trends and variability in vegetation or vegetative cover to erosion and is unitless.[367] P measures the impact of soil and land management practices on erosion and is unitless.[368]

In light of previous work on the application of RUSLE both in and outside of Morocco, this study focused on the role of each factor in RUSLE results and the influence of methodological choices when implementing RUSLE in a GIS. Table 14 lists these questions and parameters and were used to create the 15 conditions or scenarios in Table 18.

Table 15: Questions Driving the Formation of RUSLE Scenarios

Parameter	**Question**
Elevation and Land Use	The impact of input data resolution at a scale of 30 and 90 meters, which are the highest resolutions of publically available DEM and remote sensing data to decision makers in developing countries
Precipitation and Land Use	The influence of extreme values in the R and C factors during wet and dry years, due to the fact that available data is at a daily, not hourly temporal scale, and so an erosivity equation based on average and monthly values was used
Precipitation	The relationship between precipitation and R values based on annual and monthly historical precipitation data
Precipitation, Land Use, Soil Type, Elevation	The relative contribution of each factor in the RUSLE model
Land Use	The impact of variable vegetation cover by year

Source: Compiled by Madeline Clark.

R Factor

To approximate the R factor or erosivity of rainfall, this study used the Modified Fournier Index (F) developed by Arnoldus in 1977 because it was developed in the context of the Moroccan climate; it has been used as a standard in studies of erosion in Morocco. Equation 2 lists the Modified Fournier Index as it was developed by Arnoldus.[369]

Equation 2: Modified Fournier Index, Arnoldus, 1977

$$\mathbf{F = \sum_{i=1}^{12} Pi^2/P}$$

Here, F is equal to the sum of 12 terms: the value of average monthly precipitation in month (p_i) squared divided by average annual precipitation (P). The ratio of these terms provides an estimation of rainfall intensity in the absence of 30 minute and hourly precipitation data.[370] The Modified Fournier index was integrated into Equation 3 to develop an isoerodent map for Morocco.[371] The term 0.264 and the factor of 1.50 were derived empirically in 1994 by Renard and Freimund in "Using Monthly Precipitation Data to Estimate the R-Factor in the Revised USLE."[372]

Equation 3: R-Factor for Morocco, Arnoldus, 1977

$$\mathbf{R = 0.264*F^{1.50}}$$

A total of 19 stations with 36 years of data were examined, and stations and years with more than 30 percent of data missing were removed. Stations in the Chaouia Watershed were removed, except for Cheikh Reguig (due to large gaps in data), resulting in 12 stations or observation points. The 25 remaining years were for agricultural years within the periods 1984-1989, 1991-2005, and 2009-2013. Gaps and errors in data were corrected by replacing them with a simple average of the three closest stations, which were chosen by using the Nearest Neighbor Method in ArcMap's Near tool.

LS Factor

This study utilized the LS equation developed by Mitasova and Mitas in 1996, which takes into account the variation of flow length over irregular surfaces, like those occurring in the varied topography of the Basin. To preserve consistency, the original projection of the data, WGS 1984, was used to calculate the factor before re-projecting it into the Nord Maroc projection when constructing the final index. The Mitasova and Mitas equation is listed in Equation 4.[373]

Equation 4: LS Factor, Mitasova and Mitas, 1996

$$\mathbf{LS(r) = (m+1) \; [\, A(r) / a_0 \,]^m \; [\, \sin b(r) / b_0 \,]^n}$$

Here, LS at point (r) is derived by multiplying the term composed of the flow length of the upstream contributing area by cell resolution (A) at point r and dividing it by 22.1 meters (a), all raised to the power of 0.5 (m) for slope angles less than 14 degrees.[374] This term is multiplied by the second term, derived by taking the sine of the slope in degrees (b) at point r, multiplying it by 0.01745 to adjust for the slope of the standard USLE plot, dividing it by 0.09, which is the slope in degrees for the standard USLE plot (b_0), and raising it to the power of 1.5 (n).[375] The final resulting term is multiplied by m + 1, or 1.5, a relationship derived empirically by Mitasova and Mitas.[376] The terms (m) and (n) are usually derived according to a plot's rill to interill ratio, but can also be approximated by using slope in degrees according to Mitasova and Mitas.[377] This equation was entered into raster calculator in ArcMap using the format displayed in Equation 5.[378]

Equation 5: System Input, LS Factor, Mitasova and Mitas, 1996

LS = 1.5*Power (FAC*cellres/22.1, 0.5)*Power (Sin (slopedeg*0.01745)/0.09, 1.5)

A DEM was downloaded at 30 and 90 meter resolution from the Shuttle Radar Mission Topography (STRM) satellite. These results were processed by using the Fill and Sink tools in ArcMap. Flow direction, flow accumulation, and slope in degrees were obtained in order to perform the LS factor equation in ArcMap's Raster Calculator.

K Factor

This study used the algebraic version of the soil quality nomograph developed by Wirschmeier and Smith, 1978, which is a soil erodibility index based on an interaction of percent organic matter (MO), which aids in the adaption, rooting, and subsistence of vegetation; particle size (M), a function of percent clay, sand, and silt; USDA defined soil structure or texture (s); and permeability as derived from USDA drainage classes (p).[379] In the 1978 Wirschmeier and Smith equation, percent organic matter (MO) is subtracted from 12; soil particle size (M) is raised to the power of 1.14; soil structure (s) is subtracted from 2 and added to 2.5; and soil permeability (p) is subtracted from 3.[380] The

K Factor equation that is most commonly used, in both USLE and RUSLE, is listed in Equation 6.[381] The terms containing (MO) and (M) are multiplied by 2.1, 10^{-4} and added to 3.25, which is multiplied by the terms containing (s) and (p).[382] The terms and power 2.1, 10^{-4}, 12, 3.25, 2, 2.5, 3, 100, and 1.14 were derived empirically by Wirschmeier and Smith.[383]

Equation 6: K Factor Equation, Wirschmeier and Smith, 1979

$$\boldsymbol{K = 2.1\times10^{-4} \times (12-MO) \times M^{1.14}+3.25 \times (s-2) + 2.5 \times (p-3)/100}$$

Due to the lack of a local unified, reliable, and georeferenced dataset, this study used the FAO's Harmonized World Soil Database (HWSD) and Viewer to derive the terms (MO), (M), (s), and (p).[384] Tables 16 and 17 list USDA textural class categories and FAO drainage classes, respectively that are used in the HWSD and HWSD Viewer.[385] The USDA textural class categories for soil are used to derive the term (s), and the FAO drainage classes are used to derive the term (p).[386]

Table 16: USDA Textural Class

USDA Textural Class	
Code	Value
1	Clay (heavy)
2	Silty clay
3	Clay (light)
4	Silty Clay Loam
5	Clay Loam
6	Silt
7	Silt Loam
8	Sandy Clay
9	Loam
10	Sandy Clay Loam
11	Sandy Loam
12	Loamy Sand
13	Sand

Source: Compiled by Madeline Clark using data from Guidelines for Soil Description (Rome: Food and Agricultural Organization of the United Nations, 2006), 46.

Table 17: USDA Drainage Class

Drainage Code	Value
1	Very Poor
2	Poor
3	Imperfectly
4	Moderately Well
5	Well
6	Somewhat Excessive
7	Excessive

Source: Compiled by Madeline Clark using data from Guidelines for Soil Description (Rome: Food and Agricultural Organization of the United Nations, 2006), 52.

Values for K were derived using this equation rather than the traditional nomograph, which uses an index of K values derived solely by percent organic matter content and USDA soil texture class.[387] With such a small sample size, or 5 total soil classes within the Basin, the traditional nomograph yielded inconsistent results.

C Factor

Due to the lack of consistent, basin-wide georeferenced data, the inverse NDVI function developed by van der Knijff et al. was used in order to derive C Factor values.[388] The equation for deriving NDVI values from Landsat 5 TM data is listed in Equation 7.[389] To derive NDVI values from remote sensing imagery, images must be converted from raw pixel values to digital numbers representing their bandwidth.[390] For Landsat 5 TM data, the visible red (Band 3) and infrared (Band 4) bands were used.[391] To derive NDVI, the Red Band (3) is subtracted from the Infrared Band (4).[392] The resulting term is divided by the sum of the Infrared Band (4) and Red Band (3).[393]

Equation 7: Deriving NDVI from Landsat 5 TM Images

NDVI= (infrared- red) / (infrared + red)

Van der Knijff et al. in 1999 suggested that because NDVI and the C factor are inversely correlated, NDVI may be a more accurate determinant of C than land cover maps, which are often subjectively compiled.[394] The van der Knijiff et al. C Factor equation is listed in Equation 8.

Equation 8: Inverse NDVI C-Factor, van der Knijff et al., 1999

$$C = \exp\left(-\alpha * NDVI / (\beta - NDVI)\right)$$

The term (C) for a C Factor value in a specific cell or point within a remote sensing image is derived by taking the exponential function (exp) of the inverse of

NDVI.[395] The inverse of NDVI is derived by multiplying the negative coefficient (α) by NDVI within a given cell.[396] The resulting term is divided by (β) minus the value of NDVI within the same cell. Van der Knijff et al. suggest using the the values of 2 for (α) and 1 for(β).[397] According to the methods suggested by van der Knijff et al., this inverse function was entered into ArcMap's raster calculator as demonstrated by Equation 9:[398]

Equation 9: C Factor System Input

C= Exp (- 2 * "NDVI" / (1 - "NDVI"))

Results were compared visually to both Google Earth Pro and a land use map created using ArcMap's Image Classification toolset. The Maximum Likelihood Classification method was utilized to classify pixels into land use types with the same Landsat 5 TM image used to calculate the C Factor. The final land use samples were compared with maps created from the SIGMED vegetation dataset for the Bouregreg Basin and the Global Land Cover Facility's (GLCF) Global Climatology dataset.[399]

In order to understand how land cover changed through time, 60 images were obtained from the eMODIS dataset for the African continent. These images were processed further by taking monthly and yearly averages of 10-day averaged NDVI values and converting them to C values using the same inverse function of NDVI listed in Equation 7.[400]

P Factor

Detailed Moroccan information regarding agricultural practices are not available in the public domain from the MAPM.[401] To be consistent with other studies where erosion management practices are also still developing, such as that conducted by El Gaatib and Larabi in the nearby Sebou River Basin, this study assumed a dimensionless factor of 1 for the P Factor.[402] Table 18 lists 15 scenarios constructed across four conditions.

Table 18: Scenarios Constructed for RUSLE Modeling in this Study

Scenarios	Control for Scale (30-90 meter resolution)
1	Average R Factor values for the period 1984-1989, 1991-2005, 2009-2013; Static C Factor values for September 2011; and constant K and LS Factor values. 30 meter resolution. This is Scenario One.
2	Average R Factor values for the period 1984-1989, 1991-2005, 2009-2013; Static C Factor values for September 2011; and constant K and LS Factor values. 90 meter resolution. This is Scenario Two.
	Control for Variation in R and C
3-9	R Factor values for the period 1994, 1996, 2009-2013; Static C Factor values for September 2011; and constant K and LS Factor values. 30 meter resolution. These are Scenarios 3-9, which vary by R Factor year.
10-15	R Factor values for the period 1994, 1996, 2009-2013; eMODIS NDVI-derived C Factor values averaged by month, and for years 2009-2013; and constant K and LS Factor values. 90 meter resolution. These are Scenarios 10-15, which vary by R and C Factor year.

Source: Compiled by Madeline Clark.

Data and Software Used

Table 19 lists the software used for this study. A description of protocol used to process and format data is contained in Appendix 1 in the Appendices section of this report. Table 20 lists data compiled for the RUSLE scenarios constructed by this study. All factors were resampled to 30 meters in Scenarios 1 and 3-15, and 90 meters in Scenario 2. The original resolution of datasets varied between 30, 90, 250 and 500 meters in resolution. STRM data was at the 30 and 90 meter resolution, and Landsat 5 TM imagery was at 30 meters resolution. The eMODIS images were at the 250 meter resolution, and the FAO Soil Data was at a 500 meter resolution. Figure 22 illustrates the workflow used to construct the RUSLE index.

Table 19: Software Used in this Study

Name of Software	Publisher
ArcMap GUI 10.3	ESRI
ENVI 5.2	Exelis
Stata 13	Stata
Microsoft Office Excel, Access, and Word	Microsoft

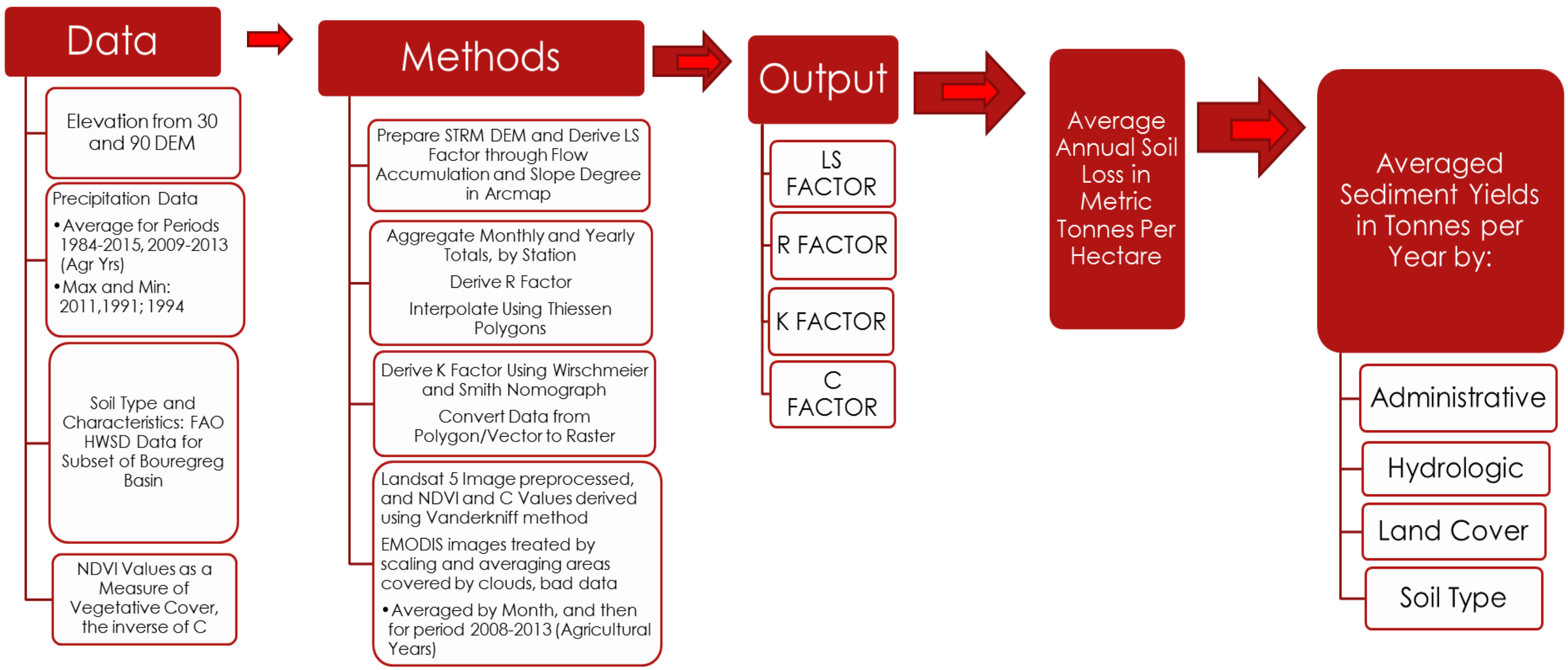
Source: Compiled by Madeline Clark.

Table 20: Data Used in this Study

Variable	Dataset	Source
Elevation	Digital Elevation Model at 30 and 90 meter resolution	Obtained from United States Geological Survey's Earth Explorer : http://earthexplorer.usgs.gov/ Collected and Published by Shuttle Radar Topography Mission http://www2.jpl.nasa.gov/srtm/
Precipitation	Daily Precipitation Values for 12 precipitation stations* in Bouregreg-Chaouia River Basins, 1984-1989, 1991-2005, 2009-2013 agricultural years (Total 26 years),	Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco. *(Aguibat Ezziar, Ain Loudah, Barrage Sidi Mohammed Ben Abdellah, Cheikh Reguig, Lalla Chafia, Ouljet Hajoub, Ras El Fatiha, Roumani, Sidi Amar, Sidi Jabeur, Sidi Moh Cherif, Tsalat)
Land cover and use	Baseline, Static: Landsat 5 30m remote sensing image, September 5 and 14 2011 for panels 2021037, 2022036, 2022037	Obtained from United States Geological Survey's Earth Explorer : http://earthexplorer.usgs.gov/ Collected and Published by Shuttle Radar Topography Mission
Land cover and use	Multi-Year: eMODIS 250m NDVI 10-day averages, 12 months at end/ 26th day of month, 2008-2013 agricultural years	Obtained from United States Geological Survey's Earth Explorer : http://earthexplorer.usgs.gov/ Collected and Published by Shuttle Radar Topography Mission https://lpdaac.usgs.gov/products/modis_products_table/mod13q1
Land cover For Reference	Global Climatology 0.5 km (500 m)-Derived from MODIS NDVI data	http://landcover.usgs.gov/global_climatology.php
Land cover For Reference	SIGMED Vegetation for Bouregreg	http://labo.um5a.ac.ma/sigmed/index.php/fr/joomlaorg/carte
Soil Type and Characteristics	Harmonized World Soil Database v1.2, 1: 500,000 (500 m) scale	http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/#jfmulticontent_c284128-2
Soil Type and Extent	Digital Soil Map of the World (DSMW), 1: 500,000 (500 m) scale	http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116

Source: Compiled by Madeline Clark.

Figure 22: Description of Workflow Used to Construct the RUSLE Index



Source: Compiled by Madeline Clark.

Section III: Results

RUSLE Factors

LS Factor

Predicted ratios of slope length to steepness causing soil loss were higher using the 30 meter resolution DEM overall, though more clustering around the river network occurred using the 90 meter DEM. Figures 23 and 24 display results for the LS Factor as yielded by the 30 and 90 meter DEM datasets, respectively. As illustrated by the map of LS Factor values for the Basin at the 30 meter resolution in Figure 23, values ranged from 0 to 211.002. In Figure 24, LS results derived using the 90 meter resolution DEM ranged from 0 to 36.2248.

Both Figures 23 and 24 indicate a similar geographical spread of values between resolutions. Higher values occurred along riverbeds, near the coast, and at highest elevation drops in the Basin. This is in agreement with the results from the hypsometric analysis, which indicate that the Basin is primarily stable, and that sources of erosion exist primarily along the fluvial channels of the drainage network. Thirty meter results had much higher values in magnitude, indicating that higher resolution DEMs may be more adept in picking up nuances in hillslopes, whereas 90 meter results seem to have a larger spread of values. This difference in spread is driven by the larger pixel size of the 90 meter DEM, which causes it to pick up coarser drainage network features.

The reduced ability of the 90 meter DEM to pick up nuances in hillsides may indicate that it is not unusable in RUSLE modeling. 90 meter DEMs are the most common resolution of DEMs among Moroccan water and agroforestry professionals and researchers consulted for this study.[403] Free, publically available DEMs from STRM at the 30 meter resolution only recently became available, which can explain the commonness of 90 meter resolution DEM use in this context.[404]

K Factor

The FAO soil map was resampled to the 30 and 90 meter resolution, but results did not change due to the fact that the extent of soil types are based on the FAO's compilation of Moroccan national soil surveys published in 1974. Figure 25 describes the distribution of K Factor values. Values for the K Factor ranged from 0.101618 to 0.636051 tons/ hectare/ hour/ $hectare^{-1}/MJ^{-1}/mm^{-1}$. K Factor values tend to be higher for loamy soils, and lowest for Vertisols, the only identified clay dominant class. Eutric Planosols surrounding the intersect of the Grou and Bouregreg Rivers near the SMBA Dam, Calcic Cambisols near Ouljet Haboub, and Calcic Kastonozems near Sidi Amar show the highest erodibility levels, respectively and in order of magnitude, though Eutric Planosols coexist with all three segments of river features in the Basin.

C Factor

Figures 26 and 27 illustrate the geographic distribution of C Factor results in raw form and by land use class, respectively. Forests displayed the lowest C Factor values, and urban areas the highest, followed by sparse vegetation and bare soil. The map in Figure 28 illustrates the spread of NDVI values in the Basin.

Figure 29 plots NDVI values against C Factor output. Though this plot displays a normal distribution, correlation between NDVI values and C Factor values was low, with an R^2 of 0.3298. This low correlation could have resulted from minor errors in classification during pre-processing of the Landsat 5 TM image to derive NDVI values. Though results were generally consistent with results obtained by studies affiliated with SIGMED, some inconsistencies between bare soil and cropland classification may have occurred. Bare soil is the most vulnerable C Factor class to erosion, and cropland rests about halfway on the spectrum of C Factor values in most studies. Inaccuracies could affect the predicted erosion rates significantly, particularly since published land use and vegetation types like cereal cultures are dominant in the Basin.

Consistent longitudinal, high-resolution remote sensing data and field surveys would improve the reliability of results because the C Factor results from multiple images could be compared and triangulated to derive average C Factor values. Granular geolocated information regarding agricultural practices and land use would also allow researchers to compare C Factor values derived from the van der Knijiff et al. inverse NDVI function with published C Factor indices, like those used in the original RUSLE.

There were significant changes in C Factor values derived with eMODIS data for years during 2009-2013, and this could play a role in average annual sediment yield over time. Figure 30 illustrates the geographic distribution of changes in C Factor values during 2009-2013. Increases in C factor values were highest (between 0.176 and 0.602), in the forested, mountainous areas near Tsalat and in the north-eastern areas of the Basin near the Aguibat Ezziar and Lalla Chafia stations. The beginning of the Maâmora Forest near Rabat-Sale and its suburbs also displayed C Factor gains in this range, which reflects a trend of intensified urban development in the area. The C Factor as derived from eMODIS 10-day averages tends to overestimate vegetation cover, which may be attributed to the lower resolution of the dataset at 250 meters.

R Factor

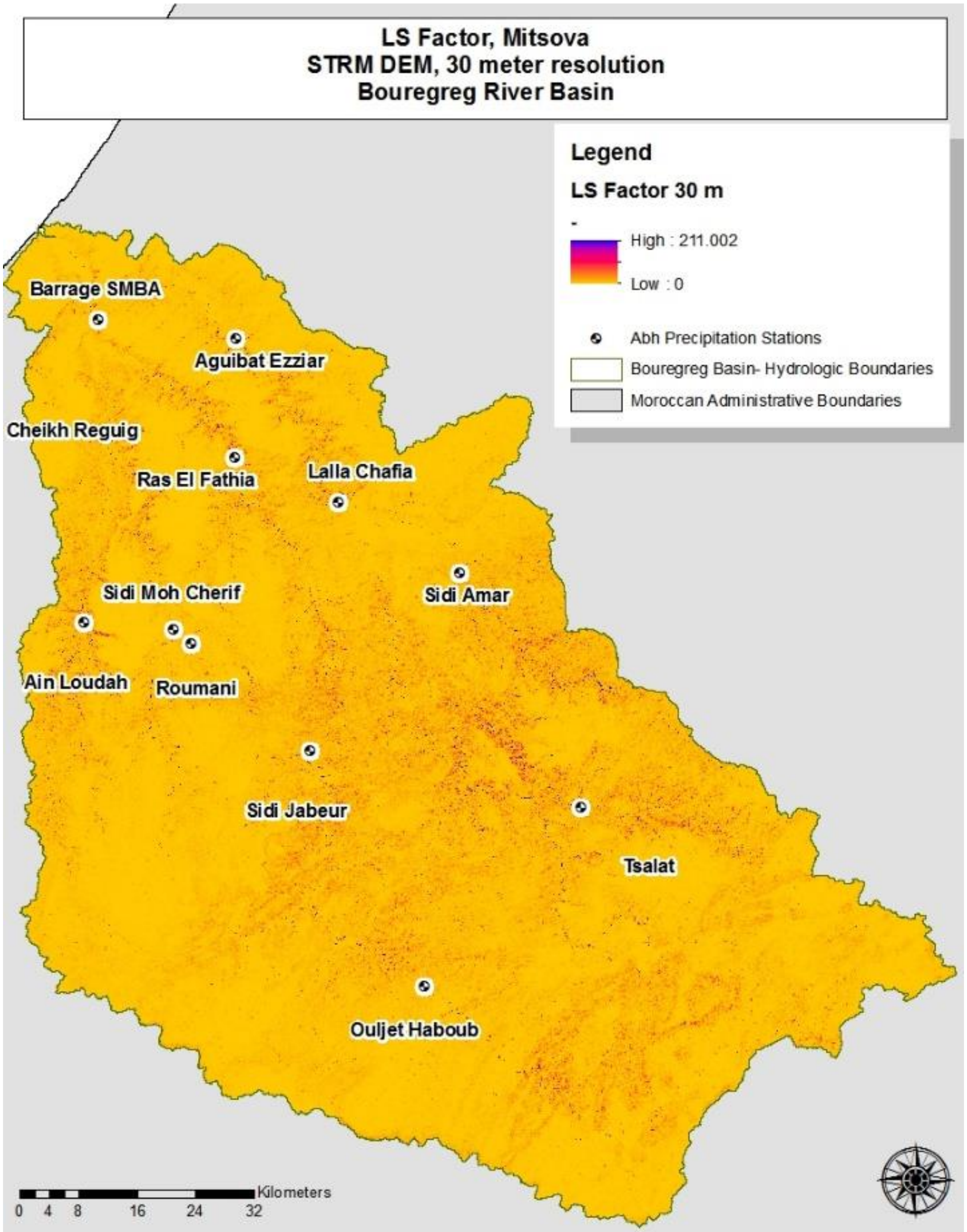
The R Factor varied considerably over time and space but did not vary directly with changes in average annual precipitation. Values for average erosivity for the entire period ranged between 58.4 and 132.7 MJ mm/ hectares^{-1}/hour^{-1}/ yr^{-1}. Figure 31 illustrates the distribution of R Factor values interpolated by the Thiessen Polygon Method.

Areas experiencing the highest R values are located in the sub-humid zones of the Basin, whereas the areas experiencing the lowest R values are located in the semi-arid zones of the Basin, which are less likely to experience intense storms. The stations located in the coastal plains, or Cheikh Reguig, the SMBA Dam, Ras El Fatiha, Aguibat Ezziar, and the mountainous Tsalat station displayed the highest values, whereas the stations located in the central plains and Ouljet Haboub displayed the lowest values. The correlation between R factor values and annual precipitation is moderate, with an R^2 of 0.5945 (see Figure 32). This may be due to the low number of observation points for basin stations, which at 12 is much lower than the minimal sample size of 30. A low density of rain gage stations is common in developing economies.

Though the most traditional application of RUSLE uses an average R value for the entire study period, this study examined variation in precipitation as a parameter, so changes in R values are considered and discussed below. Mountainous areas near the Tsalat station and coastal areas near the SMBA, Cheikh Reguig, Aguibat Ezziar, and Ain Loudah stations, consistently yielded high R factor values. Figures 33 and 34 illustrate the difference in magnitude for R factor values between the agricultural years of 1994 and 1996, respectively. These years had the lowest and highest R Factor values in the Basin during 1984-2013.

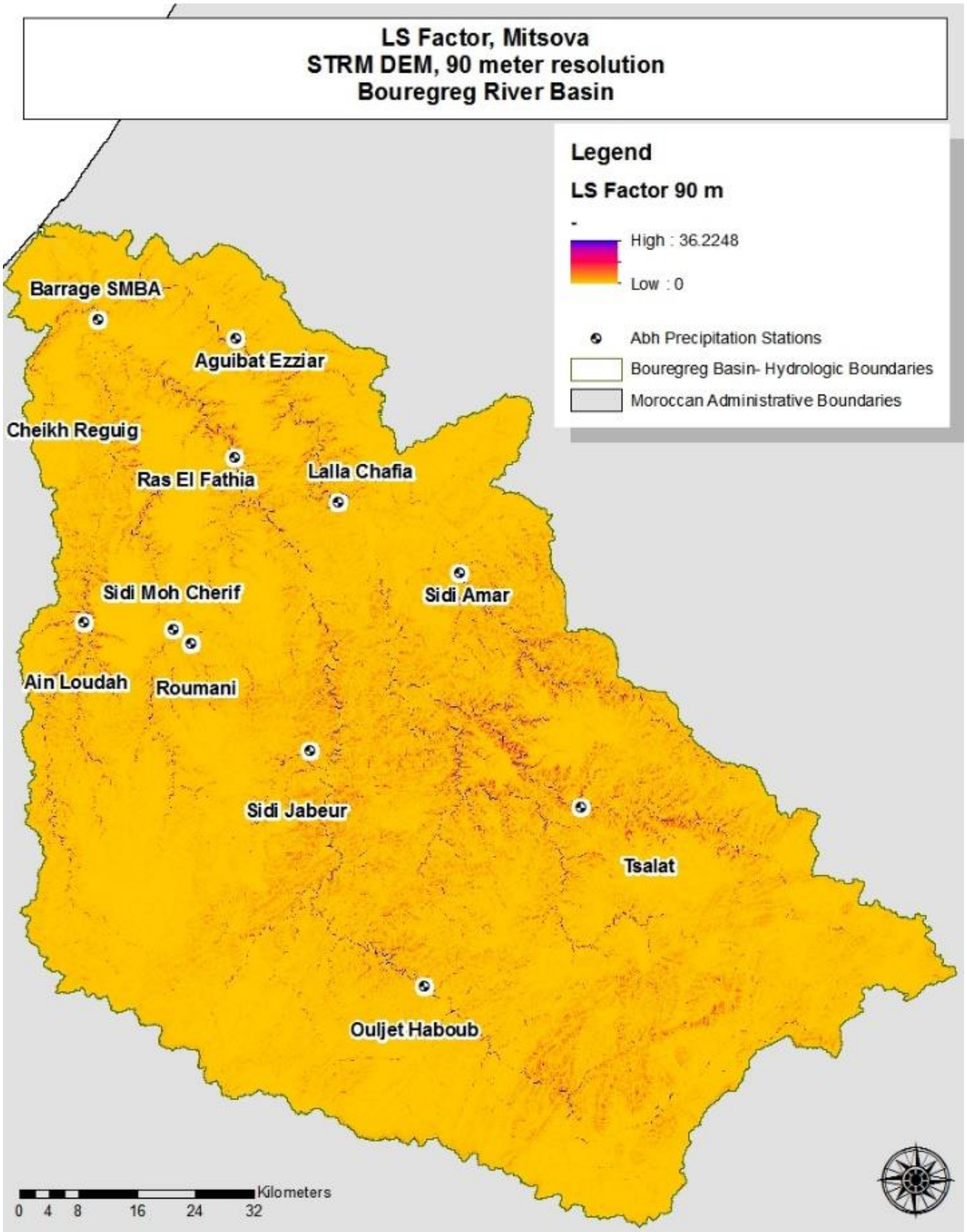
Stations recording storm events over 100 millimeters in a single day tended to produce higher R factor values at the annual temporal scale, which may be due to the fact that the R factor is sensitive to intense storm events. For example, as illustrated by Figure 34, torrential rainfall during moderate to dry periods, such as that of Cheikh Reguig in March of 1996, yielded higher R values than the highest monthly precipitation values in all stations for the entire study period.

Figure 23: LS Factor Results for the 30 meter DEM Used in this Study



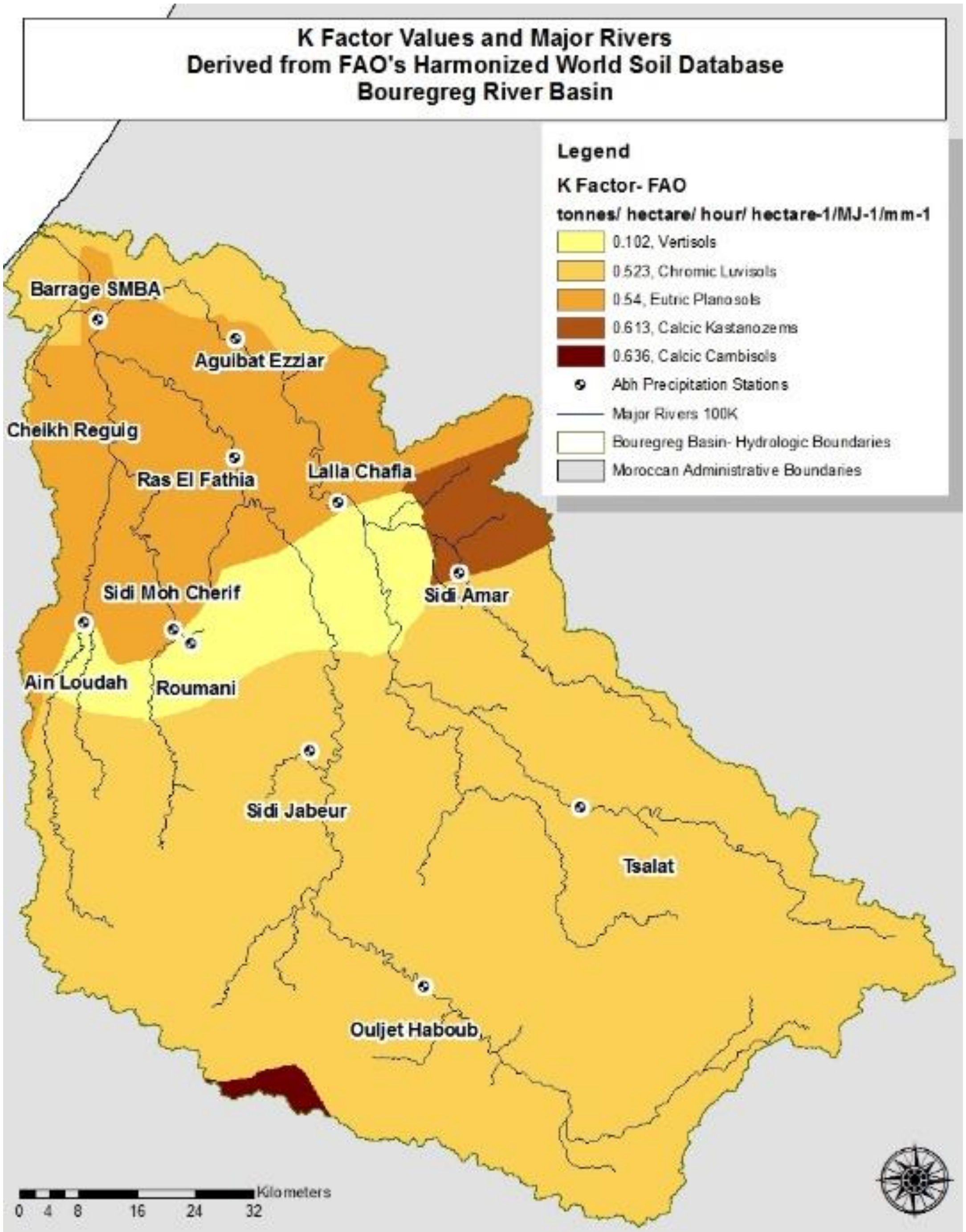
Source: Map created by Madeline Clark using data from 30 meter Digital Elevation Model, Shuttle Radar Topography Mission, accessed August 25, 2014 and February 15, 2015 at http://earthexplorer.usgs.gov/.

Figure 24: LS Factor Results for the 90 meter DEM Used in this Study



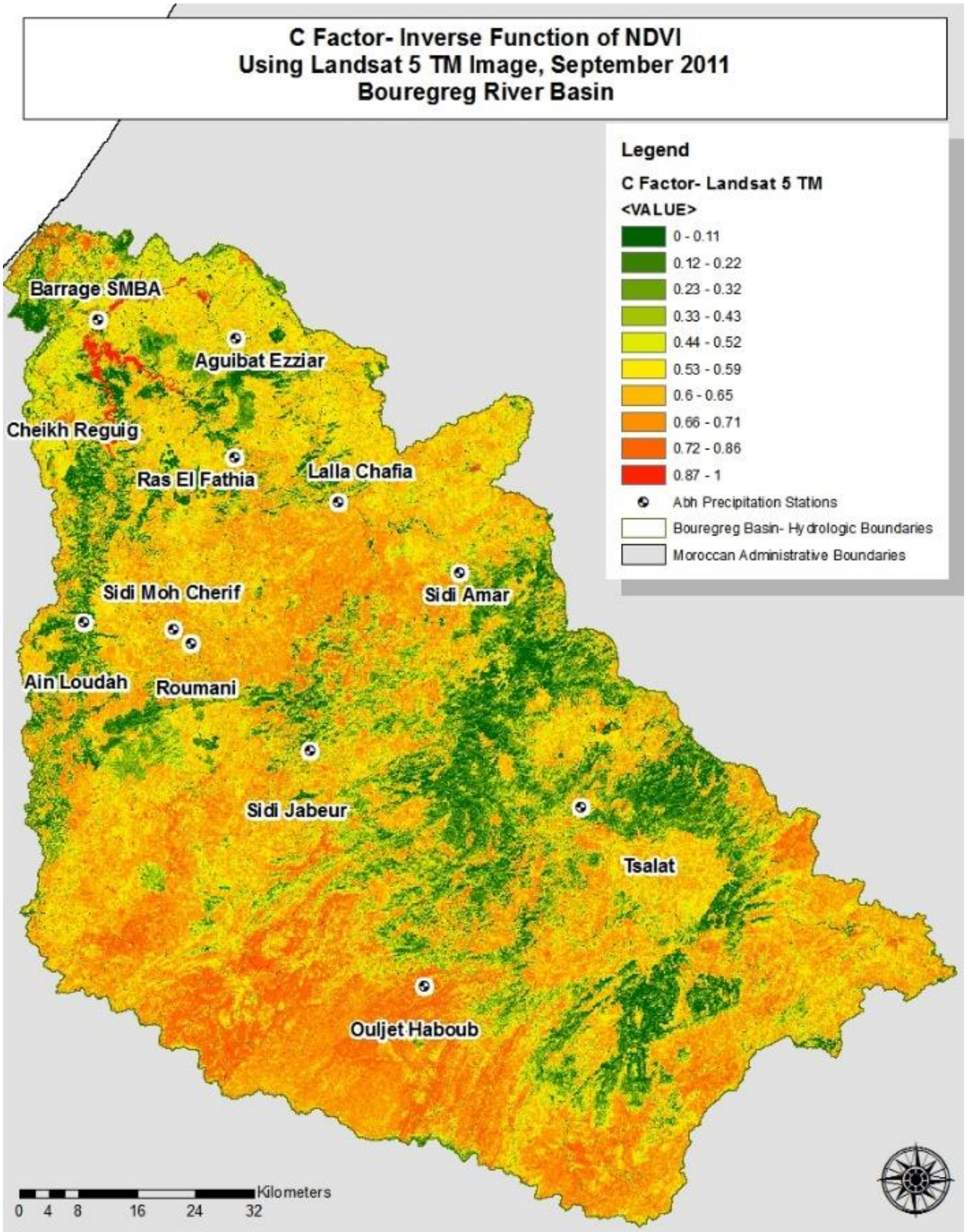
Source: Map created by Madeline Clark using data from 90 meter Digital Elevation Model, Shuttle Radar Topography Mission, accessed August 25, 2014 and February 15, 2015 at http://earthexplorer.usgs.gov/.

Figure 25: K Factor Value Distribution in the Bouregreg Basin



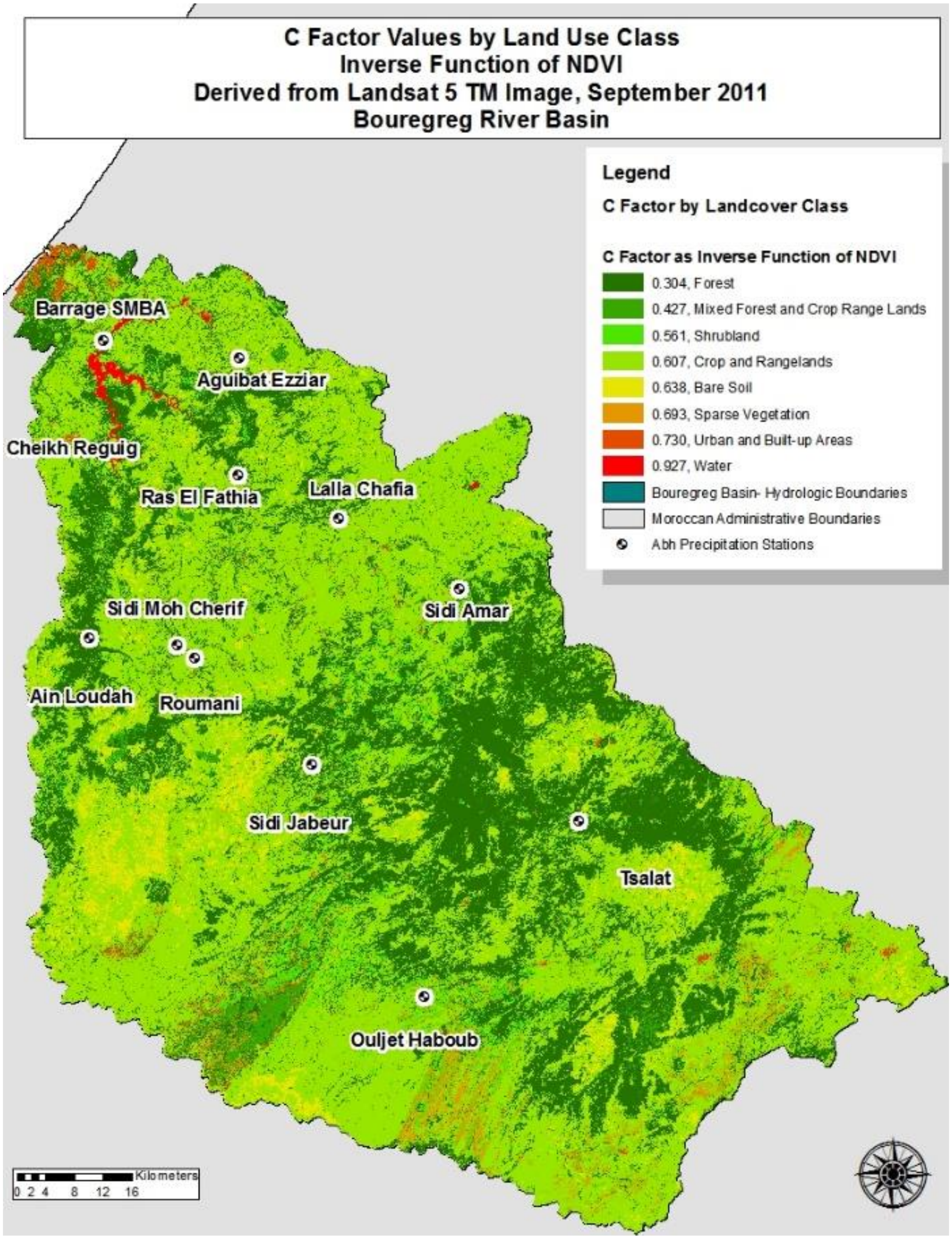
Source: Map created by Madeline Clark using data from Harmonized World Soil Database v1.2 in G. Fischer, F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, and D. Wiberg, "Global Agro-ecological Zones Assessment for Agriculture" (Laxenburg: IIASA and FAO, 2008), accessed August 20, 2015 at http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/.

Figure 26: C Factor Geographic Distribution in Raw Form



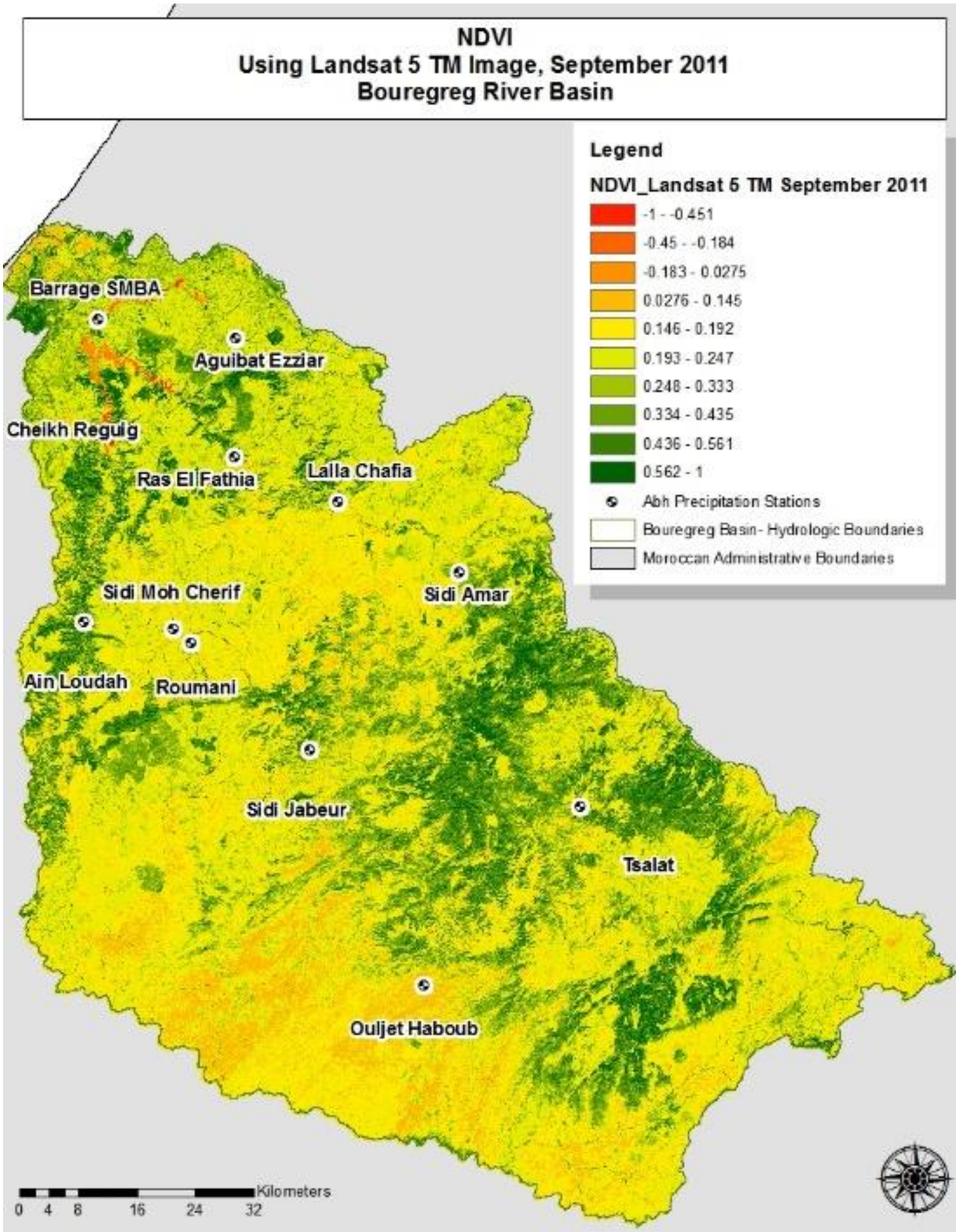
Source: Map created by Madeline Clark using data from Landsat 5 TM Images 2021037, 2022036, 2022037, September 5 and 14, 2011, Shuttle Radar Topography Mission, accessed May 23, 2015 at http://earthexplorer.usgs.gov/.

Figure 27: C Factor Geographic Distribution by Land Use Class



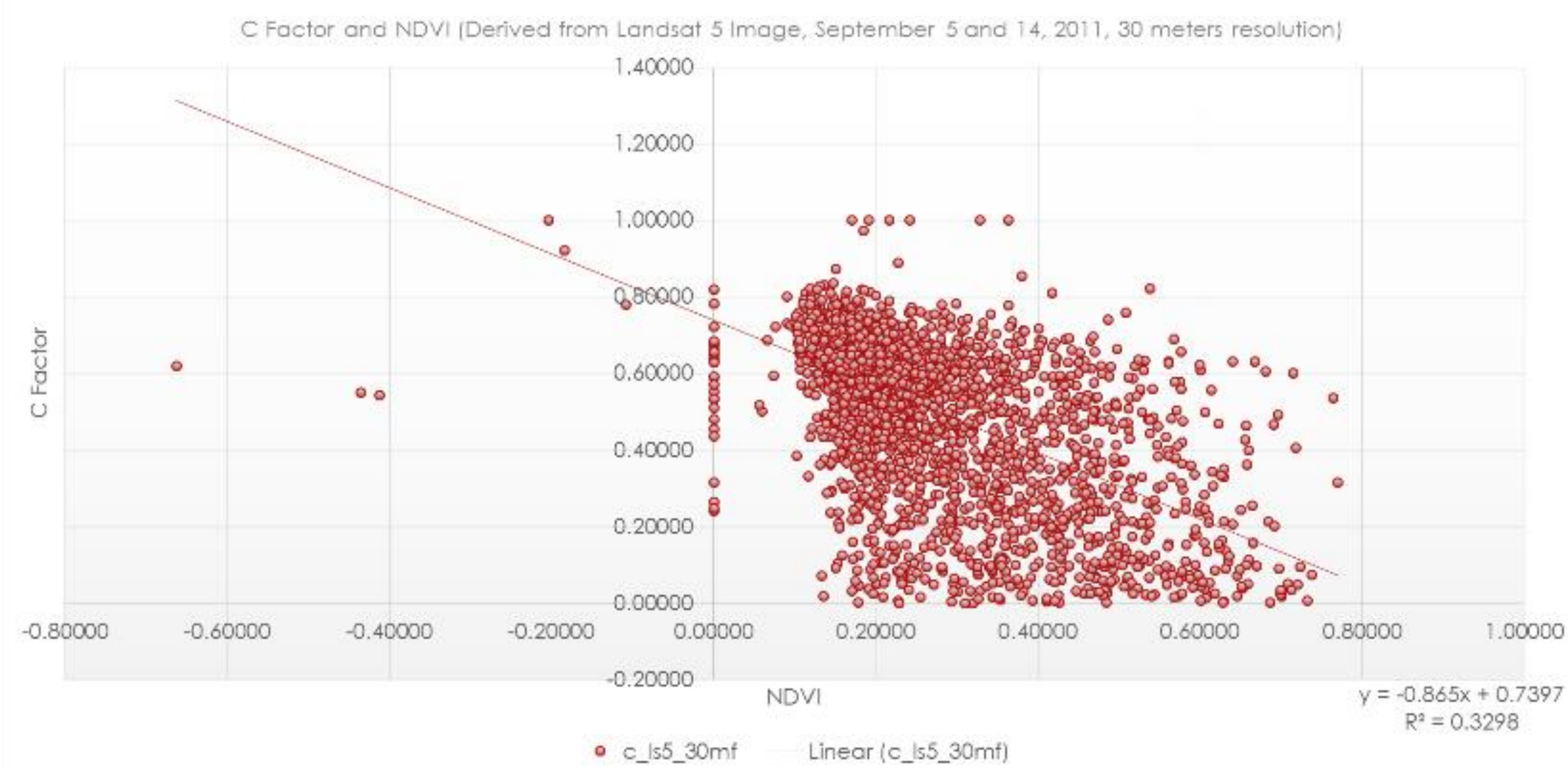
Source: Map created by Madeline Clark using data from Landsat 5 TM Images 2021037, 2022036, 2022037, September 5 and 14, 2011, Shuttle Radar Topography Mission, accessed May 23, 2015 at http://earthexplorer.usgs.gov/.

Figure 28: Distribution of NDVI Values in the Bouregreg Basin



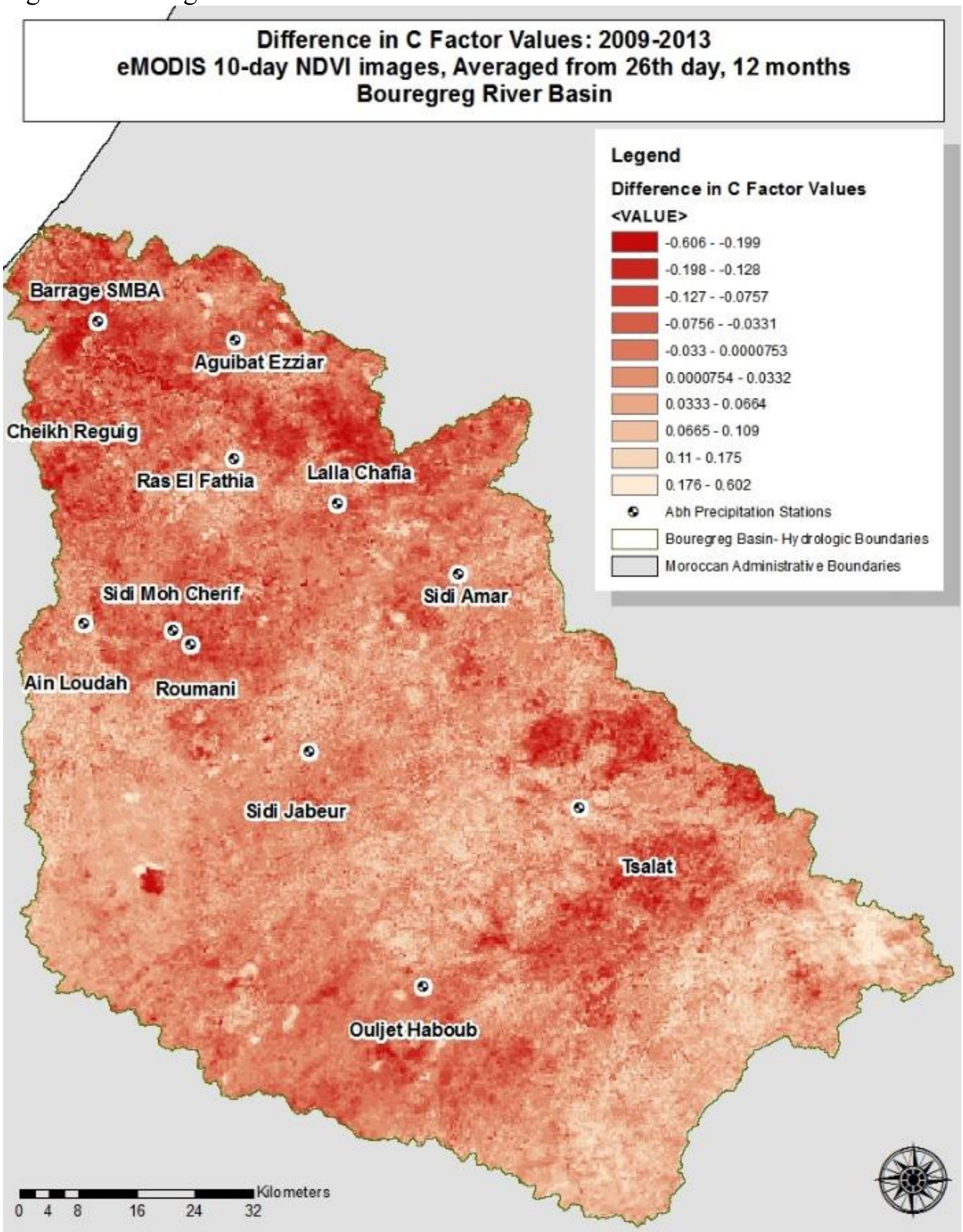
Source: Map created by Madeline Clark using data from Landsat 5 TM Images 2021037, 2022036, 2022037, September 5 and 14, 2011, Shuttle Radar Topography Mission, accessed May 23, 2015 at http://earthexplorer.usgs.gov/.

Figure 29: Plot of NDVI and C Factor Values



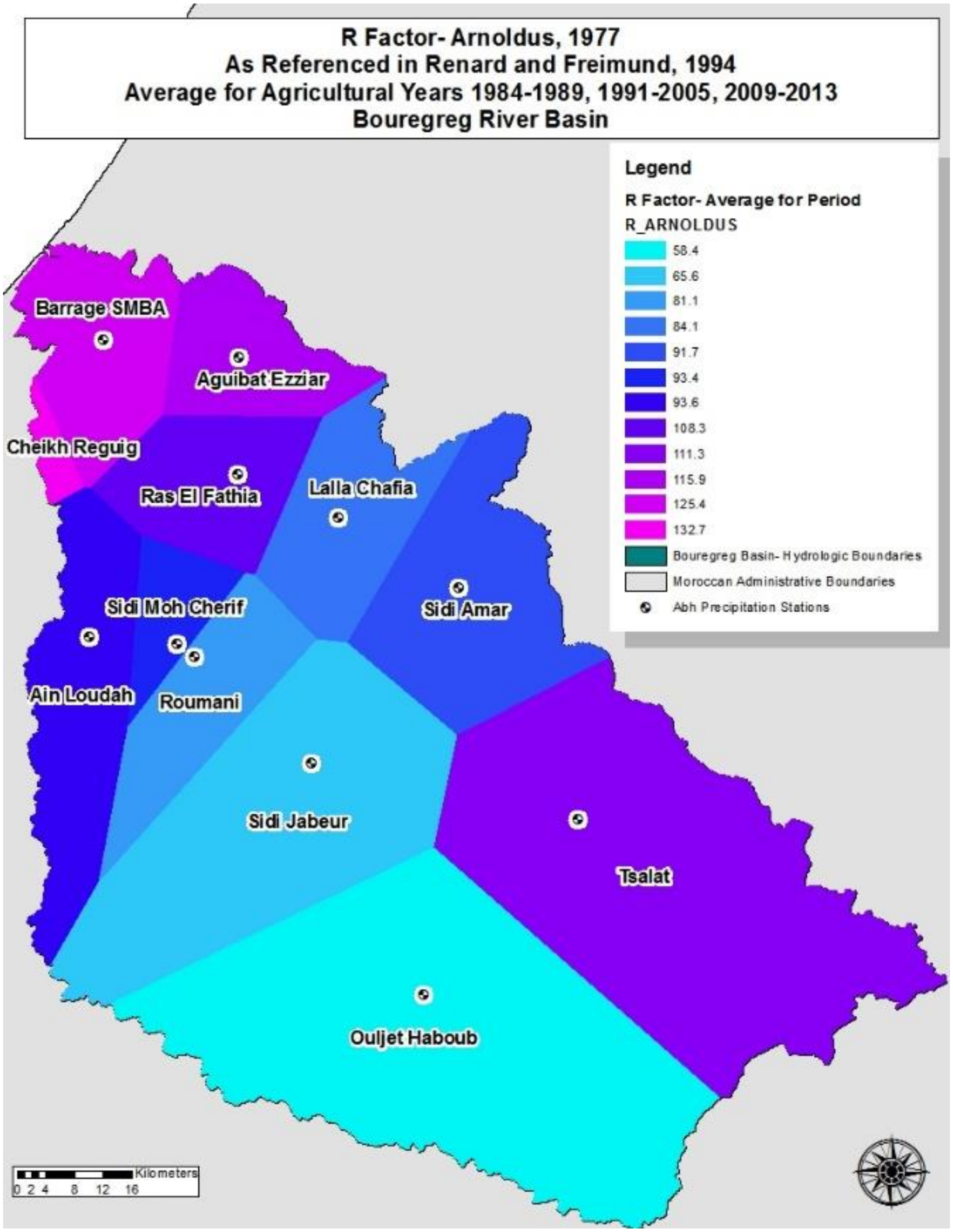
Source: Generated by Madeline Clark using data from Landsat 5 TM Images 2021037, 2022036, 2022037, September 5 and 14, 2011, Shuttle Radar Topography Mission, accessed May 23, 2015 at http://earthexplorer.usgs.gov/.

Figure 30: Changes in C Factor Values for 2009-2013



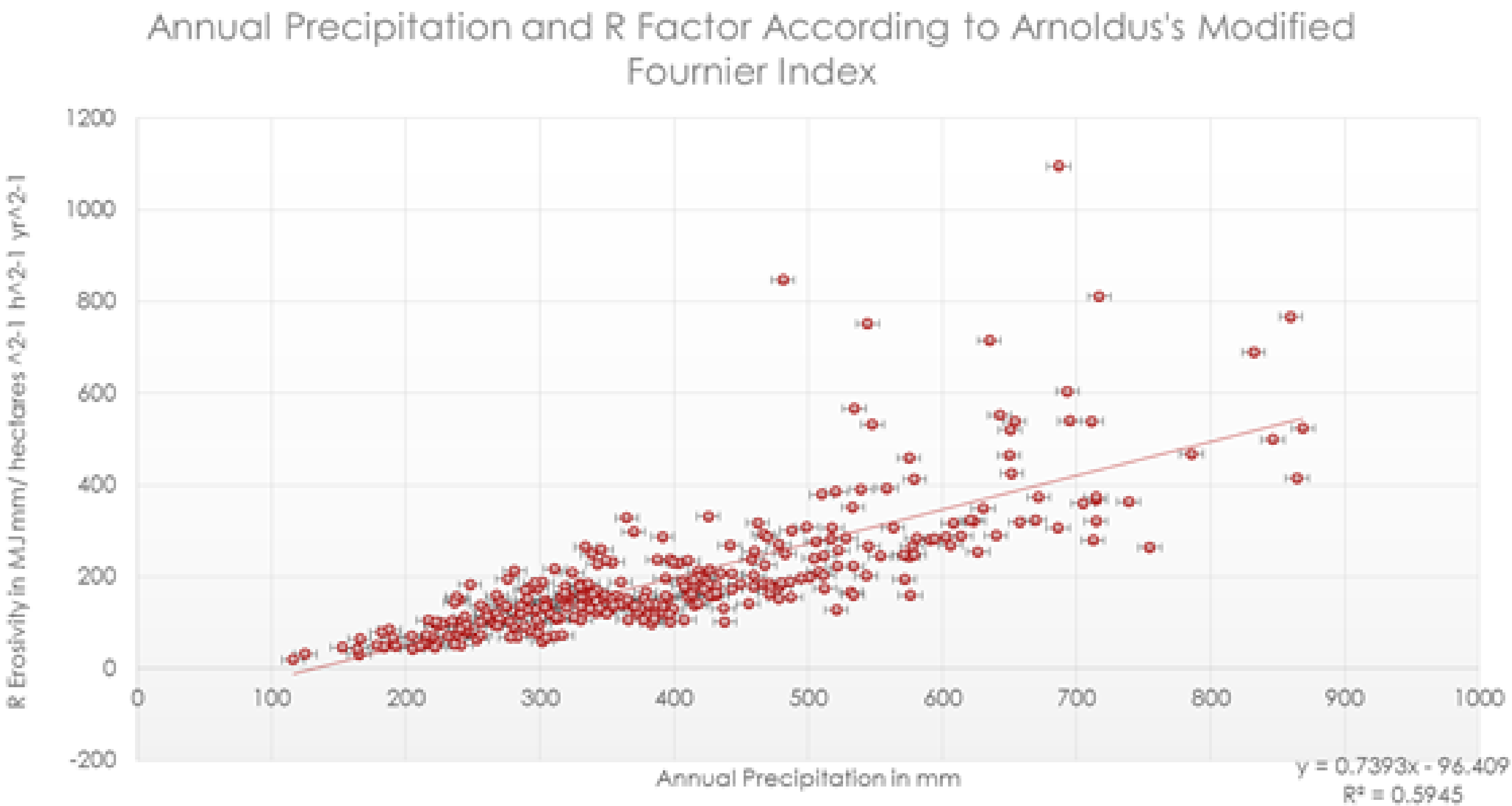
Source: Map created by Madeline Clark using data from Landsat 5 TM Images 2021037, 2022036, 2022037, September 5 and 14, 2011, Shuttle Radar Topography Mission, accessed May 23, 2015 at http://earthexplorer.usgs.gov/.

Figure 31: Interpolated R Factor Values Using Thiessen Polygon Method



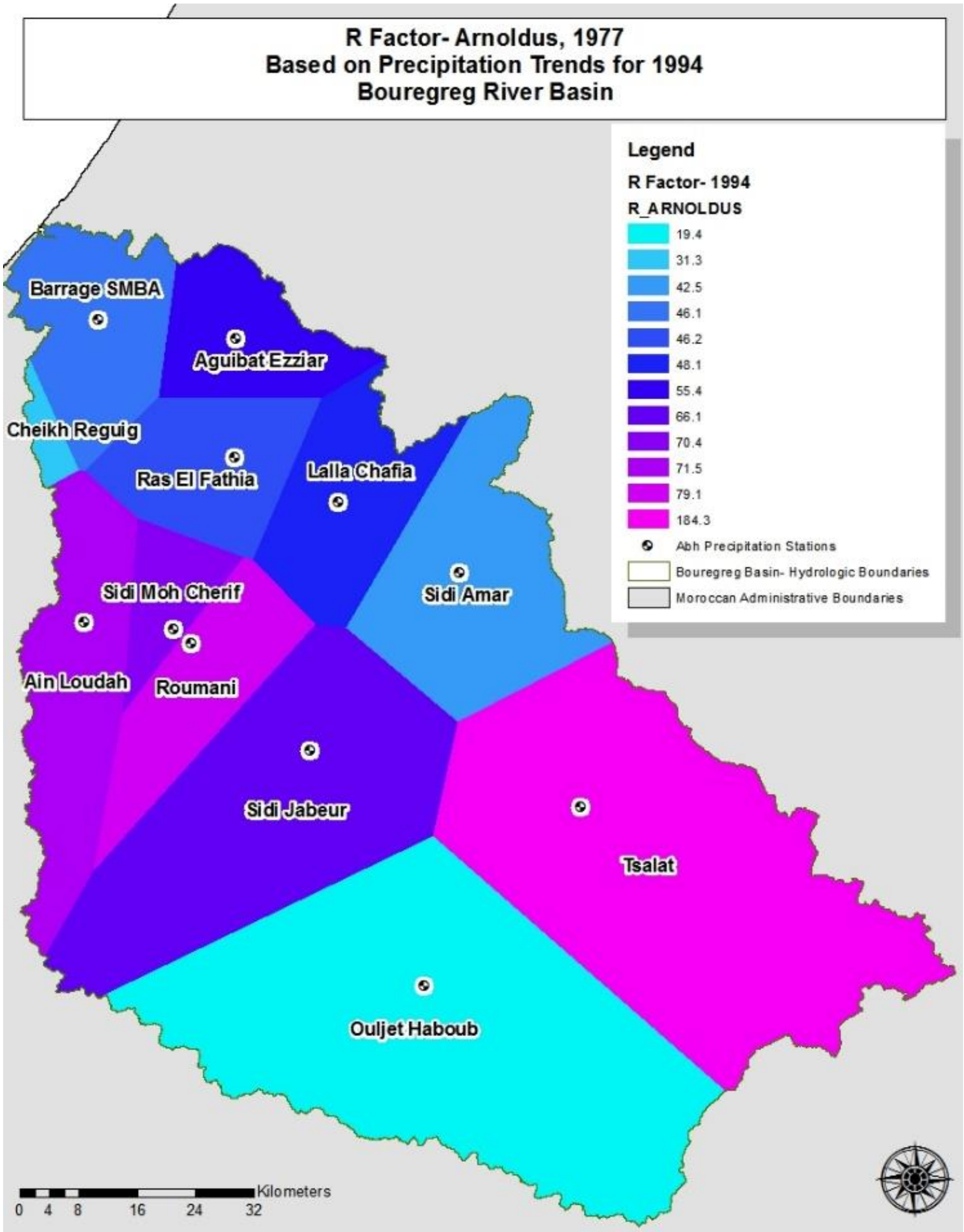
Source: Map generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015; Rivers and Bouregreg hydrological boundaries created using 30 meter STRM DEM.

Figure 32: Plot of Annual Precipitation and R Factor Values



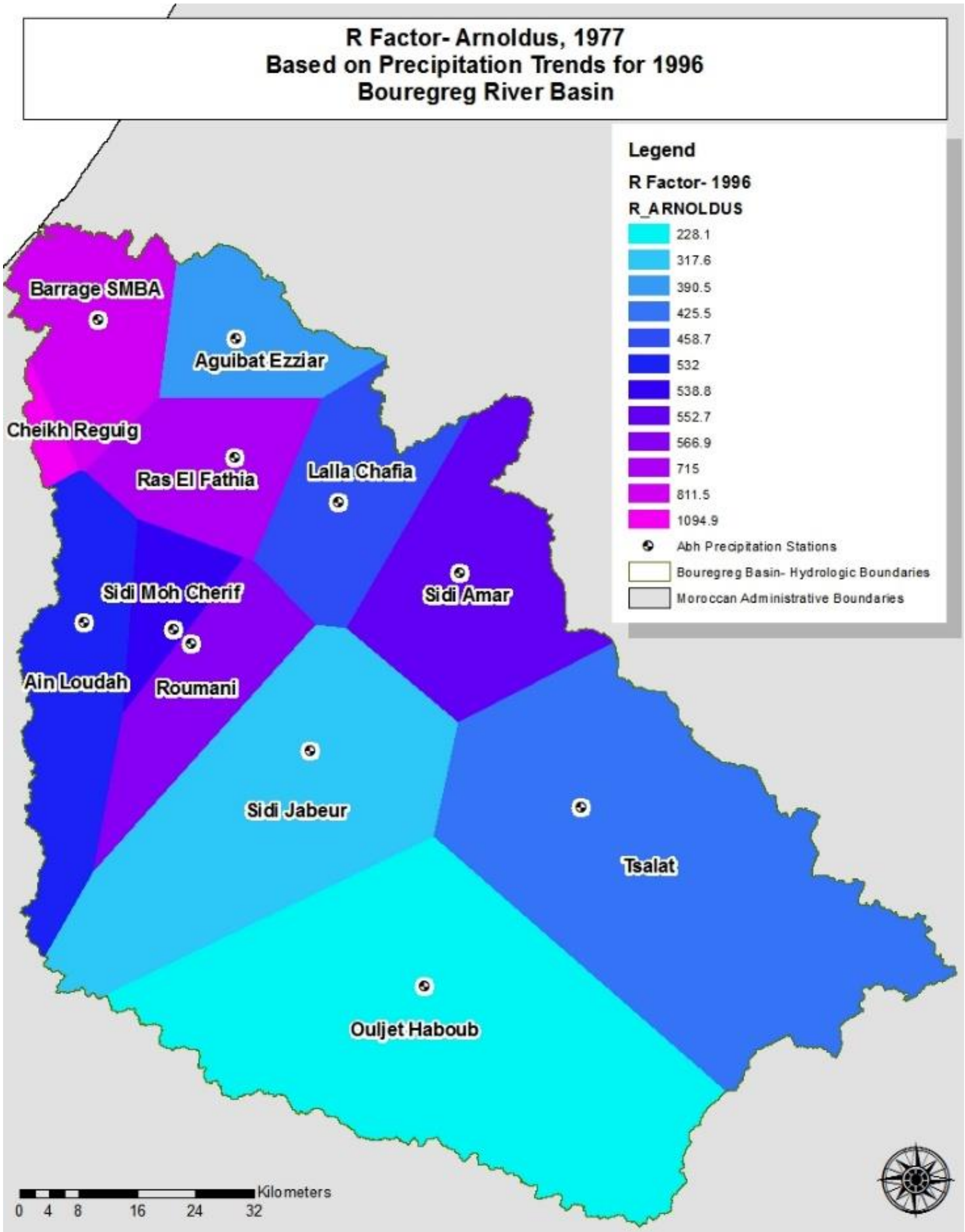
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015; Rivers and Bouregreg hydrological boundaries created using 30 meter STRM DEM.

Figure 33: R Factor Values for 1994



Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015; Rivers and Bouregreg hydrological boundaries created using 30 meter STRM DEM.

Figure 34: R Factor Values for 1996



Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015; Rivers and Bouregreg hydrological boundaries created using 30 meter STRM DEM.

RUSLE RESULTS BY SCENARIO

Predicted soil loss rates varied considerably over the 15 Scenarios. Across results, soil loss rates were higher along river beds. LS and K factor values influenced the distribution of values, whereas R factor values seemed to influence the intensity of values. The C Factor had a moderate influence on both the magnitude and spread of results, but a higher resolution longitudinal dataset should be used in order to further explore its effect on predicted erosion rates. Because the resolution of datasets varied between 30 and 500 meters, moderate bias was introduced into the results. Using datasets with an identical, 30 meter or higher resolution to derive RUSLE factors would remove this bias and improve the accuracy and reliability of predictions.

Figures 35 and 36 display the results for the 30 and 90 meter scenarios, which examined variation in the resolution of the DEM used to derive the LS factor. Erosion rates in the 30 meter condition ranged from 0 to 10,356 tons/hectare/year. For the 90 meter condition, soil loss rates ranged from 0 to 1,282.47 tons/hectare/year. The difference in magnitude between the 30 and 90 meter scenarios is consistent with the results of Gardner et al. regarding the sensitivity of RUSLE results to data resolution.

Tables 21 and 22 display the percentage of each erosion risk class for the 30 and 90 meter resolution conditions. In the 30 meter resolution scenario, the model detected minimal (0-5 tons/hectare/year) erosion risk for approximately 98 percent of the Basin, where the 90 meter resolution scenario detected minimal erosion risk for about 82 percent of the Basin. Low erosion risk (6-15 tons/hectare/year) were detected in about two percent of the Basin for the 30 meter condition, and about four percent of the Basin for the 90 meter scenario. Moderate erosion risk (15-25 tons/hectare/year) was detected in 0.10 percent of the Basin for the 30 meter scenario, and about two percent of the Basin for the 90 meter scenario.

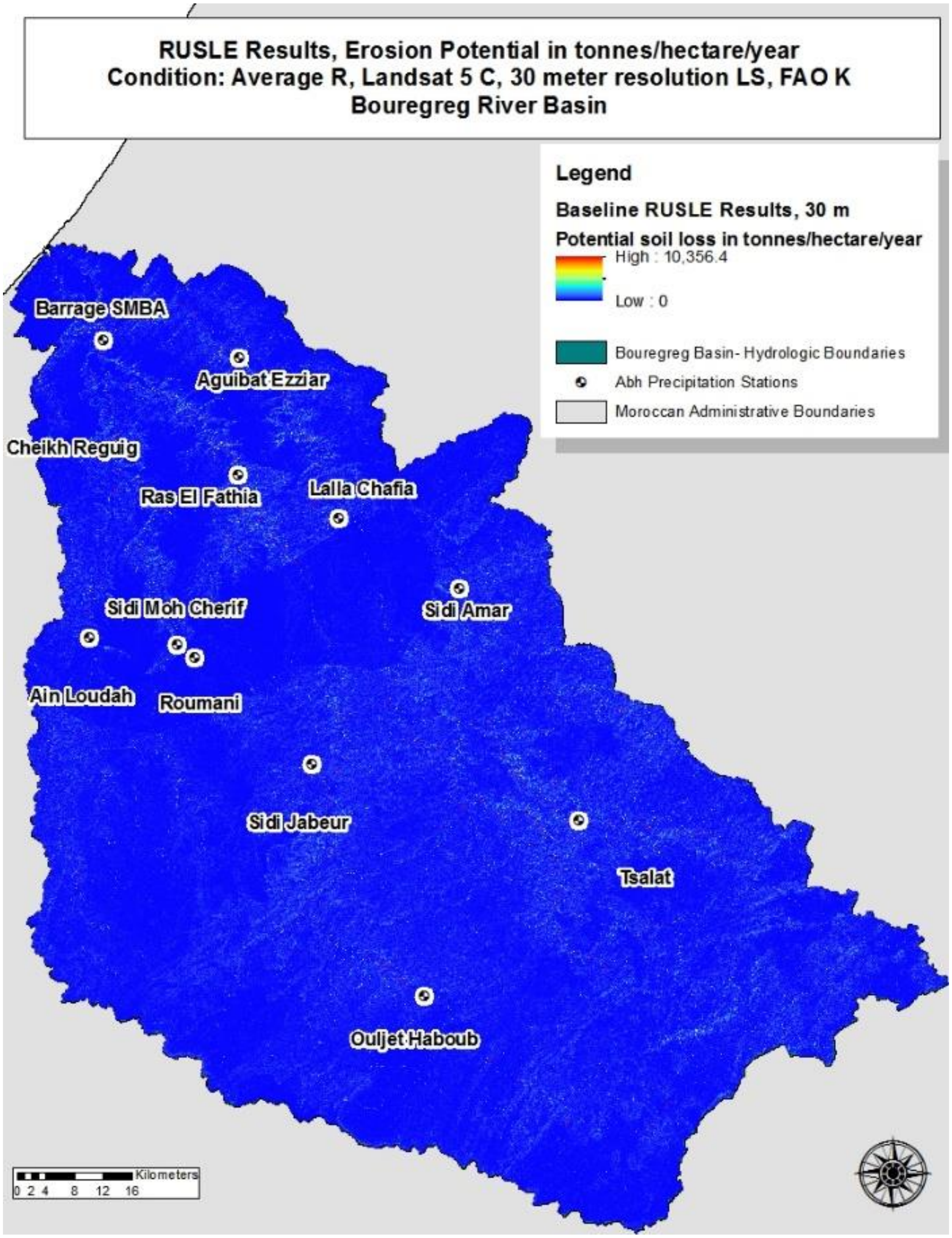
The spread of severe (26-50 tons/hectare/year) and extreme (greater than 50 tons/hectare/year) erosion risk was greater in the 90 meter condition. Where the 90 meter resolution condition detected severe and extreme erosion in roughly four and eight percent of the Basin, respectively, the 30 meter condition detected both of these risk classes in less than one percent of the Basin. This difference in spread may not be advantageous; rather, it may just reflect the coarser resolution of the 90 meter scenario. The 90 meter resolution scenario tended to detect erosion in coarse clusters around large features like channels, suggesting that 90 meter resolution data is not sensitive to sheet or interill erosion and not suitable for use in RUSLE modeling. These results indicate that a 30 meter resolution or higher may be the most appropriate resolution for datasets when modeling sheet or interrill erosion, which is also consistent with the conclusions of Gardner et al.

As displayed in Figure 37, the datasets of the 30 meter condition caused the model to predict 4,108.85 more soil lost in tons/hectare/year. This metric indicates a general increase of the power of resolution in the LS factor when moving from 90 to 30 meters. To this effect, the 90 meter scenario predicted 673.494 less soil lost in tons/hectare/year. This underestimation occurred in the most sensitive areas. If Morocco uses 90 meter resolution data to estimate soil loss, values would be lower, which could lead to insufficient attention to the rates of soil loss in vulnerable areas that exceed tolerable, or even severe rates. Stakeholders would be unprepared to respond to extreme flood events and this could lead to the unnecessary loss of human life and property.

In Scenarios Three to Nine (see Table 18), the role of variability in the R Factor was examined. There was a difference of 61,900 tons/hectare/year in maximum potential soil erosion rate between the highest and lowest R factor value scenarios, or 1996 and 1994. Differences between scenario outputs indicated that rainfall variability and intensity influenced predicted average soil erosion.

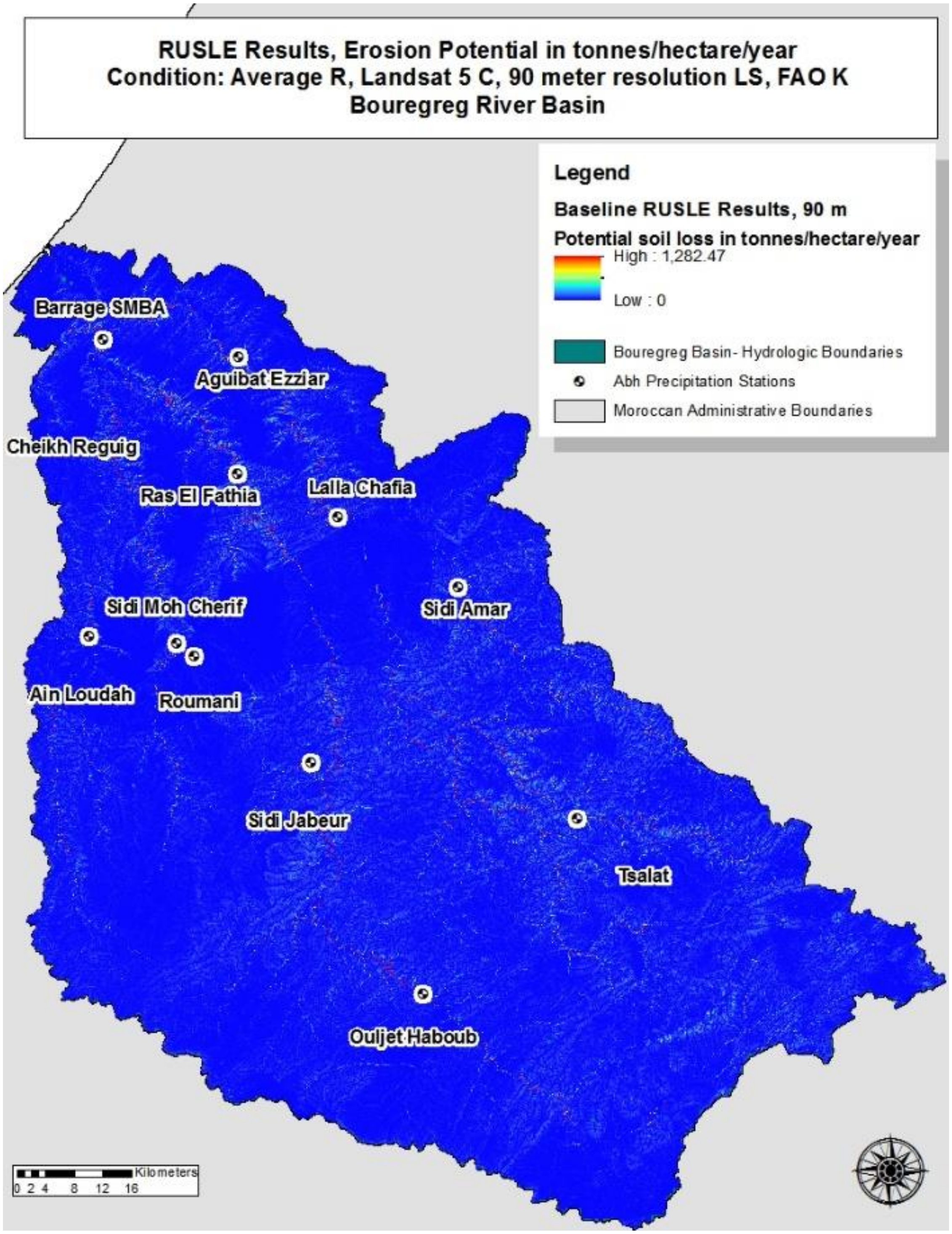
Variability in vegetative cover was examined in Scenarios 10-15 (see Table 18). Some increase in erosion rates occurred from 2011-2012, but differences in vegetative cover may co-vary with precipitation yields. Keeping all other factors constant, there was a change of 97 tons/hectare/year in the maximum potential erosion rate during 2009-2013. The original dataset resolution of 250 meters may have muffled results, however. Though the eMODIS dataset was used because it is easy to access and process, the resolution at 250 meters remains very coarse. To obtain full coverage of the Bouregreg Basin, three panels of 30 meter resolution Landsat data are required. Obtaining these images in a longitudinal series is difficult due to the persistence of cloud cover for the study area.

Figure 35: RUSLE Results for the 30 meter scenario



Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 36: RUSLE Results for the 90 meter scenario



Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Table 21: RUSLE Results for the 30 Meter Scenario

Potential Erosion Rate in tons/hectares/year	Erosion Risk	Percent of Basin	Area in Hectares
0-5	Minimal	98.20%	1,050,250.41
6-15	Low	1.56%	16,673.31
16-25	Moderate	0.10%	1,041.84
26-50	Severe	0.06%	671.40
>50	Extreme	0.09%	917.10

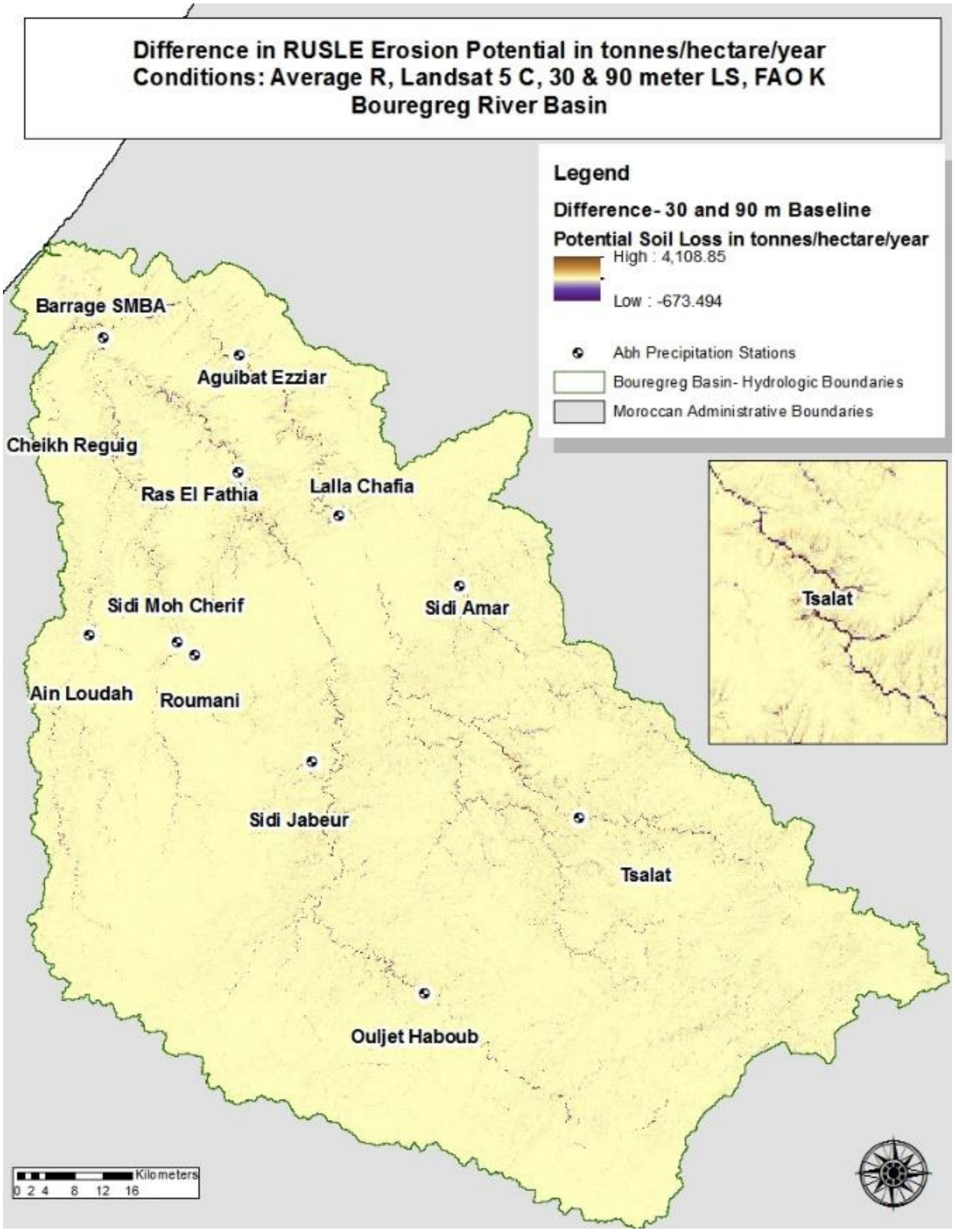
Source: Generated by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Table 22: RUSLE Results for the 90 Meter Scenario

Potential Erosion Rate in tons/hectares/year	Erosion Risk	Percent of Basin	Area in Hectares
0-5	Minimal	81.65%	117,874.71
6-15	Low	3.92%	5,655.33
16-25	Moderate	2.08%	3,000.33
26-50	Severe	3.56%	5,145.84
>50	Extreme	8.79%	12,689.28

Source: Generated by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 37: Difference in RUSLE Results, 30 and 90 Meter Scenarios



Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

RESULTS BY HYDROLOGIC UNIT

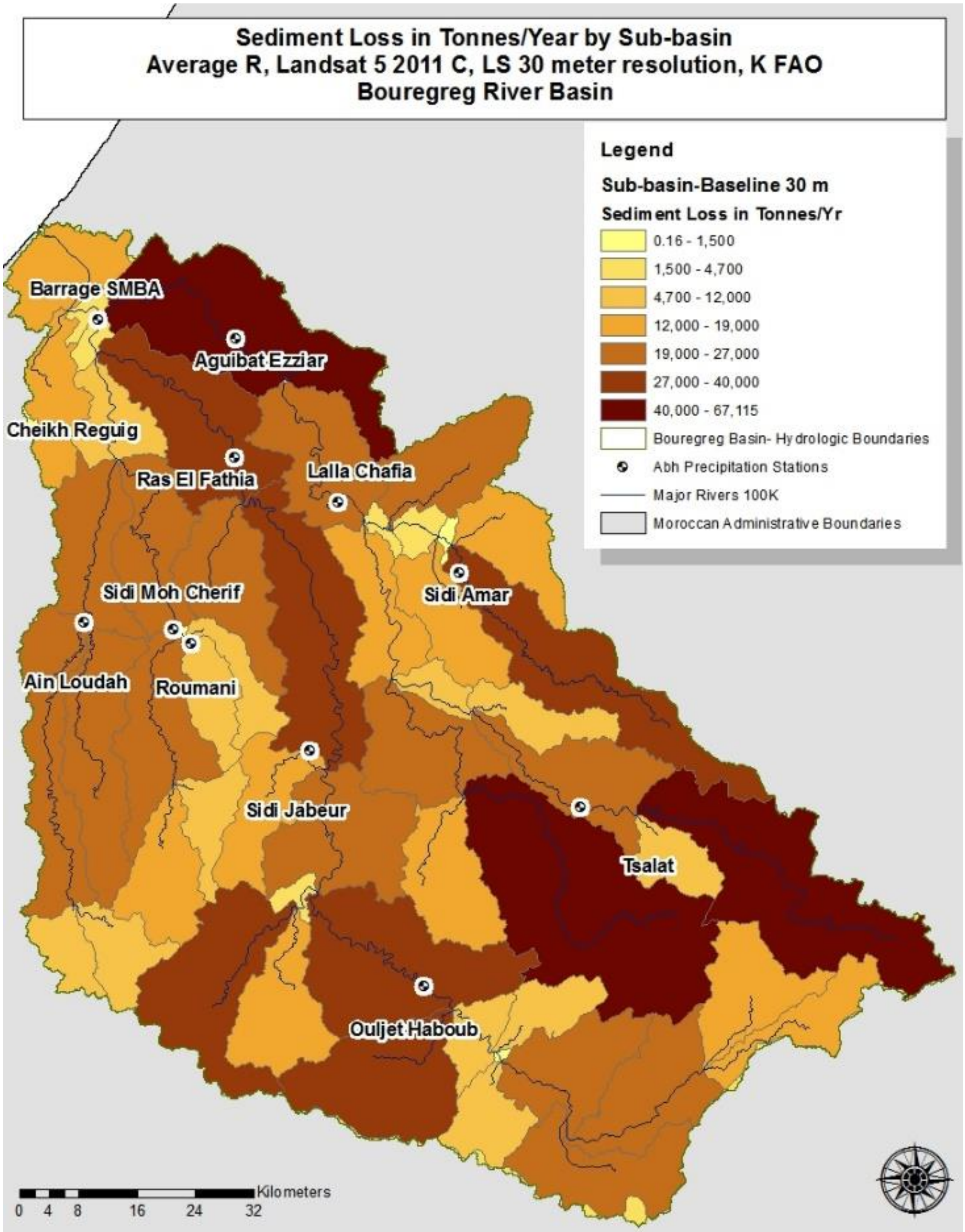
The manner in which raw results are aggregated influenced the magnitude of the RUSLE scenarios' predicted erosion rates. Figures 38 and 39 display RUSLE results for the 30 meter scenario agreggated by sub-basin and watershed, respectively. In the 30 meter scenario, results grouped by sub-basin yielded a net sediment loss ranging from 0.1611 to 67,115 tons of soil per year, with a mean soil loss rate between 0 and 16.84 tons/hectare/year. When grouped by watershed, sediment loss ranged from 0 to 18,285.8 tons of soil per year, with a mean soil loss rate ranging from 0 to 20.895 tons/hectare/year. There is a 48,832 difference in the magnitude of the maximum predicted erosion when moving from sub-basin to watershed aggregates, and difference in soil loss rates of more than 4 tons/hectare/year.

Grouping predicted erosion rates by watershed also affected the results of the 90 meter scenario. Figures 40 and 41 display RUSLE results for the 90 meter scenario by sub-basin and watershed, respectively. In the 90 meter scenario, sediment loss ranged from 0 to 52,795 tons of soil per year, with a mean soil loss rate between 0 and 3.353 tons/hectare/year when aggregated by sub-basin. When aggregated by watershed, sediment loss ranged from 0 to 19,505.2 tons of soil per year, with a mean soil loss rate between 0 and 30.378 tons/hectare/year. There was a significant difference in the net average soil loss between the sub-basin and watershed aggregates, or in this case 52,792 tons of soil per year. Methods for deriving aggregate soil loss rates by geographical and administrative zones should focus on aggregating results by watershed or micro-catchments according to these results.

When aggregated by watershed, the 30 meter condition displayed three erosion risk classes, or minimal (0-5 tons/hectare/year lost), low (5-15 tons/hectare/year lost), and moderate (15-25 tons/hectare/year lost). Figures 42 and 43 display the results of the 30 meter scenario reclassified by risk class for the entire basin, and for the most vulnerable watersheds. Most of the Basin does not display more than minimal risk. Watersheds at low and moderate risk tended to concentrate around the river network just upstream of the SMBA Dam on the Upper Bouregreg and Grou Rivers and near the Sidi Jabeur Gage in the central plains of the Basin.

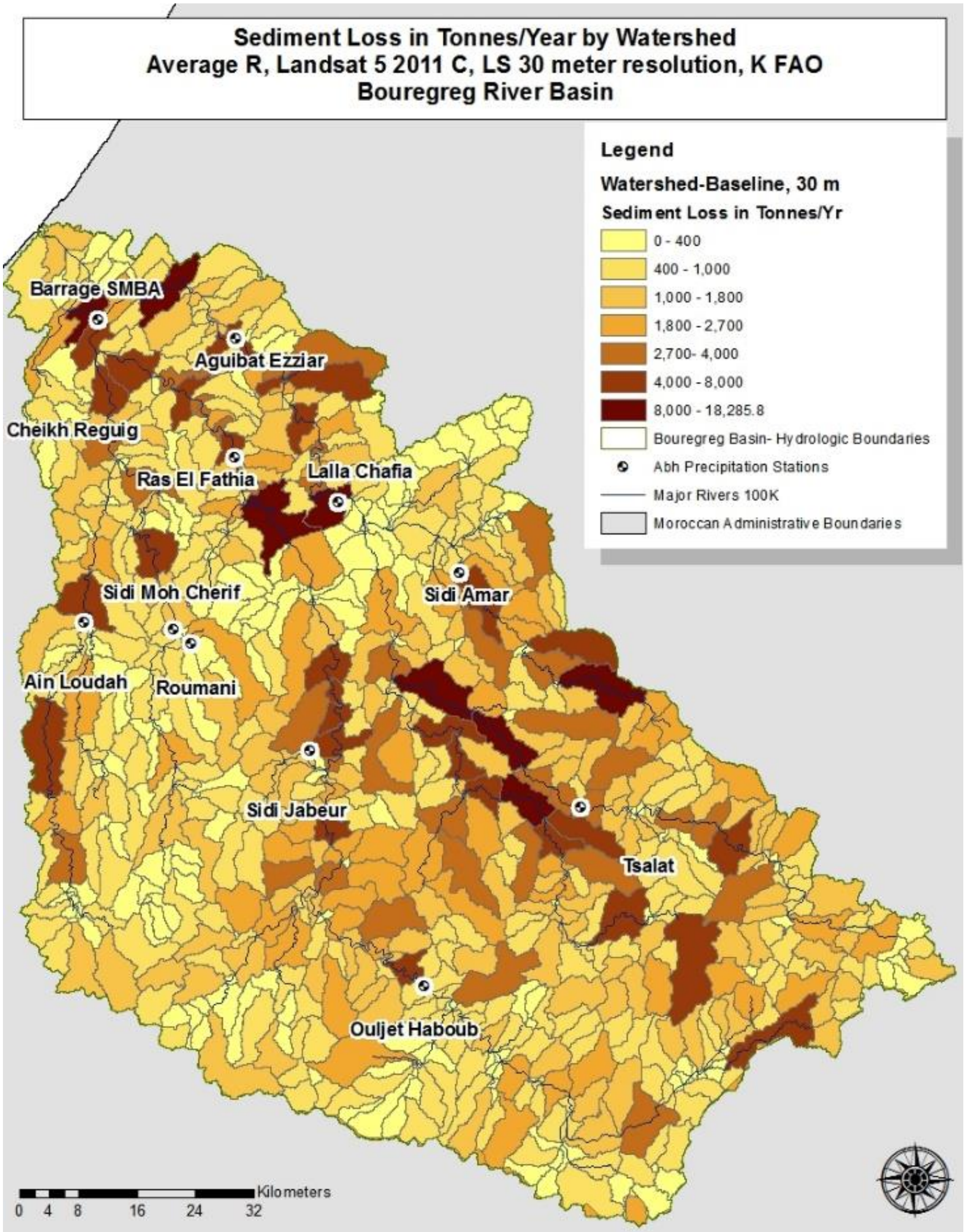
In the 90 meter condition, four risk erosion classes emerged with the addition of severe (25-50 tons/hectare/year). Figures 44 and 45 illustrate a greater proliferation of watersheds experiencing low and moderate values around the same areas that the 30 meter condition identified. Courser pixel resolution may drive the larger spread of risk classes. However, for both 30 and 90 meter scenarios (see Figures 46 and 47) moderate and severe erosion risk occur just upstream of the SMBA Dam between the Ras El Fatiha station and the dam, upstream of the Aguibat Ezziar station, and in the mountainous regions near the Tsalat station.

Figure 38: RUSLE Results by Sub-Basin for the 30 Meter Scenario



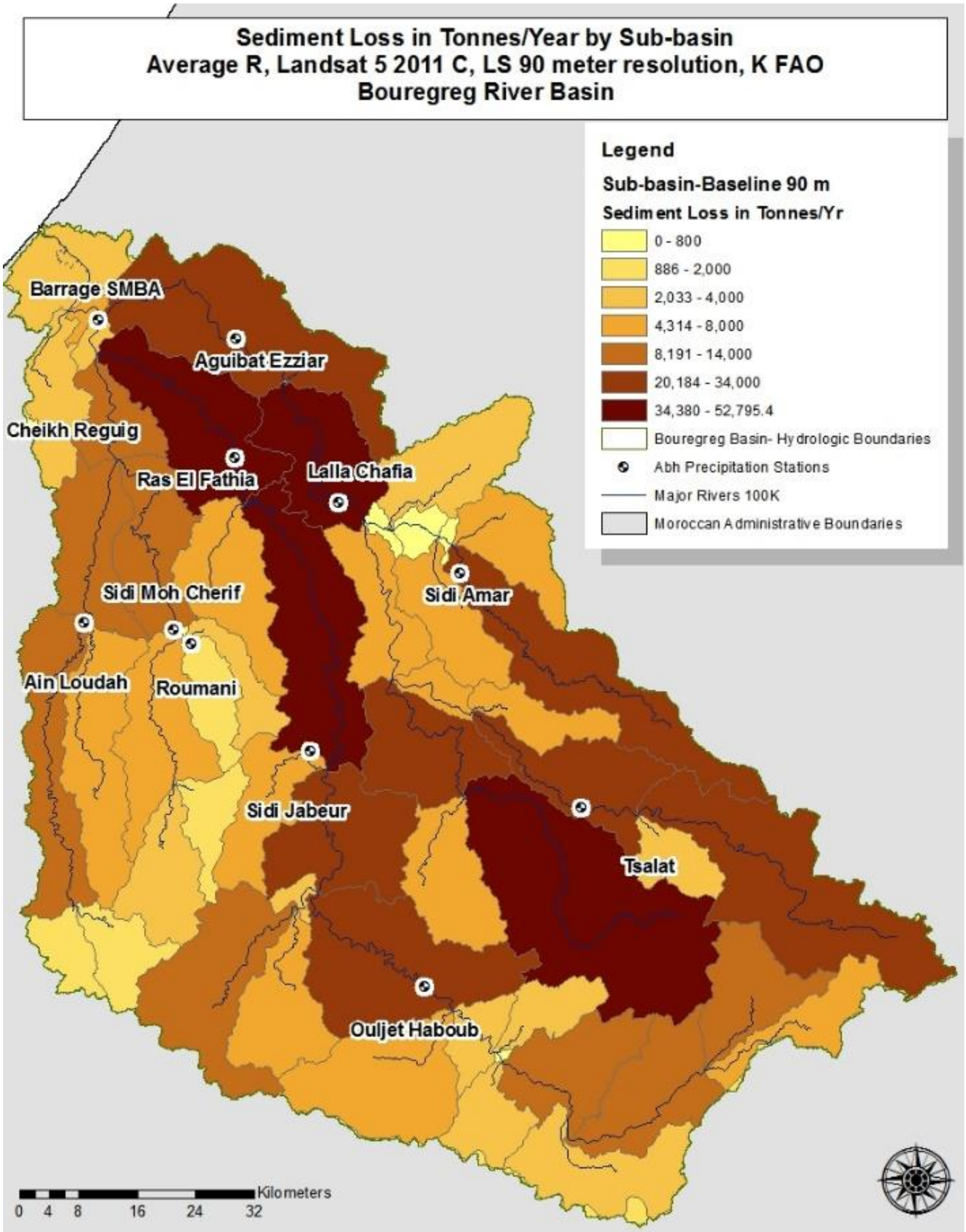
Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 39: RUSLE Results by Watershed for the 30 Meter Scenario



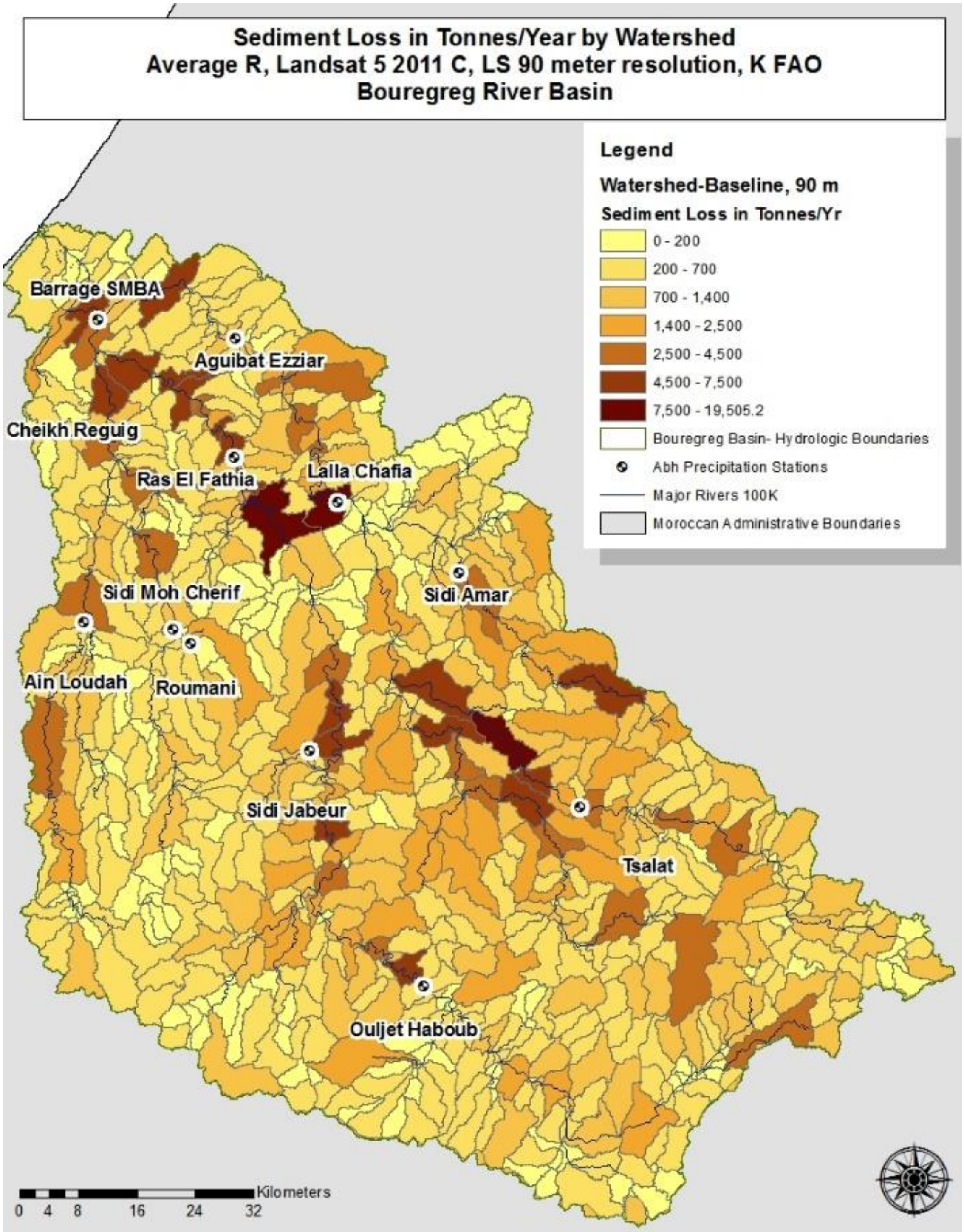
Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 40: RUSLE Results by Sub-Basin for the 90 Meter Scenario



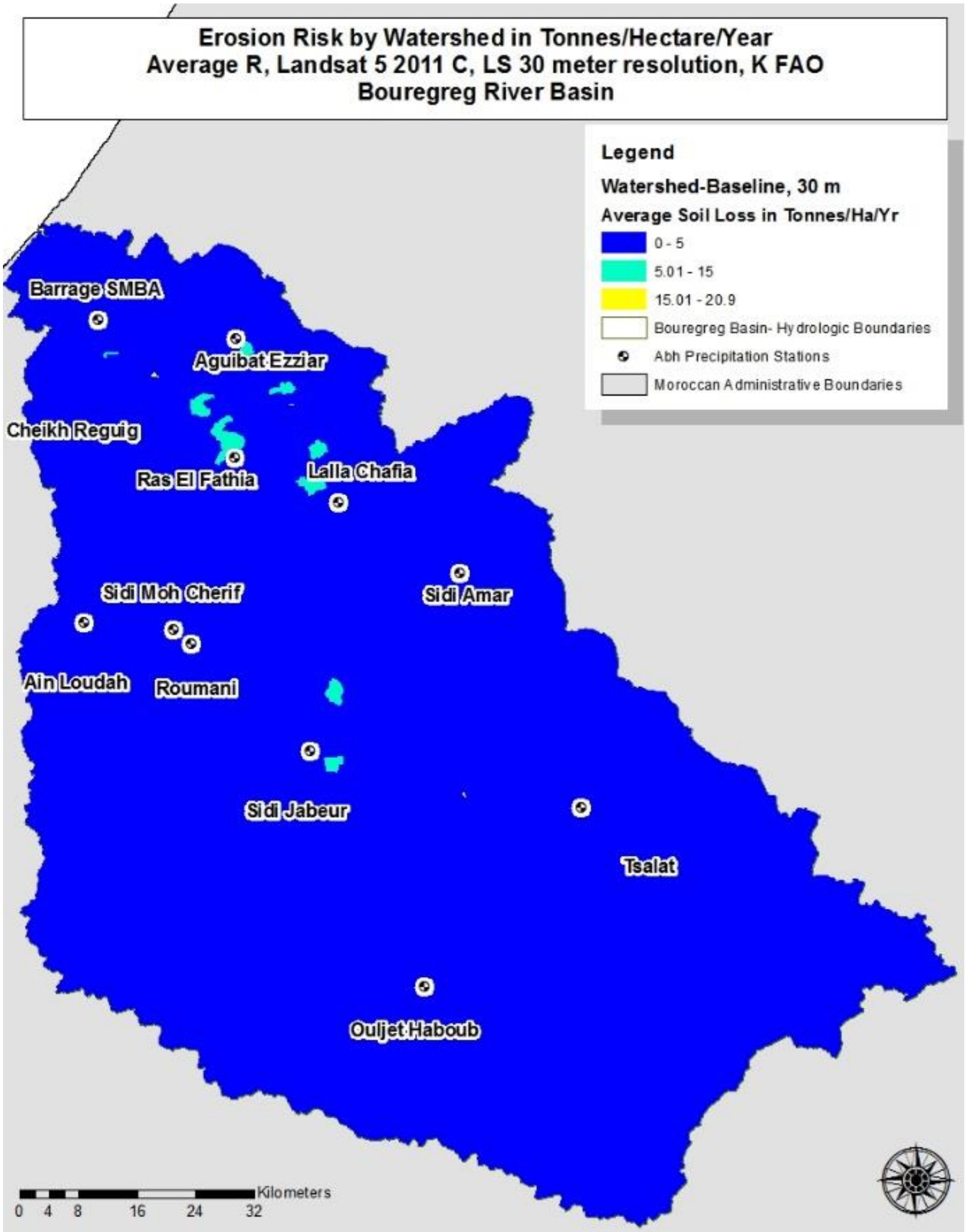
Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 41: RUSLE Results by Watershed for the 90 Meter Scenario



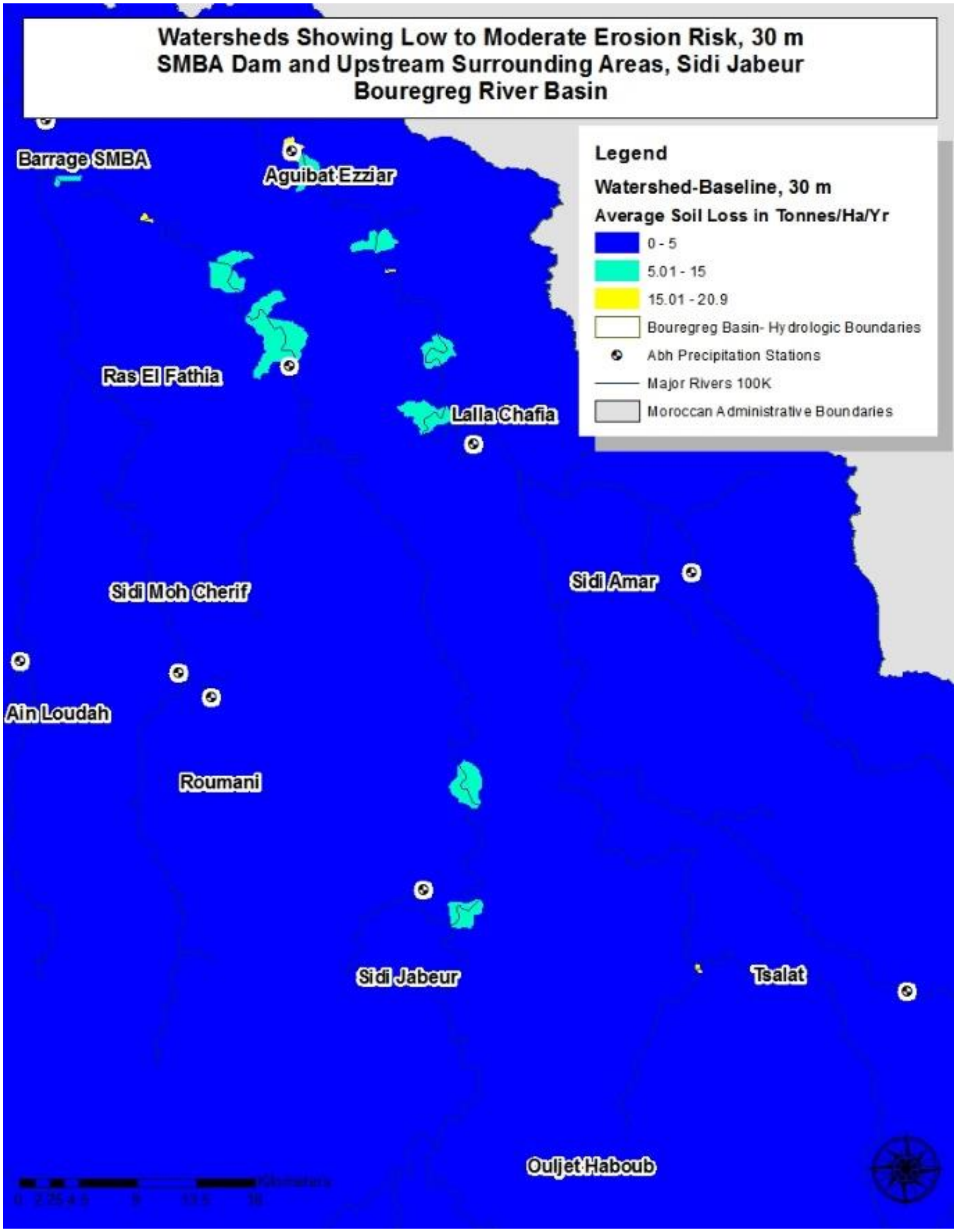
Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 42: Erosion Risk, 30 Meter Scenario, Bouregreg Basin



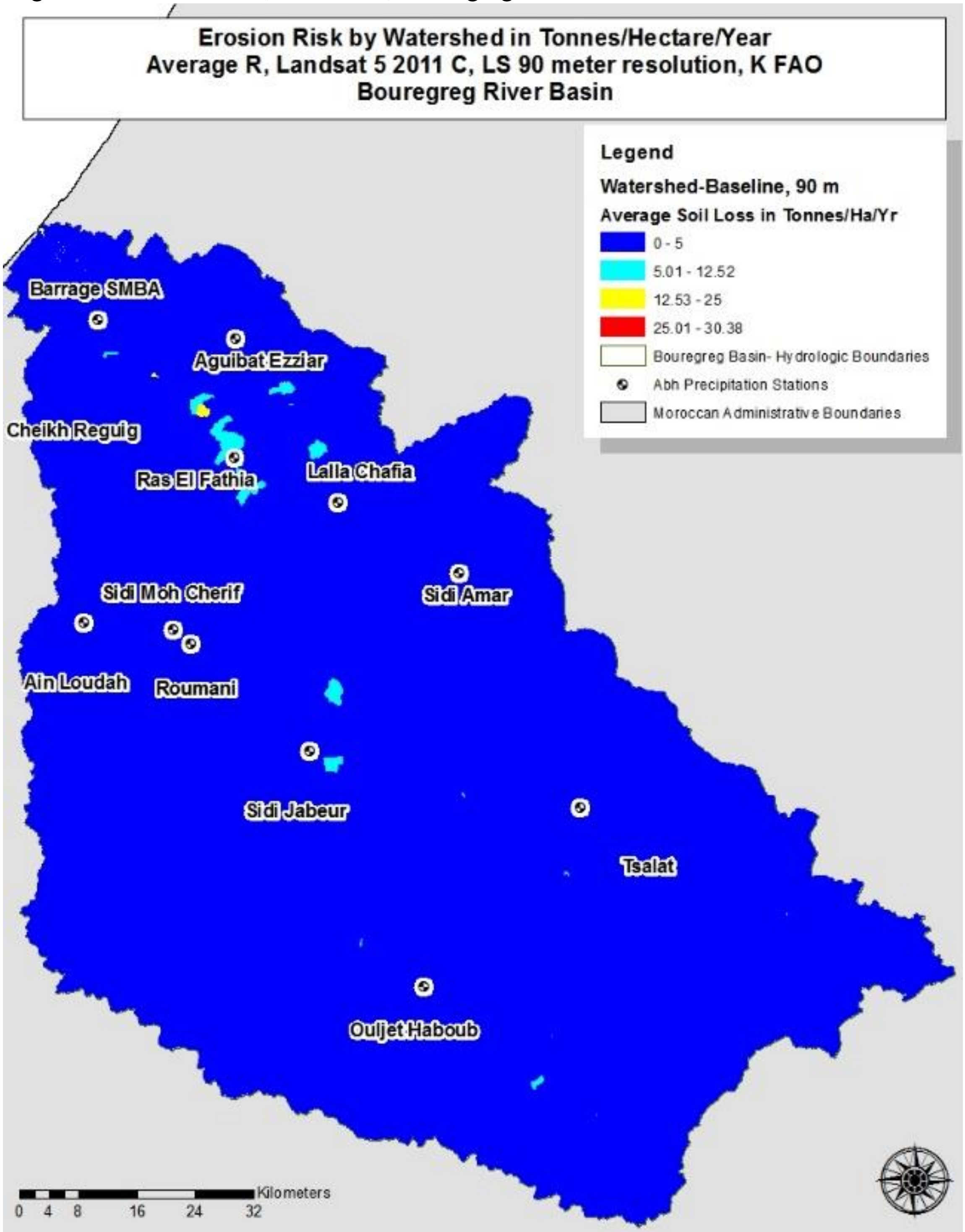
Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 43: Erosion Risk, 30 Meter Scenario, Areas near SMBA Dam



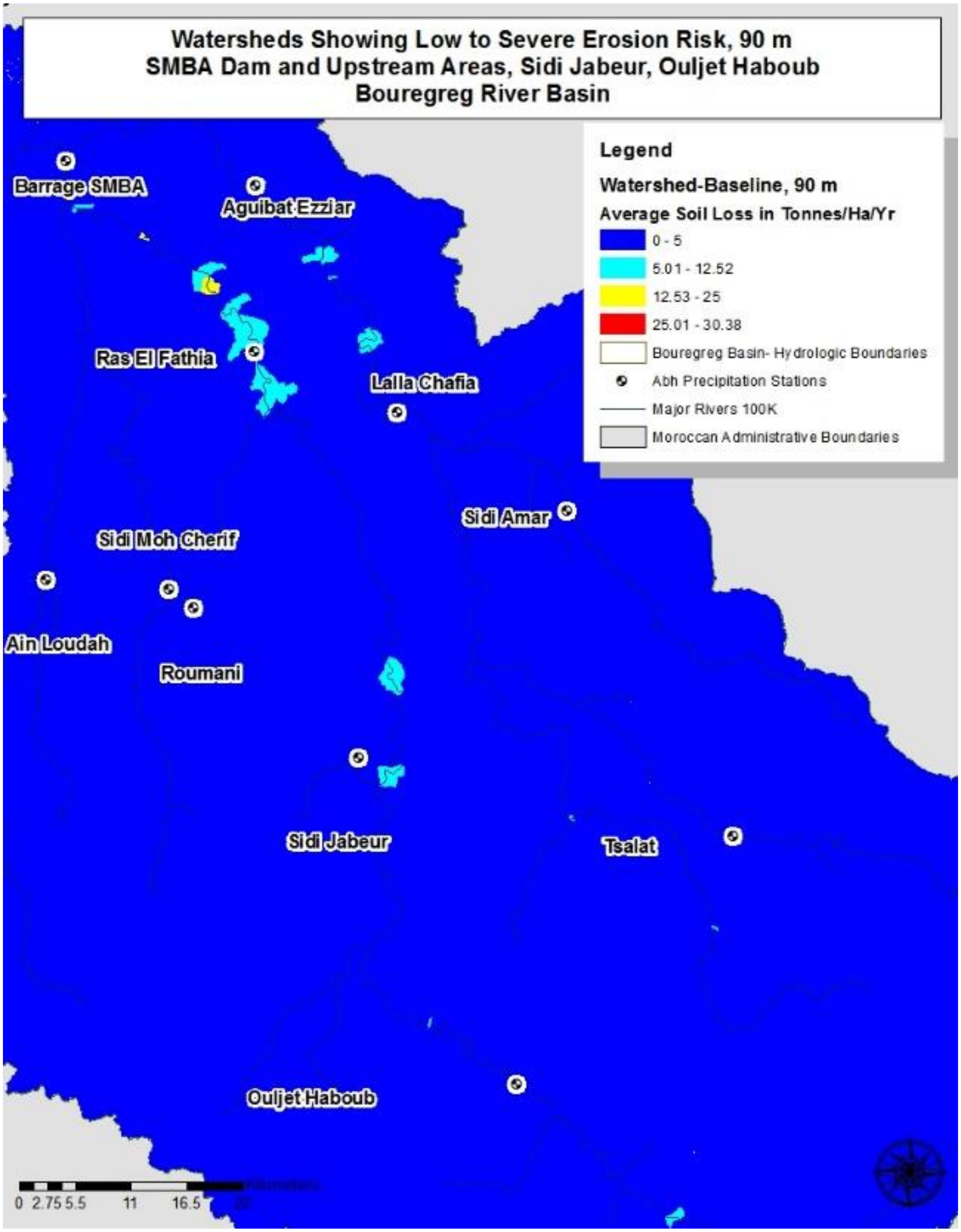
Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

.Figure 44: Erosion Risk, 90 Meters, Bouregreg Basin



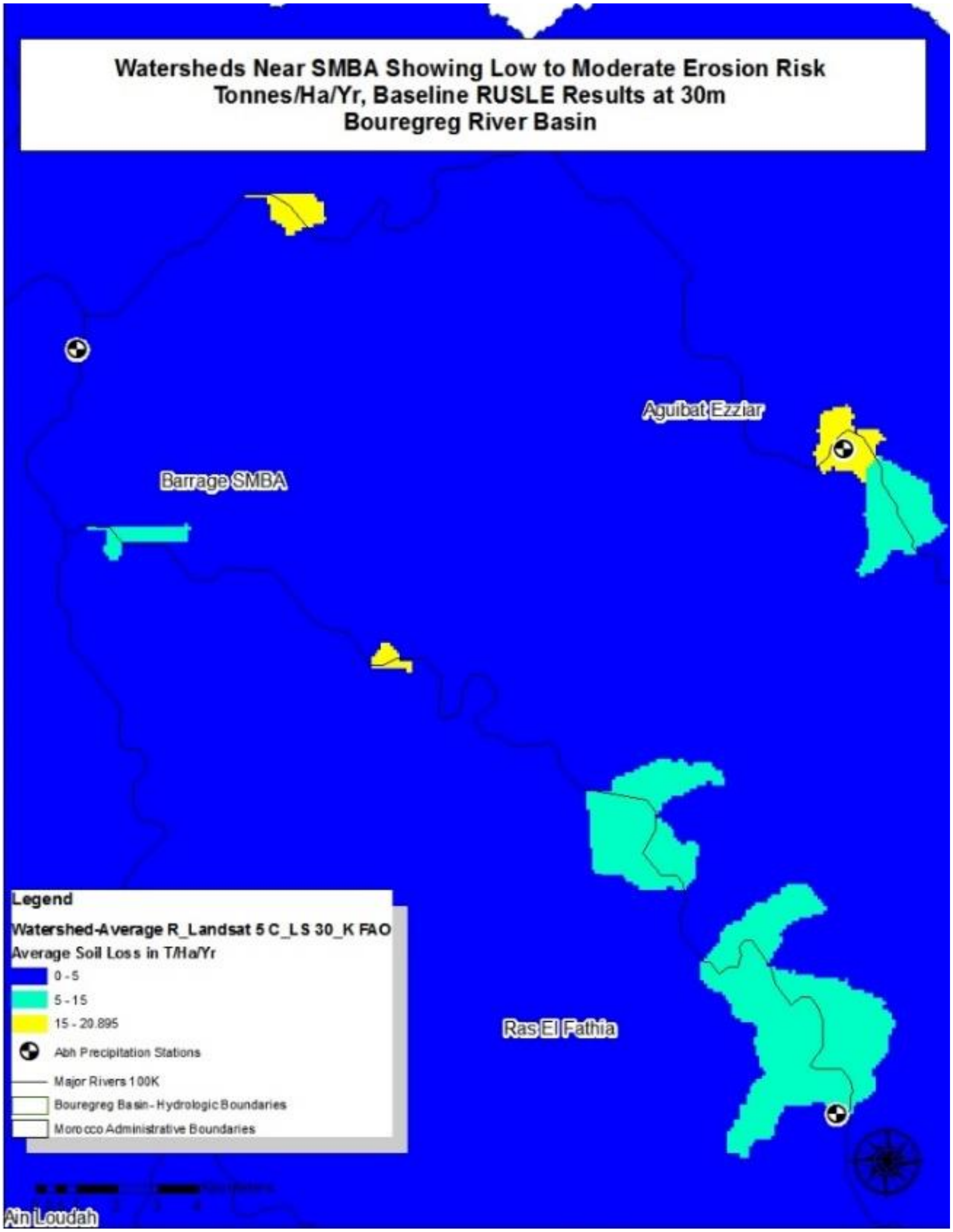
Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 45: Erosion Risk, 90 Meters, Areas near SMBA Dam



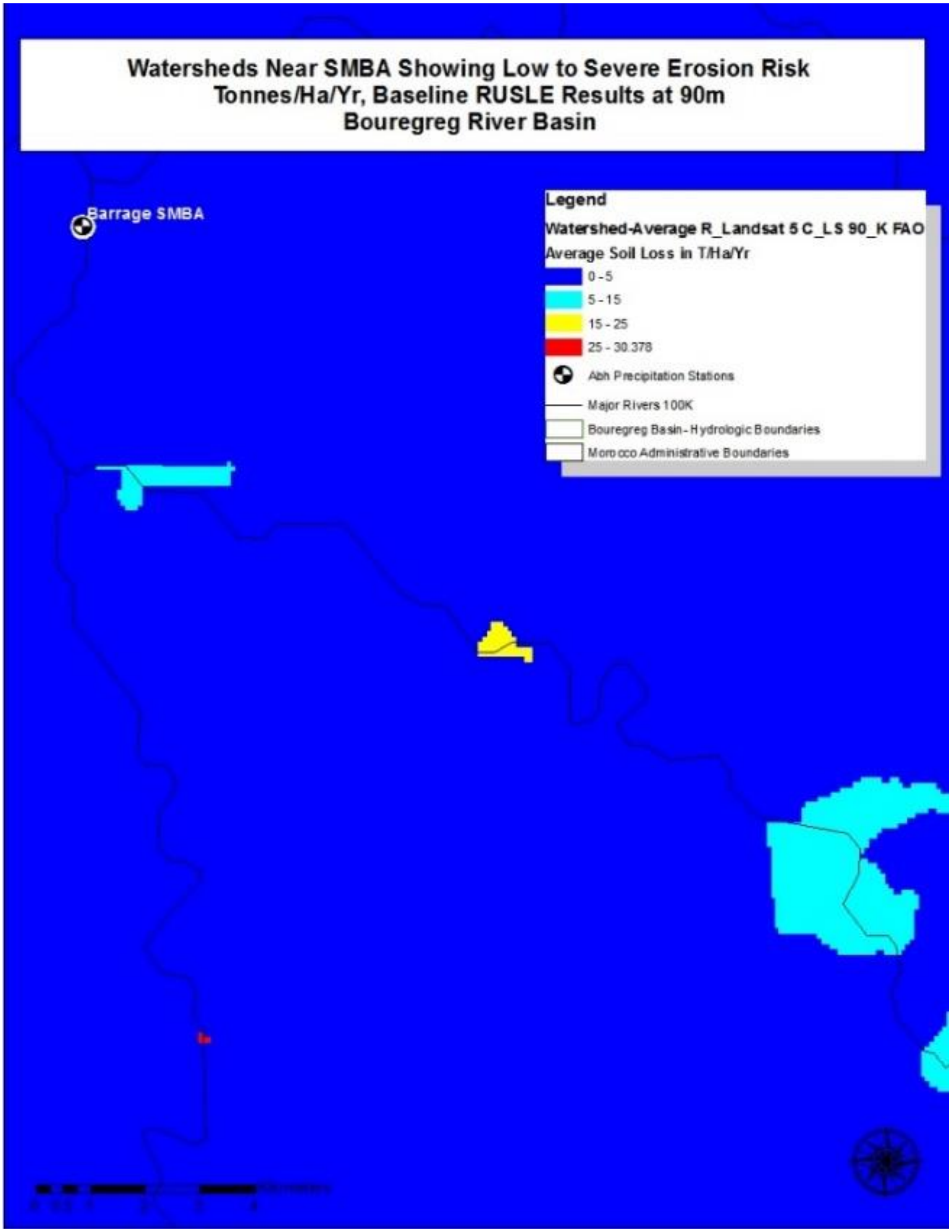
Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 46: Areas of Moderate and Severe Risk, 30 Meters



Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 47: Areas of Moderate and Severe Risk, 90 Meters



Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

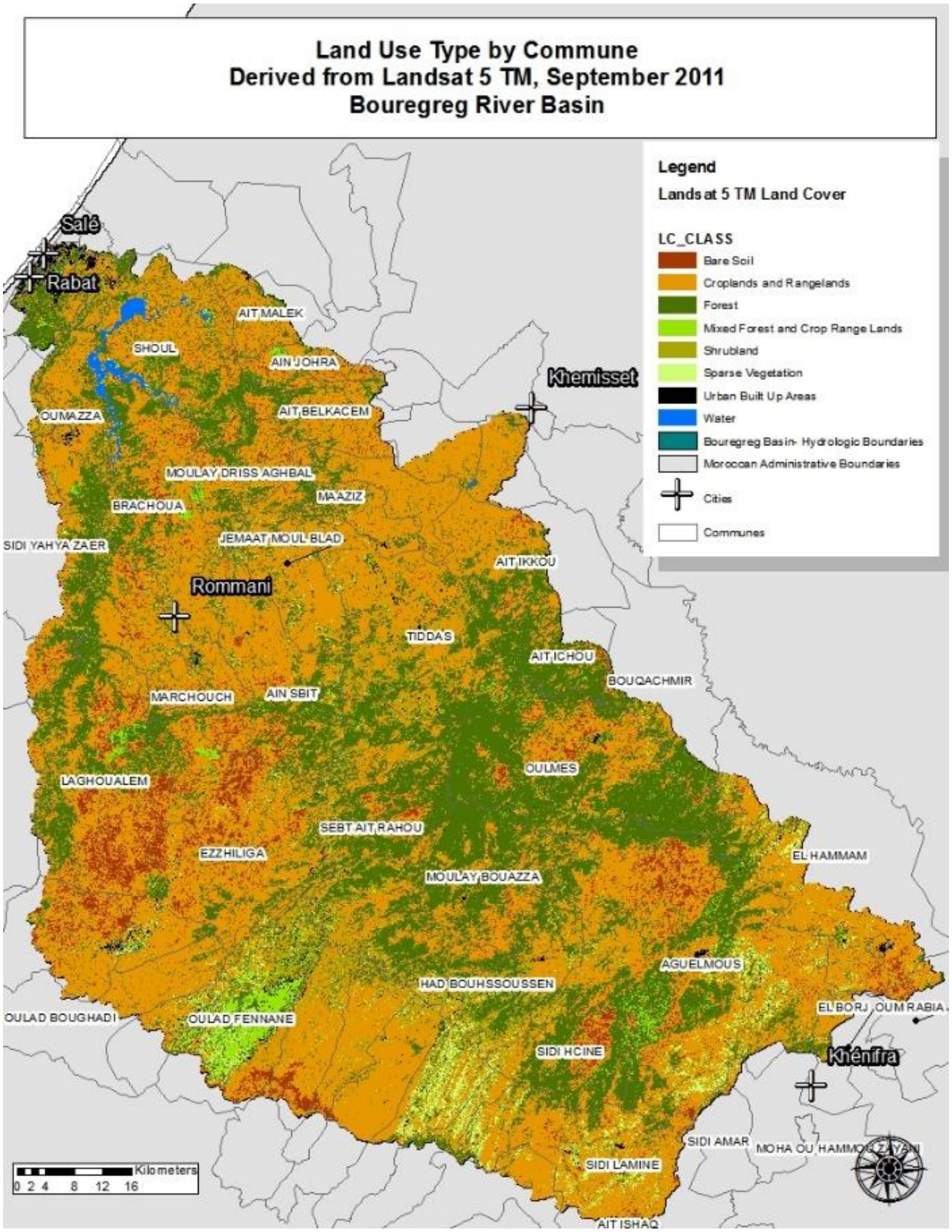
RUSLE RESULTS BY LAND USE TYPE

The reliability of results aggregated by land use type hinges on the accuracy of the image classification conducted on the Landsat 5 TM image. Figure 48 illustrates that sparse vegetation, forest, shrubland, mixed forest and crop and rangelands do appear to have been identified with some degree of confidence. Figure 49 demonstrates that average predicted erosion rates averaged between 0.351 tons/hectare/year for bare soil and 1.379 tons/hectare/year for sparse vegetation when grouped by land use classes.

The results for the land use types of sparse vegetation, mixed forest and cropland (0.923 tons/hectare/year), urban and built-up areas (1.071 tons/hectare/year), forest (1.087 tons/hectare/year), and shrubland (1.281 tons/hectare/year) yielded rates that were consistent with previous studies. Not all land use classes yielded typical predicted erosion rates, however. Bare soil yielded the lowest erosion rates, which is difficult to understand other than the fact that it occupies a small percentage of the Basin. Cropland also yielded lower soil loss rates than expected (0.692 tons/hectare/year), which could be attributed to pixels conforming to bare soil and sparse vegetation conditions being misclassified as cropland. If these pixels were averaged in with more representative pixels, this could have decreased the average predicted soil loss rate for the entire land use class.

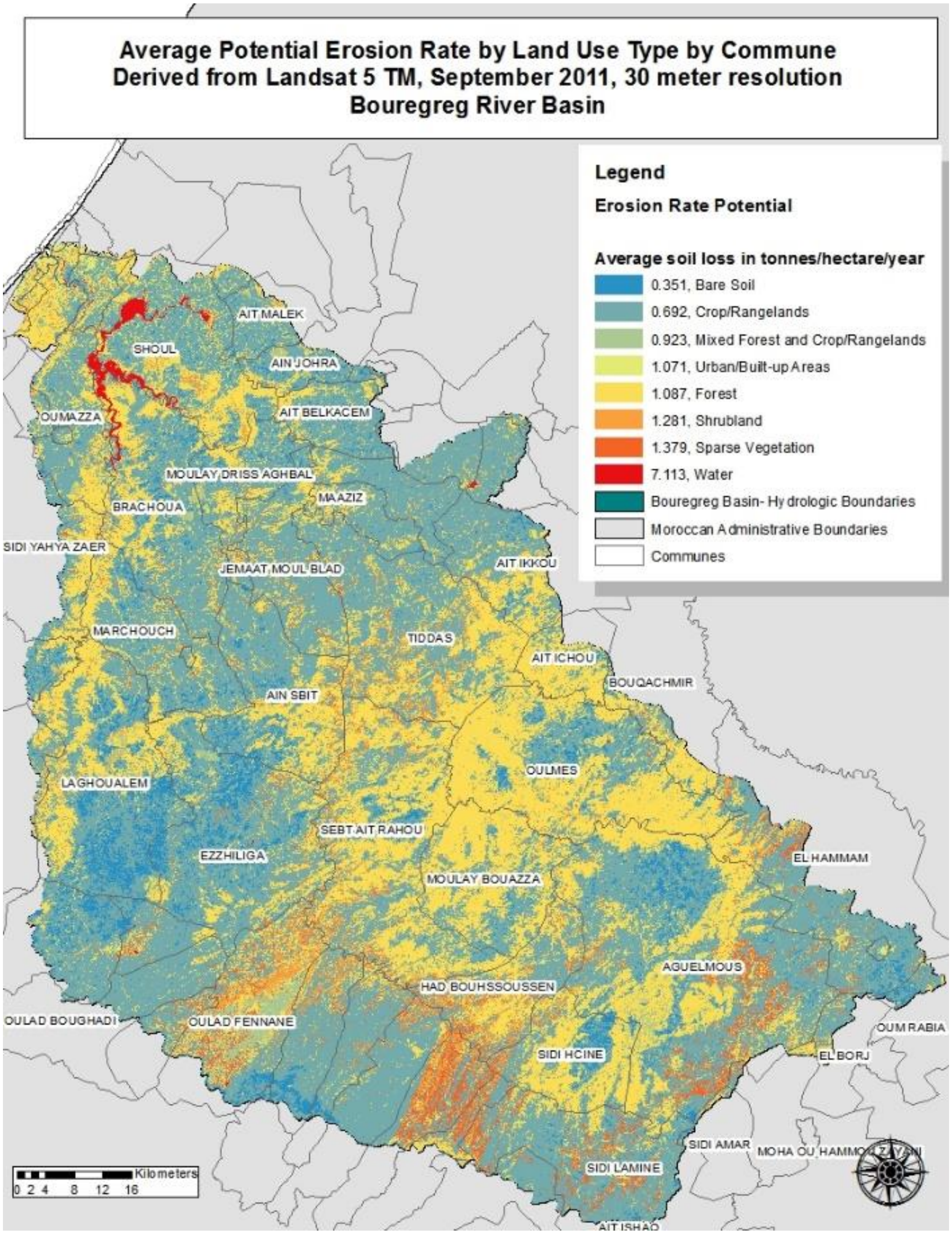
As discussed in the Results by RUSLE Factor section, some pixels in the processed Landsat image may have been misclassified. This misclassification may have influenced predicted erosion rates. Until the Moroccan government makes verified information on agricultural practices and land use in the Basin available in the public domain, classified remote sensing images will continue to contain some degree of error.

Figure 48: Land Use Type by Commune



Source: Map created by Madeline Clark using data from Landsat 5 TM Images 2021037, 2022036, 2022037, September 5 and 14, 2011, Shuttle Radar Topography Mission, accessed May 23, 2015 at http://earthexplorer.usgs.gov/; Rivers and Bouregreg hydrological boundaries created using 30 meter STRM DEM and administrative boundaries provided by the GIS Department at L'ONEP.

Figure 49: RUSLE Results by Land Use Type and Commune

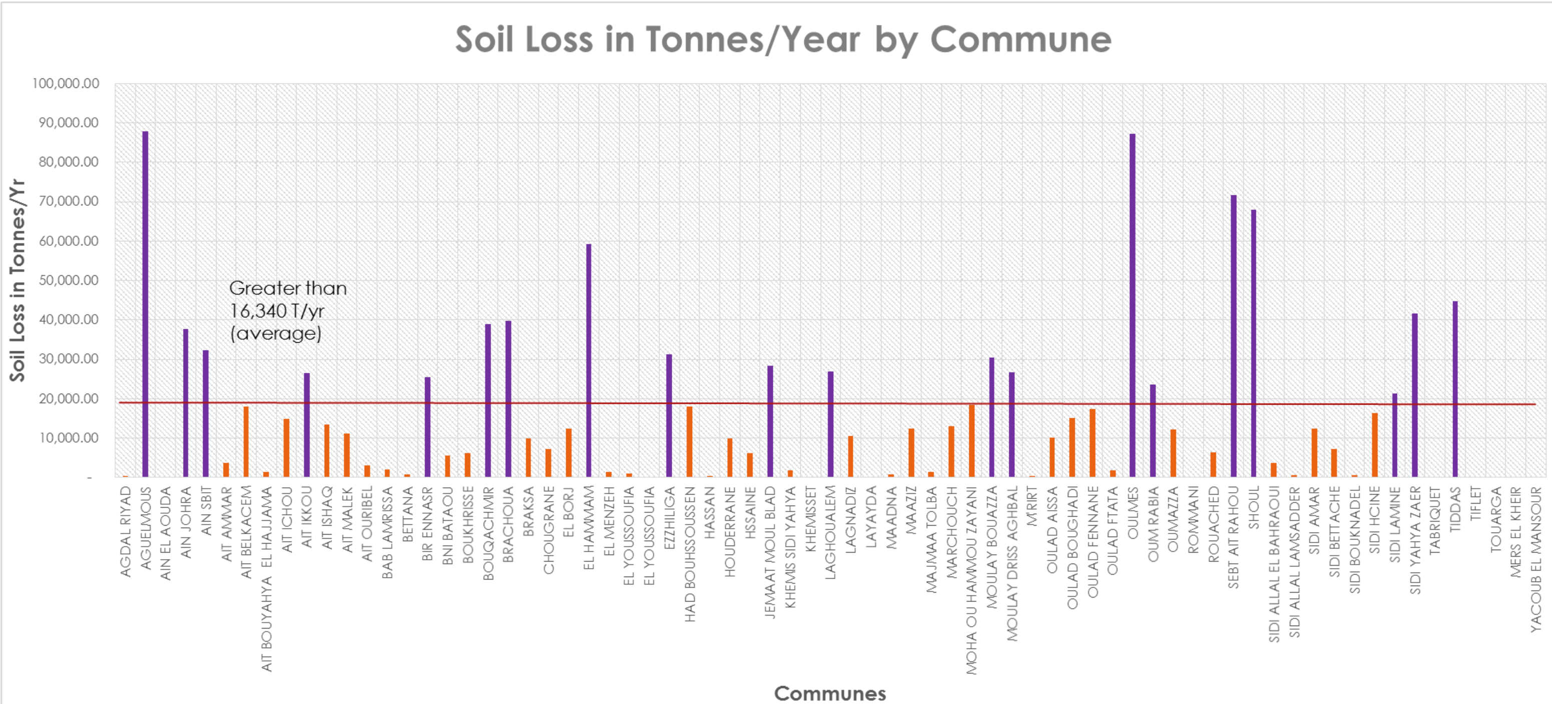


Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 50 displays soil loss by commune according to the results of this study. If the communal urban agencies, development authorities, ABHBC, and HCEFLCD were to have recommended mitigation measures based on these results, these measures would advocate increasing biological interventions in the forests contained by the Oulmes, Aguelmous, Sebt Ait Rahou, and Shoul Communes. Biological interventions such as increasing vegetative cover through reforestation are recommended for these mountainous areas of the northeast of the Basin. These areas demonstrate increases in the C Factor from 2009-2013, which indicates that forest areas decreased in vegetative cover. Where sparse vegetation is a dominant land use type, such as the Oulad Fennane, Had Bouhssoussen, and Sidi Lamne communes in the south of the Basin, local stakeholders should attempt to stabilize the soil by planting vetiver and monitoring agricultural and grazing practices that put pressure on the region’s topography.

The results of the RUSLE model scenarios constructed in this study suggest that the entire Bouregreg Basin deserves higher priority in the PNABV and efforts of the HCEFLCD and ABHBC. High erosion rates clustered around the drainage network of the Basin, which indicates that channel and gully erosion is the primary catalyst for soil loss in the Basin. Channel and gully erosion also contribute the most to dam sedimentation. Because the Basin's primary function is to produce drinking water for the densest urban centers in Morocco, the Moroccan government should support further investigation into basin-wide estimates of soil erosion using models that estimate sheet, channel, and gully erosion.

Figure 50: Soil Loss in Tons/Year by Commune



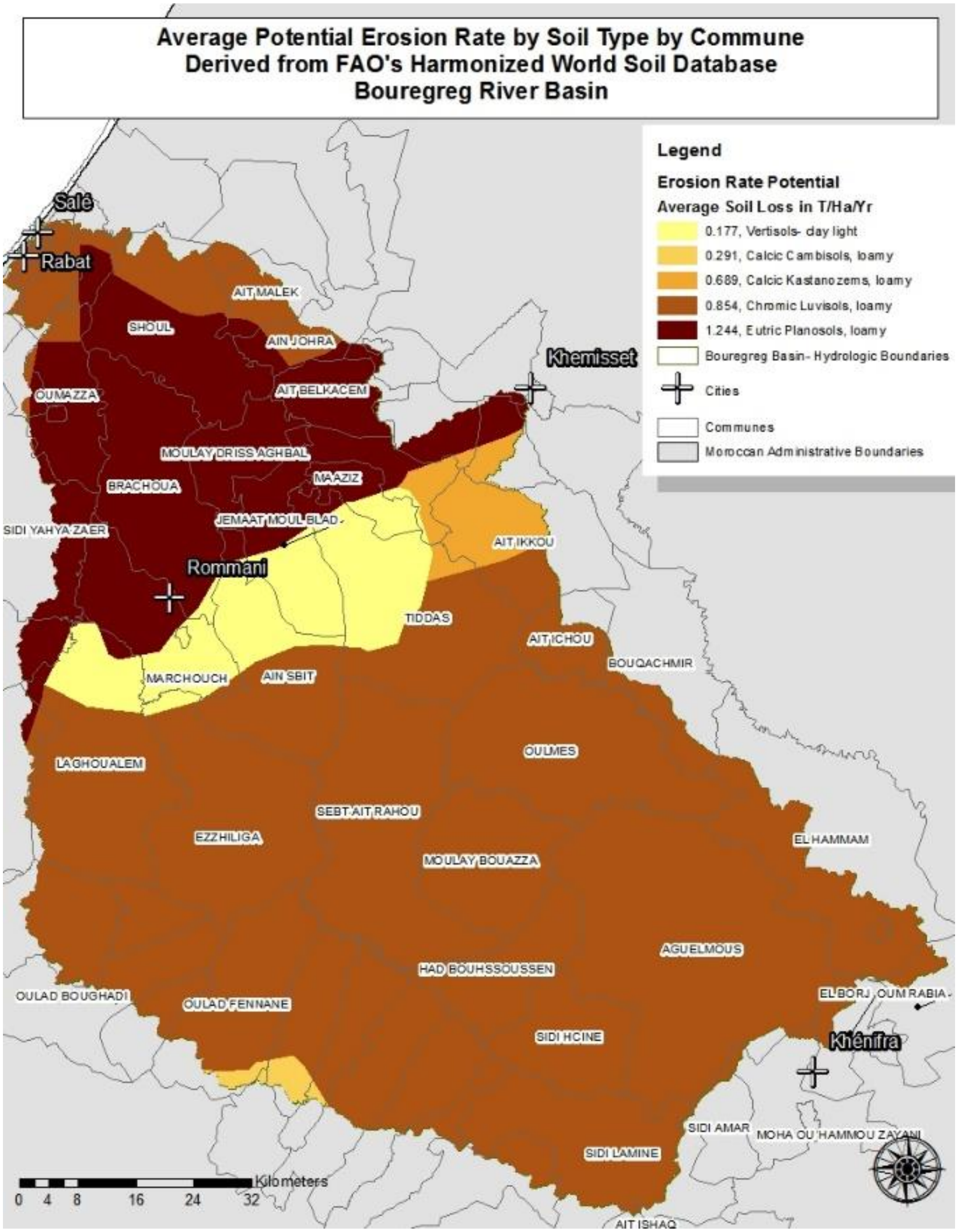
Source: Produced by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

RUSLE RESULTS BY SOIL TYPE

Figure 51 illustrates erosion rates by soil type. Fragile Eutric Planosols on the coastal swath of areas just upstream of the SMBA Dam display the greatest predicted erosion rates, or 1.244 tons/hectare/year. Figure 52 indicates a moderate, but significant correlation between soil type and the rate of potential soil erosion, with an R^2 of 0.6269. Calcic Kastanozems were removed from the regression because the area of an FAO soil type influences results in the averaging of rates.

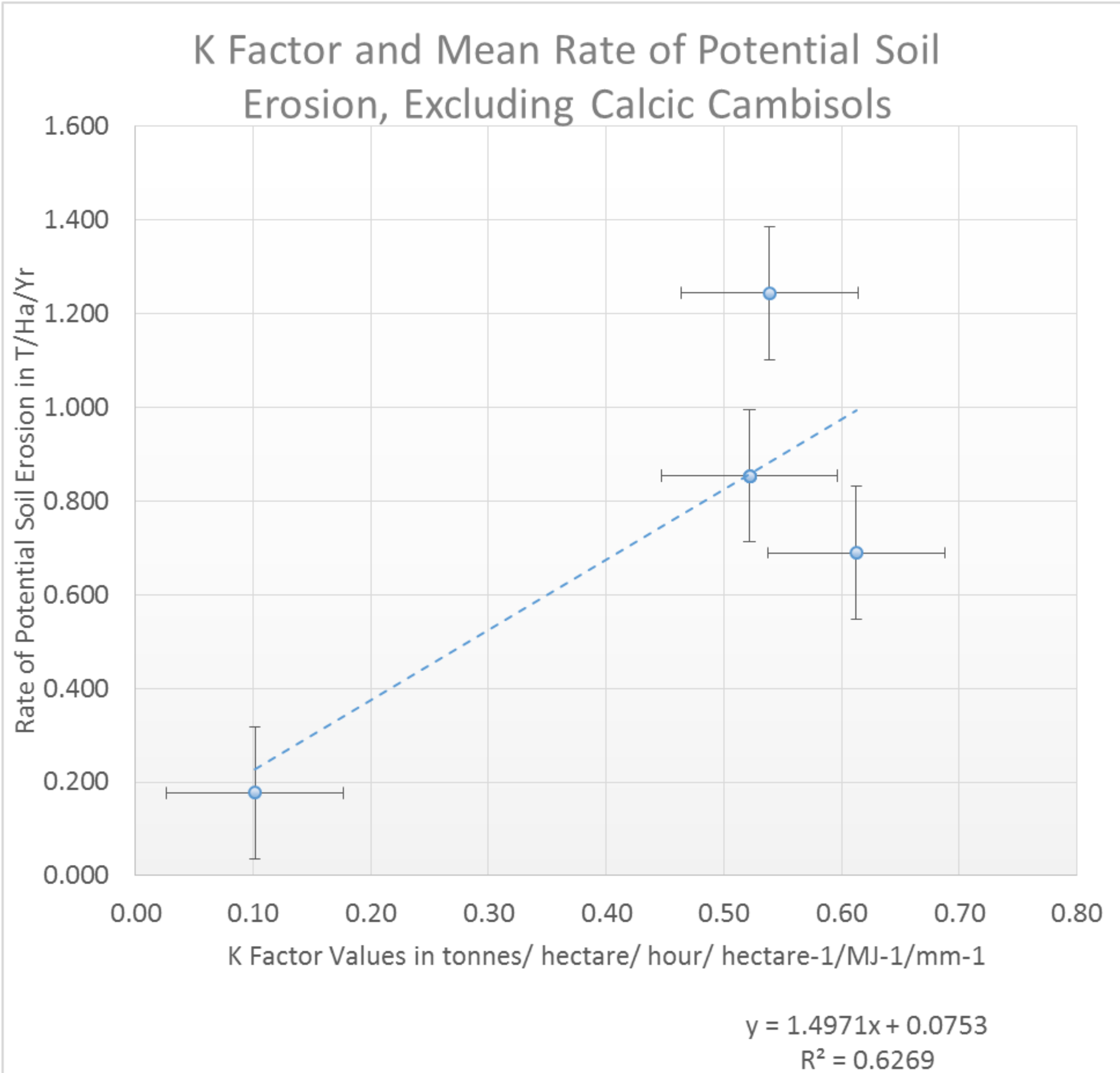
Figures 53 and 54 display the distribution of erosion potential rates by commune for the 30 and 90 meter scenarios. All soil loss rates among communes are below 5 tons/hectare/year, which is the threshold for tolerable soil loss. However, many communes in the Basin experience high net soil loss. For both the 30 and 90 meter scenarios, the Shoul, Moulay Driss Aghbal, Brachaoua, Jemaat Moul Blad, Ain Sbit, Tiddas, Sebt Ait Rahou, Oulmes, Bou Qachmir, El Hammam, and Agelmous Communes have net soil loss rates that exceed 32,000 tons/year. There is an approximate 26,000 tons/year increase in magnitude of soil loss for the 30 meter condition, indicating that using datasets that are coarser in resolution than 30 meters may bias policy-making in erosion mitigation and produce harmful outcomes though neglecting areas at risk for erosion. Communes and municipalities that experience elevated risk in terms of topography and vegetation cover, such as Shoul and Roumani, respectively, should actively pursue soil conservation mitigation measures.

Figure 51: RUSLE Results by Soil Type and Commune



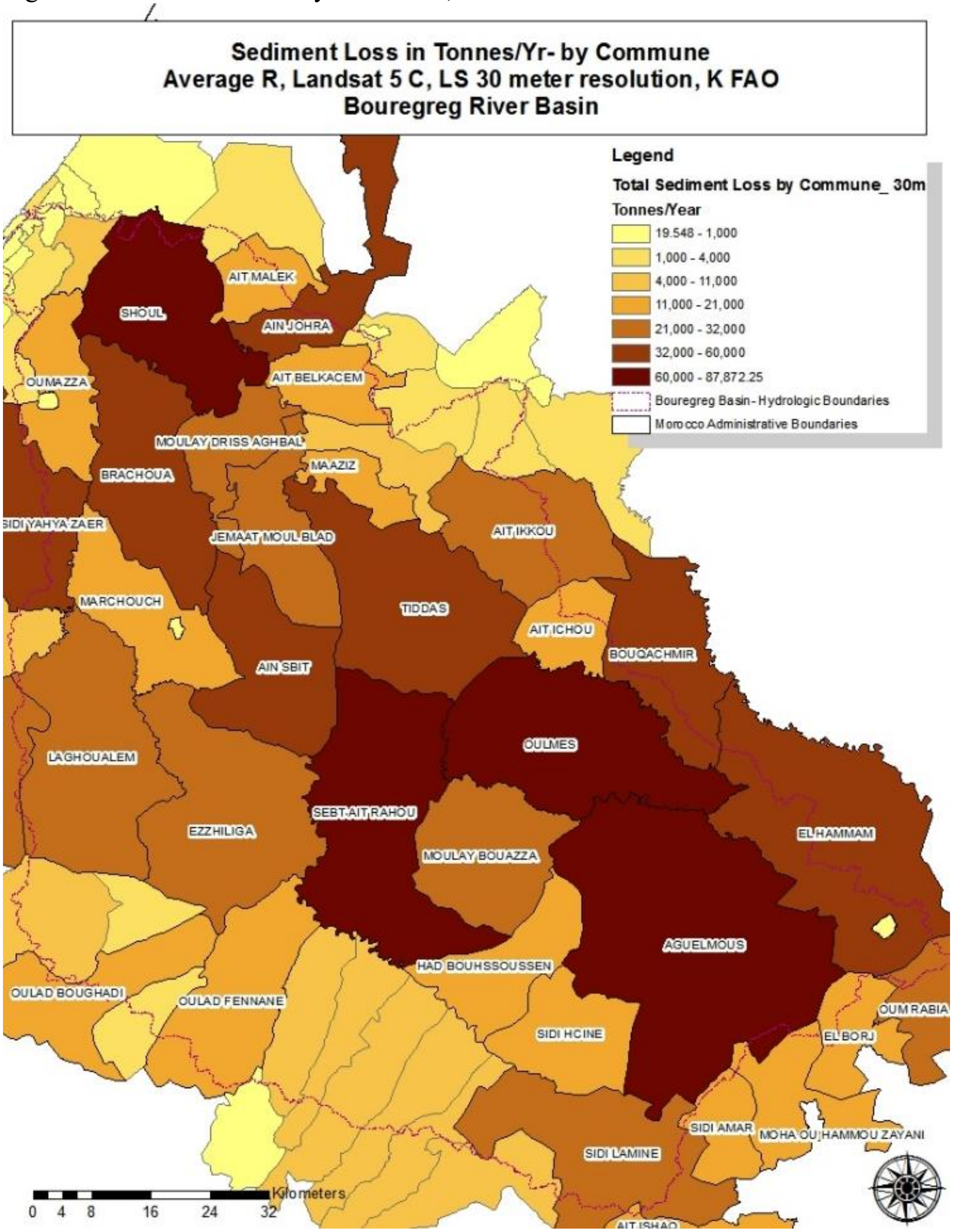
Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 52: K Factor Values and Soil Loss in Tons/Hectare/Year



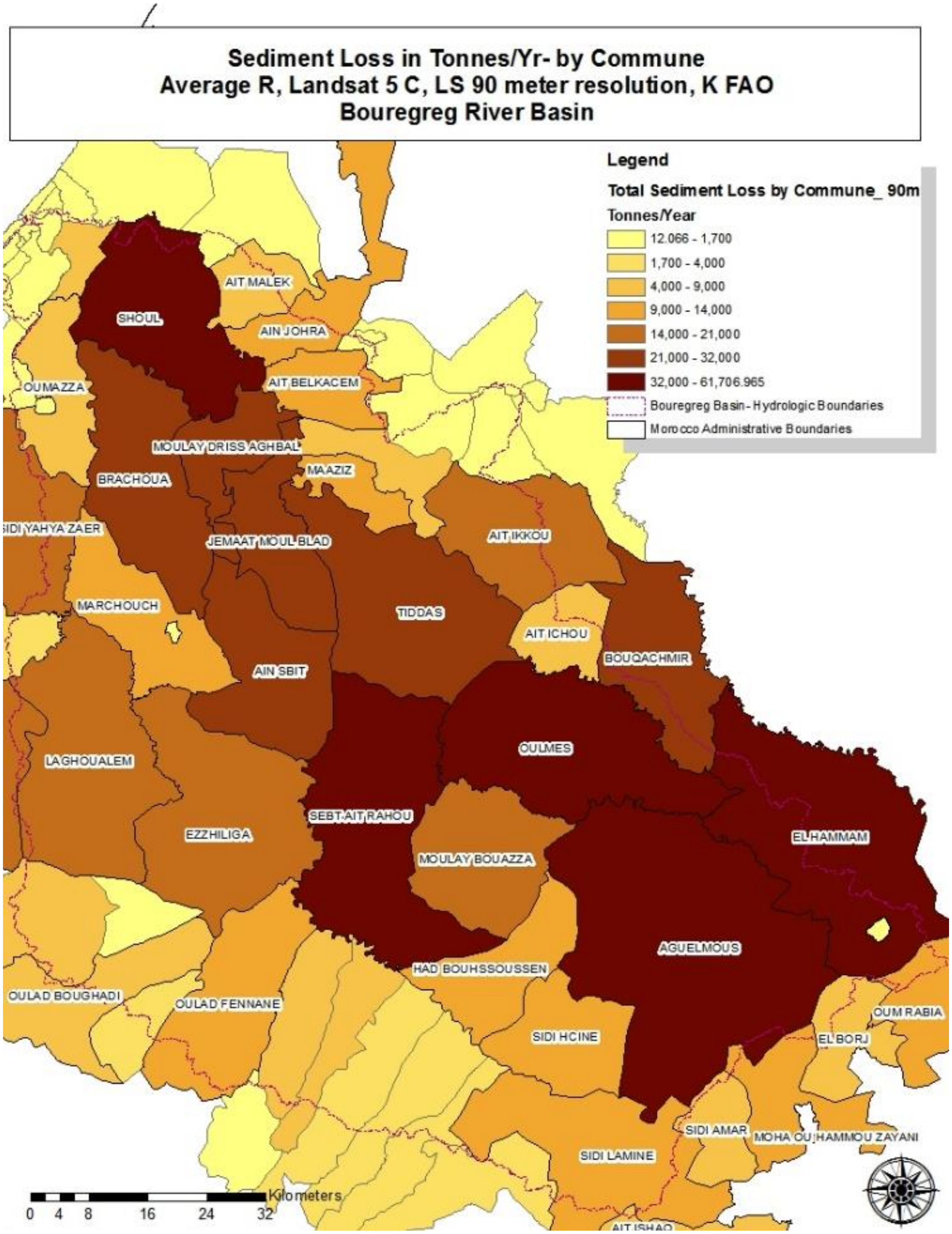
Source: Generated by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 53: RUSLE Results by Commune, 30 Meters



Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Figure 54: RUSLE Results by Commune, 90 Meters



Source: Map created by Madeline Clark in 2015 using data from the GIS Department of L'office Nationale de l'eau Potable, Agence du Bassin de Bouregreg-Chaouia in Benslimane, Shuttle Radar Topography Mission, and the Harmonized World Soil Database cited in this report.

Section IV: Discussion and Recommendations

MODEL RESULTS

Erosion risk within the Bouregreg Basin is minimal, between 0 and 5 tons/hectare/year. Moderate to severe erosion, at greater than 15 and 25 tons/hectare/year, does occur in localized areas basin-wide, primarily in the long, steep slopes that characterize forested areas in the mountains and surrounding river beds. Areas where vegetative cover is in flux also seem to be at risk. Data for a longer period and greater cell resolution should be used in future modeling efforts because estimated soil loss rates increase with cell resolution.

To model erosion at an interval less than one year data at a 30 minute or hourly interval or less for at least 20 years for input would allow Morocco to use more robust rainfall and runoff intensity equations in RUSLE modeling, like that of Wirschmeier and Smith.[405] Given the variability of rainfall for both the Bouregreg Basin and Morocco in the relatively short study period of 25 years, this study recommends that future researchers invest in modeling erosion rates for individual storms.

The scenarios constructed indicate variability in the R and LS factors influence the magnitude of model results. The K and LS factors influence the distribution or spread of potential erosion. It must be noted that this also could be due to the interpolation method used to predict the distribution of R factor values. Intense storm events may also cause greater spatial variability in erosion. However, the limited number of stations available did not permit the use of more robust statistical methods like kriging or splining, which require at least 30 location points in space.

Despite the fact that RUSLE is an empirical model, and that the datasets used here displayed a moderate to severe degree of uncertainty, this study successfully identified areas believed previously to be at risk, such as the Hannanat Catchments near Aguibat Ezziar, and areas just upstream of the SMBA Dam. Further, sediment loss and erosion rates are comparable to previous studies, at least regarding sheet and rill erosion. Areas where erosion risk exceeded severe or extreme values (over 25 and 50 tons/ hectare/year, respectively) concentrate around the drainage network, indicating that channel or gully erosion may be the dominant form of erosion, which is consistent with the studies of Yassin et al.[406] The model thus performed well as a regional-level tool for estimating sheet and rill erosion, and identifying areas where more serious forms of erosion should be investigated. This study demonstrates that the RUSLE model can provide a quick assessment of a basin so that decision makers can efficiently plan field studies for verification.

Though the RUSLE model alone should not be used to model erosion in the Basin, the results of this study can be used to advocate for more refined erosion models. These models can include an empirical model like MUSLE that uses runoff in place of rainfall erosivity, or preferably a process-based model such as WEPP that provides a full picture of water-based erosion dynamics in the Basin if adequate data exists. Incorporating estimates of channel and gully erosion would be more relevant for inferring information about dam sedimentation.

Data Availability and Reliability

The availability and quality of available data influenced the results of this study. For example, with less than 30 minute or hourly values, the generalizability of R-Factor results is limited, because annual and monthly averages and equations must be used, which is not very informative when designing mitigation measures. Tables 23 and 24 in the Appendices section of this report list statistics regarding data quality for the entire dataset produced by the ABHBC. Datasets contained errors and blanks, demonstrating low reliability, and rain gage station density is low.

Regarding the resolution of the STRM DEM used for this study, even a 30 meter resolution may be too coarse for interrill or sheet erosion. If datasets such as the eSOTER database contained soil characteristic information to the same extent as the FAO HWSD dataset does, this would have improved the accuracy of this study's results. This improvement in accuracy relates to scale and resolution, as the eSOTER dataset is more granular at a 1:250,000 scale, whereas FAO is at a 1:5,000,000 scale. The generalizability of the C Factor and P Factor results were also limited because comparable land use and cover maps produced by the Moroccan government at the municipal level were not available for this study in geo-referenced format.

A NOTE ON INFORMATION MANAGEMENT AND ACCESS IN MOROCCO

Information management relates directly to accountability. Issues in the free exchange of information, collaboration, and the standardization of methods occur within the water, agricultural, and forestry sectors of Morocco. Morocco's administrative, political, and social culture do not encourage the free exchange of data among stakeholders or open access to data. These barriers may reflect the residual threats of past and current penalties for the unauthorized sharing of information and the lack of protection for intellectual property.[407]

A case can be made based on the 1948 Universal Declaration of Human Rights (Article 19) for the presence of the right to information (RTI). In 1996 the International Covenant on Civil and Political Rights (ICCPR) strengthened Article 19 to define RTI more concretely.[408] In 2003, the UN Convention against Corruption created Articles 10 and 13, which promote transparency in public administration by creating expectations that information will be shared when it relates to the fight against corruption.[409]

Morocco's revised constitution of July 2011 establishes a right to access public information in Article 27.[410] This version of the Moroccan constitution recognized RTI for the first time and made authorities responsible for granting those rights.[411] Article 27 originally stated that all information generated by public agencies was legally bound to be released to the public, though it has been reinterpreted through revisions by members of the Moroccan Parliament.[412] These revisions limit the power of Article 27 to only include citizens that have a vested legal interest in the matter or members of the press, and it does not include an independent monitoring and evaluation entity as previously intended.[413] In practice, local authorities and these members in Parliament have continued to delay the full implementation of the law through amendments restricting its applicability.[414] In its current definition, Article 27 only protects the right to publically produced information and individuals with a vested interest in obtaining it.[415] A clear definition of what comprises a vested interest still does not exist.[416]

Amendments to Article 27 could impose financial and legal penalties on citizens that attempt to pursue information from an agency, especially if this chase leads to court.[417] For example, a citizen can be penalized if she/he incorrectly requests information, or once obtaining it alters it or uses it in a way not originally intended.[418] Article 27 in its current form is unclear, and this ambiguity both limits its ability to protect the rights of those asking for and producing information and puts it in conflict with the original intent of Law 31-13.[419]

Implied penalties and overt restrictions on sharing information directly reflect the tone from previous legislation. For example the Statute of Public Service of 1958 forbids public sector employees from sharing trade secrets or information relevant to national security to employees in other sectors, and in particular foreigners.[420] Penalties include 200 MAD ($20.82 USD) and one year of prison for sharing secrets with Moroccans, and 10,000 – 200,000 MAD ($1,040.79 - 20,815.70 USD) and five years of prison for sharing secrets with foreigners.[421] Only the Minister of the supervising ministry can grant exceptions, which presents a high barrier to accessing information.[422]

Transparency International Maroc has recommended that Article 27 could be improved by: (a) better defining responsibilities in implementing the law; (b) returning the form of the law to one that is not restrictive and that can be interpreted and defended in court; (c) developing an actionable strategy for the implementation of the right to information by various administrations; (d) training and raising the awareness of staff in charge of providing for the information; and (e) providing the means to involve associations and any component of civil society in actions related to information.[423] Table 25 lists selected recommendations of Transparency International to the government, public, private, civil society, and media sectors of Morocco that pertain to the scope of this study.[424]

Table 25: Recommendations of for Implementing RTI

Actor	Recommendations
Government	The government should develop the infrastructure of public departments and utilities necessary to implement this right, through training public officials in producing, managing and disseminating information, and allocating necessary budgets.
Public Sector	The public sector should develop the infrastructure for and knowledge of the production, management, and dissemination of information within the public sector.
Private Sector	The private sector should develop a comprehensive guide to the sources of available information that directly concern public-private contracting and complete an assessment of these sources, and call on all private sector stakeholders to develop an ethics charter, putting information owned by the private sector at the disposal of the public among its objectives.
Media	Actors in Morocco's civil society should conduct further studies on the status of e-governance, online services, and the needs of citizens, professionals, and people with special needs and allocate resources to electronic training and education, both for social development and a means of the enjoyment of rights.
Civil Society	The media should engage strongly in demanding the right of access to information for all persons, focus on advocating for the right of access to information for all persons, call for the implementation of the Archives Law, and necessary amendments to improve its utility, and work with civil society to coordinate joint work on the right of access to information.

Source: Adapted from "It Belongs to You: Public Information in Morocco." (USAID and Transparency International: Transparency Maroc, 2013). 46.

Transparency International Maroc further recommends that corruption in the judiciary sector be addressed.[425] Moroccans have difficulty in using the judiciary to appeal bureaucratic refusals to provide information to which they have a right, which is included in the language of Article 27.[426]

Legislation for protecting intellectual property can improve how soil erosion estimates are constructed. Though Morocco signed the Trade-Related Aspects of Intellectual Property (TRIPS) agreement as part of its Free Trade Agreement (FTA) with the United States,[427] this policy primarily protects U.S. interests in enforcing its own copyright laws and does not accomplish much in the way of instilling norms in Morocco outside of industrial production.[428] Copyrights and respect for them could help make sure that people are given credit and compensated for their work. If Moroccan citizens feel that they will be compensated or at least acknowledged by credit in publication, then this could lead to a more open and collaborative research community.

Moroccan legislation such as the Archives Law (no 69.99) of November 2007, and the Environmental Impact Studies Law (No. 12.03) of June 2003, relate to the access of information in the water and land management sectors.[429] The Archives Law regulates conditions for viewing public archives held by state, local authorities, public institutions, and facilities, and private bodies entrusted with administering a public service.[430] In the absence of language regarding the implementation of the Archives Law, it has not yet come into force.[431]

The Environmental Impact Studies Law stipulates that before an administration licenses an industrial or similar project, the public shall be informed of the content of the project's environmental impact study.[432] It also requires that a public inquiry be opened to enable the public to view the information and the main conclusions of the study, with the exception of projects deemed confidential.[433] Those responsible for the project must indicate in writing what data he or she considers confidential and send this notice to the administration in charge of supervising the environmental impact assessment process.[434] The term confidential is confined to information or data whose nature would harm the interests of the project owner if the data were released to the public.[435]Otherwise, information related to a project's environmental impact is not considered confidential.[436]

Within the environmental sector, policy decisions are not proactively published and only general information is made accessible and available.[437] Morocco has been engaged in modernizing its agencies since 2002, however. All but a few of its ministries have an online presence.[438] Table 25 contains a selection of websites with data on environmental resources made available to the public, though most links to raw data require log-in credentials. Online information provided by public entities in the environmental sector typically includes: (a) specific organization structure; (b) contact information; (c) information on services; (d) access to e-services; (e) information on public procurement; and (f) registers and databases.[439] This information and data are inconsistent in their availability across organizations, and are not always regularly updated.[440] It is also not clear that the ministries and other public, private, and scientific entities have working internal rules and norms for publishing and sharing information.[441]

Table 26: Government Websites with Publically Accessible Data

Platform	Producer	Content	Spatial Scope	Temporal Scope	Link
Fertimap	IAV and OCP	Soils in Morocco.	Morocco	Not clear	http://www.fertimap.ma/map.phtml
eSOTER	INRA	GIS and tabular data of Soil Survey.	North-Central Morocco	2008-2012	http://www.esoter.net/
State of the Environment	MEMEE	State of environmental resources.	Morocco, by region	2010 Snapshot	http://www.environnement.gov.ma/index.php/en/etat-env-en
Agricultural Statistics	MAPM	Statistics (StatAgri), prices of agricultural goods (Assar), Online maps (GeoPortail), Agricultural Forecasting (CGMS-Maroc).	Morocco, by region and commune	Not clear	http://www.agriculture.gov.ma/
Services, Cartography	ABHs	Climate, water balance, reservoir statistics, permits, and online maps.	Hydrologic Basin	Varied	http://www.abhbc.com/#
Our Products	METEO Maroc	Data on climate parameters and air quality; audit information; online maps of precipitation, temperature, and air quality; software packages.	Morocco and selected major cities in North Africa	2 days, hourly; 3-hourly, decadal, depending on parameter	http://www.meteomaroc.com/cartes
Regions	L'ONEP	Data and Activities accessible by region.	Morocco, by region	Not clear	http://www.onep.ma/

Source: Compiled by Madeline Clark with data from BasKem, 2013, "Products," e-SOTER, ISRIC World Soil Information, accessed March 29, 2015 at http://www.esoter.net/; "Cartes," MeteoMaroc, accessed October 14, 2014 at http://www.meteomaroc.com/cartes; "Regions," l'Office National de l'Electricité et de l'Eau Potable, accessed August 5, 2015 at http://www.onep.ma/; "Services," L'Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, accessed September 7, 2014 at http://www.abhbc.com/index.php/services; "State of the Environment," Ministre de l'Energie, des Mines, de l'Eau et de l'Environnement, accessed October 14, 2014 at http://www.environnement.gov.ma/index.php/en/etat-env-en; "Statistiques & Veille Économique," Ministère de l'Agriculture et de la Pêche Maritime, accessed October 14, 2014 at http://www.agriculture.gov.ma/rapports-statistiques; dTetrimap, 2013, "Carte de fertilité des sols cultivés au Maroc," Fertimap, Ministère de l'Agriculture et de la Pêche Maritime et le Groupe Office Chérifien des Phosphates. accessed November 15, 2014 at http://www.fertimap.ma/map.phtml.

To conclude, institutional and pragmatic barriers prevent the timely and equitable relay of information between suppliers and end-users of data in the water and land management sectors of Morocco. These limitations result are listed in Table 26.

Table 27: Barriers Limiting Coordination in Morocco

Type	**Description**
Institutional	Limited protection of intellectual property, leading to an unwillingness to share data.
	Variable response time and accountability in data producing centers. This may be attributed in part to the fact that oversight in this domain is still emerging.
	Administrative barriers in both the public and private sector that limit or block channels of communication between suppliers and end users of data.
	Strong tendency exists to rely on European and American models and technology. This tendency may even be best described as donor or investor-driven, and leads to bias in model selection.
Pragmatic	Variable data quality, historically and by region, due to a tendency for water sector actors in remote and less prosperous areas to use traditional methods of information recording, archival, and management.
	Varying technological capacities for processing data, leading to a subdued and stagnant demand for changes in information management.

Source: Compiled by Madeline Clark.

RECOMMENDATIONS

Though a number of field studies have been completed for specific areas within the Bouregreg Basin, results are not available in raw form and are not geo-located. Due to the fact that these are conducted with different geographical scopes by organizations with vastly different aims and objectives and methods, it is difficult to compare and scale up these results. As a result, these inconsistent and incomplete datasets mean that a user cannot develop a basin-wide perspective on the balance of soil. To dynamically model erosion, stakeholders should focus on quantification, standardization and consolidation, comparison, coordination, and reporting in formulating best practices for information and data management. The following section elaborates on these principles in data management.

Quantification

Data on vegetative cover for the period prior to the droughts beginning in the late 1970s to the present day should be compiled to provide an idea of how the climatic parameters of precipitation and temperature affect vegetative cover. Without a clear idea of how these parameters co-vary, it will be difficult to tease out the effect of human activities.

Though micro-catchment level information in a non-georeferenced format is available for some parts of the Basin, it is generated by different authorities and thus incomparable. This information would vastly improve the quality of the C and P Factors, and allow for accurate, high resolution, micro-catchment level studies to be completed relatively quickly for all parts of the Basin, and then aggregated to yield basin-level results. This methodology could be replicated for all basins within Morocco to provide a national-level idea of sheet, rill, and channel and gully erosion, and verify the dominant erosive processes in Morocco.

Standardization and Consolidation

This study used the RUSLE model, which is the model that Moroccan policy makers primarily use. Currently, donors are introducing other models. The diversity of soil erosion estimate models leads to disparity in outcomes, based on units, coverage, and data quality, as some methods are primarily qualitative. As Morocco moves toward the use of more complex, computation heavy, and geospatial methods, stakeholders could be consulted about what has worked the best for them according to local conditions. The result of this dialogue could determine a national standard for erosion modeling. To prevent redundancy, institutions could record and publish their results. Current institutions in the Moroccan government monitoring research should be made responsible for compiling a comparative, comprehensive database of research conducted by Moroccan researchers that would help future students and researchers coordinate to more efficiently produce reliable, usable research.

Topographic, precipitation, vegetation, and soil type information are currently available to some degree of spatial and temporal resolution, but these datasets are constructed to serve the particular interest of the agencies that created them. Across stakeholders, there should be an effort to reconstruct old datasets and create workflows for recording and maintaining new datasets that are flexible, robust, and reliable. Data should be sent to an independent source for verification before publication and use, or maintained by a single agency. Current and future monitoring instruments should also be checked for quality and consistency in recording data.

Comparison

Currently, there is no standard way within Morocco to record, maintain, and share data that has been verified by an independent agency. This means that stakeholders are not monitoring how data are recorded beyond their input into the system. As studies are completed, they are not tagged with metadata reflecting their source, quality, and usability. If data producers do not make an effort to create datasets with meta-data attached, other users will not be able to or use in years to come.

Ground-level vegetation and climate station records should be supplemented or compared to global-level satellite data. Global datasets at 250 meter or greater resolution exist. Though their abundance and ease of access is growing, some of these factors are not comparable to station data because they exist at scales that cannot be disaggregated in space and time. For example, 30 meter and 10-15 meter remote sensing data are available without charge. However, the scale of these data is not sufficient for highly localized phenomena like erosion. Further, the size of remote sensing images, grids, and other complex data sets, especially when used for a large geographical area at a high resolution over time, render data access and processing very difficult without the appropriate tools, technological capabilities and human capital. Locating a consistent time series for climatically-based remote sensing images is difficult due to the near-constant cloud cover over the coast of Morocco during the rainy season (December to January).

Coordination

There is little sharing of information among stakeholders beyond the boundaries of a project. Projects guided by international donors tend to lead to better coordination. Entities with a vested interest in an issue like erosion may not be consulted, which has led to stagnation within the field. For example, L'ONEP has a vested interest in dam sedimentation, but does very little in terms of mitigation.

Interviews with INRA and HCEFLCD indicated data redundancy and gaps.[442] When a subject such as erosion is defined, agencies that are not named as being directly responsible may shirk responsibility for involvement, especially when this involves financial and management responsibility. However, when gains are high, such as with international projects, coordination works better and involvement levels and communication are higher. This could be due in part to conflicting incentives within the working environments of different sectors.

Reporting

In Morocco, studies and reports published by public sector entities may either be accessible or difficult to find. This trend is also reflected in the sharing and publishing of datasets, as described in Table 25 of this report. For example, although the MEMEE, MAPM, and the ABHs have made steps to publish data for public consumption, most of these are outdated or in aggregate form. The uneven application of the Article 27 regarding environmental information and inherent qualities of Moroccan culture regarding the possession and consumption of information may contribute to this phenomenon. In addition, students and non-affiliated researchers, even Moroccan nationals, have a difficult time accessing information. Barriers to students in critical fields such as the natural and social sciences and engineering to accessing information slows innovation within the water and land management fields.

OVERCOMING CHALLENGES TO THE STUDY OF EROSION IN MOROCCO

This study has reported limitations on the modeling of soil erosion in Morocco. Recurring arguments include data quality and availability, parameter selection, and model suitability. With regard to data quality, the resolution of all factors influences the magnitude and spread of predicted erosion rates. The most reliable soil maps for the calculation of the K erodibility factor are at the 1:5,000,000 scale and date from the FAO's efforts to collect soil information from Morocco in 1974. The recommendation of this study is that decision makers in the environmental management divisions of the both water and agricultural sectors collaborate with commune and province-level government administrations and present a plan to the CSEC for updating the National Soil Survey conducted in the 1970s.

Stakeholders interested in soil erosion could discuss a strategy for bringing agency and university specialists together to contribute datasets regarding soil, climate, biodiversity, land use, and land management practices from the micro-catchment-level up. After these datasets have been compiled, stakeholders could cooperate to construct a national database from which empirical and physical models can be developed or fitted to the Moroccan context, much in the way of the development of the USLE and WEPP in the United States. Gaps in data could be identified. Appropriate methods could be used to simulate missing data.

To ensure that the quality of information produced nation-wide is high, stakeholders could also establish standards in data and information production and management practices. However, standards vary substantially from organization to organization and by geographic location. Stakeholders could encourage members of the scientific community to peer-review these standards to ensure the robustness of methods and the validity of information.

To aid in selecting parameters and appropriate methods for estimating and predicting erosion, stakeholders could develop tools to accommodate a wide range of expertise in the agro-forestry and water sectors. In light of the impacts of climate change, many factors could affect process-based models. Tools that optimize model selection could make it easier to find an appropriate model for a study's scope and objectives. Creating and adopting a model optimization tool can also help avoid the publishing and perpetuation of errors.

Parameter selection can be based on fuzzy logic or genetic algorithm methods. There are actors in academia and among Morocco's scientific institutes, such as the IEA at L'ONEP and IAV that are already engaged in applying these methods to some aspects of erosion modeling, water quality optimization, and energy efficiency. Selection of parameters and models could be based on the availability of data, technical expertise of stakeholders implementing the models, erosion type, and climatic and physical context.

Stakeholders should also discuss how to implement these reforms in data collection and information management and changes in model implementation by geographical and administrative extent. Responsibility for these changes should rest on the already-defined, but agreed upon catchments and administrative units that possess the political power to implement and enforce policy at the sub-basin level, with coordination from the ABHs and relevant national actors, including the HCEFLCD, MEMEE, MAPM, and scientific institutes. These efforts could culminate in clearly defined, implementable data collection, management, and modeling workflows that are uniform in process, calibrated to local conditions, and able to provide accurate results for planners and erosion mitigation implementation.

This study provided an important start in examining how to improve data management and model selection in Morocco through a case study of soil erosion using the most common method for modeling erosion in one of its most critical basins. Future directions for researchers looking to improve overcome the challenges identified in this study should include the verification of RUSLE model results through comparison with output from other models and real field measurements. The exploration of erosion mitigation strategies that offer co-benefits, such as rainwater harvesting, could improve the water and agroforestry sectors of Morocco and North Africa.

Notes

[1] Rachid Dahan et al., A Review of Available Knowledge on Land Degradation in Morocco (Aleppo, ICARDA, 2012), 10.

[2] Dahan et al., 13.

[3] Dahan et al., 10.

[4] K.G. Renard et al., Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Equation (RUSLE), (Washington: USDA, 1997), 17.

[5] Renard et al, 17.

[6] Lahlou, Abdelhadi, "The Silting of Moroccan Dams," Sediment Budgets IAHS 174 (1988): 71.

[7] Lahlou, "The Silting of Moroccan Dams," 71.

[8] "Employment in agriculture (% of total employment)." 2012. The World Bank. Accessed October 14, 2014. http://data.worldbank.org/indicator/SL.AGR.EMPL.ZS.

[9] "Agriculture, value added," 2014, The World Bank, Accessed October 12, 2014, http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS/countries.

[10] Rivas, Todd, Erosion Control Treatment Selection Guide (Washington: USDA, 2006), 1.

[11] Rivas, 1.

[12] Ibid.

[13] Rivas, 1-2.

[14] Ibid.

[15] Ibid.

[16] Ibid.

[17] Ibid.

[18] Rivas, 3-5.

[19] Ibid.

[20] Ibid.

[21] Ibid.

[22] Ibid.

[23] Ibid.

[24] Ibid.

[25] Ibid.

[26] Rivas, 6-7.

[27] Dahan et al., 11.

[28] Dahan et al., 12-13.

[29] Rivas, 1-7.

[30] Elinor Ostrum, Governing the Commons: The Evolution of Institutions for Collective Action (Cambridge: Cambridge University Press, 2011), 1-5.

[31] Dahan et al., 12-13.

[32] Ibid.

[33] Ex-Ante Evaluation, Watershed Management Project Loan to the Kingdom of Morocco," JICA (2007): 104.

[34] "Ex-Ante Evaluation, Watershed Management Project Loan to the Kingdom of Morocco," 104.

[35] A. Laouina, " Le Bassin Versant du Bouregreg, Caractéristiques Géographiques, » in "Gestion Durable des Terres," eds. Abdellah Laouina and Gil Mahé, (Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo, 2013), 5-20.

[36] "Morocco Watershed Protection and Management Project: Final Report." (Washington D.C., USAID, 2005). 5-16.

[37] Nash et al., 160.

[38] Nash et al., 160-165.

[39] "4: Deforestation- Environment. Mafia Maâmora," TelQuel Magazine, April 28, 2005, http://geres-asso.org/article_deforestation4.html.

[40] Dahan et al., 12-13.

[41] A. Omerani, "Watershed management," in "Institutional implications of participatory approaches." Decentralization and Rural Development 20 (Rome, FAO, 2002).

[42] Lahlou, "The Silting of Moroccan Dams," 71-75.

[43] Ibid.

[44] Ibid.

[45] Sediment Committee, "Sedimentation and Sustainable Use of Reservoirs and River Systems," (Draft Bulletin, ICOLD, 2009), 31-57.

[46] Sediment Committee, "Sedimentation and Sustainable Use of Reservoirs and River Systems," (Draft Bulletin, ICOLD, 2009), 31-35.

[47] Sediment Committee, 31-57.

[48] Ibid.

[49] Ibid.

[50] Lahlou, Abdelhadi. 1996. "Environmental and Socioeconomic Impacts on Erosion and 'Sedimentation in North Africa." Erosion and Sedimentation Yields: Global and Regional Perspectives IAHS: 491-493.

[51] Ibid.

[52] Ibid.

[53] R. Choukr-Allah, "Comparative study between Moroccan water strategies and WFD," in Dialogues on Mediterranean Water Challenges: Rational Water Use, Water Price Versus Value and Lessons Learned from The European Water Framework Directive, eds. S. Junier, M. El Moujabber, G. Trisorio-Liuzzi, S. Tigrek, M. Sernegu, R. Choukr-Allah, M. Shatanawi, and R. Rodríguez, (Bari : CIHEAM, 2011): 181 -182.

[54] A. Ouassou et al., "Application of the drought management guidelines in Morocco (Part 2. Examples of application)," in Drought Management Guidelines Technical Annex, eds. A. Iglesias, M. Moneo, A. López-Francos (Zaragoza: CIHEAM / EC MEDA Water, 2007). 343-372.

[55] Ouassou et al., 343-372.

[56] Ibid.

[57] Ibid.

[58] Ibid.

[59] Ibid.

[60] Ibid.

[61] Bouchaib El Hamouri, "Water resources in Morocco: Potential, Exploitation and Handicaps." (Rabat: Institute Agriculturale et Vétérinaire, 2007). 1-5.

[62] Ibid.

[63] Ibid.

[64] Fry, Al. "Facts and Trends: Water." World Business Council for Sustainable Development (2005), 8, accessed at http://www.unwater.org/downloads/Water_facts_and_trends.pdf.

[65] Hamouri, 1-5.

[66] Ibid.

[67] Ibid.

[68] Ibid.

[69] Ibid.

[70] Ibid.

[71] Ibid.

[72] "World Population Prospects: The 2012 Revision," United Nations, Department of Economic and Social Affairs (2012), accessed on Nov 15, 2014, http://esa.un.org/wpp/unpp/panel_indicators.htm.

[73] "World Population Prospects: The 2012 Revision."

[74] Ibid.

[75] Ibid.

[76] Ibid.

[77] Cables, Rick, Mary Peterson, Mike Cheveas, and Melissa Outhman, "Technical Assistance Scoping Mission to the US Agency for International Development and the Moroccan Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification: Mission Dates: May 5 – 19, 2007." USAID (2007): 3-10.

[78] JICA, 104.

[79] Cables et al., 3-10.

[80] "Institution," Haut-Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification, 2009, http://www.eauxetforets.gov.ma/fr/institution.aspx, paragraphs 2-3.

[81] "Institution," 2-3.

[82] Ibid.

[83] JICA, 104.

[84] "Institution," 2-3.

[85] M.Yassin et al., "Evaluation de l'érosion au Microbassin de Sidi Sbaa: Application du Modèle MUSLE," Annales de la Recherche Forestière au Maroc 42 (2011): 171.

[86] Yassin et al., "Evaluation de l'érosion au Microbassin de Sidi Sbaa: Application du Modèle MUSLE," 171.

[87] Ibid.

[88] Ibid.

[89] Ibid.

[90] Ouassou et al., 343-372.

[91] Ibid.

[92] Loi d'leau 10-95. 1995. Ministere de l'Energie et les Mines et l'Eau et l'Environment, Royaume Du Maroc.

[93] Ibid.

[94] Choukr-Allah, 181-188.

[95] Ouassou et al., 343-372.

[96] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, "Le Plan Directeur d'Aménagement Intégré des Ressources en eau Du Bassin Hydraulique Du Bouregreg et de La Chaouia, Rapport De Synthèse," (2012) : 11-72.

[97] Mohammed Yassin, Interview by Author, Rabat, Morocco, June 30, 2015.

[98] Ahmed Wagdy and Khaled AbuZeid, "Challenges of Implementing IWRM in the Arab Region." (Proceedings of WWF4, Mexico City, 2006).

[99] Wagdy and AbuZeid

[100] Ouassou et al., 343-372.

[101] Ibid.

[102] Ibid.

[103] Wagdy and Abuzeid, 5.

[104] Ibid.

[105] Ouassou et al., 343-372.

[106] Ibid.

[107] Ibid.

[108] "It Belongs to You: Public Information in Morocco." 2013. Transparency Maroc and Transparency International. USAID. 5-10.

[109] Abuzeid, Khaled, "Policy Analysis of National Water Plans in Selected Arab Countries," (Proceedings of 3rd Regional Workshop on Water Governance in the Arab Region, Water Governance Forum, Arab Water Council & Inwent, Marrakesh, 2008).

[110] "Morocco Watershed Protection and Management Project: Final Report," 8-16.

[111] "The Green Morocco Plan- What is it exactly?" Economia, 2014, http://www.economia.ma/fr/numero-07/wp/le-plan-maroc-vert-c-est-quoi-au-juste.

[112] "The Green Morocco Plan"

[113] "Strategy," Ministere d'Agriculture et Pêche Maritime, 2009, http://www.agriculture.gov.ma/pages/la-strategie.

[114] Loi n° 12-03 relative aux études d'impact sur l'environnement, Ministere de l'Energie et les Mines et l'Eau et l'Environment, Royaume Du Maroc, 1995.

[115] "National Human Development Initiative (INDH) Project," (Washington, DC: World Bank, 2012), accessed at http://documents.worldbank.org/curated/en/2012/01/16420886/morocco-national-human-development-initiative-indh-project.

[116] Mustapha Hajji, Interview by Author, Rabat, Morocco, May 13, 2015.

[117] Hajji, Interview with Author.

[118] Luca Fé d'Ostiani, "Watershed Management Case Study: Mediterranean Watershed Management: a Key Component of Rural Development in the Mediterranean Region" (Rome: FAO, 2004): 12-15, 22-27.

[119] d'Ostiani, 12-15, 22-27.

[120] Ibid.

[121] Ibid.

[122] Ibid.

[123] "Morocco Watershed Protection and Management Project: Final Report," 8-16.

[124] Ibid.

[125] Ibid.

[126] Ibid.

[127] Ibid.

[128] Ibid.

[129] Ibid.

[130] Ibid.

[131] Ibid.

[132] Ibid.

[133] Ibid.

[134] "JICA, 104.

[135] Ibid.

[136] Ibid.

[137] Ibid.

[138] Ibid.

[139] Ibid.

[140] Hsieh Wen Shen and Pierre Y. Julien, "Erosion and Sediment Transport," in Handbook of Hydrology, ed. David Maidment, (New York: McGraw-Hill, 1993): 12.1.

[141] Nearing, Mark, "Soil Erosion and Conservation." Publications from USDA-ARS / UNL Faculty 1290 (2013): 365-376.

[142] Nearing, 367.

[143] Nearing, 365-376.

[144] Renard et al., 11-13.

[145] Nearing, 365-376.

[146] Renard et al., 11-13.

[147] Ibid.

[148] Ibid.

[149] Ibid.

[150] Ibid.

[151] Ibid.

[152] Ibid.

[153] Ibid.

[154] Ibid.

[155] Ibid.

[156] Ibid.

[157] Ibid.

[158] Ibid.

[159] Renard et al., 11-13.
[160] Ibid.
[161] Yassin et al., "Evaluation de l'érosion au Microbassin de Sidi Sbaa: Application du Modèle MUSLE," 171-181.
[162] Helena Mitasova and Lubos Mitas, "Modeling soil detachment with RUSLE 3d using GIS," University of Illinois at Urbana Champaign, 2009, accessed at http://www4.ncsu.edu/~hmitaso/gmslab/denix/usle.html/, paragraphs 4-5.
[163] Nearing, 365-376.
[164] Ibid.
[165] Ibid.
[166] Ibid.
[167] Ibid.
[168] Ibid.
[169] Ibid.
[170] Edward P. Gardner and Julie L. Myer, "Sensitivity Of RUSLE to Data Resolution: Modeling Sediment Delivery in the Upper Little Tennessee River Basin," (Paper presented at the proceedings of the 2001 Georgia Water Resources Conference, held March 26-27, 2001, at the University of Georgia), Ed. Kathryn J. Hatcher. 1-3
[171] Gardner and Meyer, 1-3.
[172] Ibid.
[173] Ibid.
[174] Ibid.
[175] Yassin et al., "Evaluation de l'érosion au Microbassin de Sidi Sbaa: Application du Modèle MUSLE," 172.
[176] Renard et al., 11-19.
[177] Ibid.
[178] Ibid.
[179] Lahlou, "The Silting of Moroccan Dams," 71-77.
[180] B. Heusch, "L'Erosion Hydraulique au Maroc: Son Calcul et Son Contrôle," Al Awamia 36, (1970) : 39-63.
[181] Heusch, 39-63.
[182] Ibid.
[183] Ibid.
[184] Ibid.
[185] Ibid.
[186] H.M.J. Arnoldus, "Methodology Used to Determine the Maximum Potential Sheet and Rill Erosion in Morocco," FAO Soils Bulletin 34 (1977): 39-51, in Kenneth, G. Renard and Jeremy R. Freimund, "Using Monthly Precipitation Data to Estimate the R-Factor in the Revised USLE." Journal of Hydrology 154 (1994) 295-297.
[187] Arnoldus, "Methodology Used to Determine the Maximum Potential Sheet and Rill Erosion in Morocco," 39-51.
[188] Ibid.
[189] Ibid.
[190] Ibid.
[191] Ibid.
[192] Ibid.
[193] Ibid.
[194] Lahlou, "The Silting of Moroccan Dams, 71-77.
[195] Ibid.
[196] Ibid.
[197] Ibid.
[198] Ibid.

[199] Lahlou, “The Silting of Moroccan Dams, 71-77.

[200] Lahlou, “The Silting of Moroccan Dams, 75.

[201] Lahlou, “The Silting of Moroccan Dams, 71-77.

[202] Lahlou. “Environmental and Socioeconomic Impacts on Erosion and Sedimentation in North Africa,” 491-500.

[203] Ibid.

[204] Lahlou, “The Silting of Moroccan Dams, 71-77.

[205] Lahlou. “Environmental and Socioeconomic Impacts on Erosion and Sedimentation in North Africa,” 491-500.

[206] Loi de l’eau 10-95

[207] Hsieh Wen Shen and Pierre Y. Julien, 12.1.

[208] Lahlou. “Environmental and Socioeconomic Impacts on Erosion and Sedimentation in North Africa,” 491-500.

[209] M.Chikhaoui and M. Naimi, "Dégradation des Sols dans Le Rif Marocain, " HTE 149/150 (2011): 56-60

[210] Chikhaoui and Naimi, 56-60.

[211] Ibid.

[212] Hanaa El Yadari, “Evolution spatio-temporelle des conditions de surface dans le bassin versant Tleta (Rif Occidental)" (Diplôme Final Project, Institute Agronomique et Vétérinaire de Hassan II, 2012), iv.

[213] Yadari, iv.

[214] Rabii El Gaatib and Abdelkader Larabi, "Integrated Evaluation of Soil Erosion Hazard and Risk Management in the Oued Beht Watershed Using Remote Sensing and GIS Techniques: Impacts on El Kansra Dam Siltation (Morocco), » Journal of Geographic Information Systems 4 (2014): 677-689.

[215] El Gaatib and Larabi, 677-689.

[216] Ibid.

[217] Ibid.

[218] Abdellah Laouina and Gil Mahé, “Gestion Durable des Terres,” (Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo, 2013).

[219] Laouina and Mahé

[220] d’Ostiani, 22-27.

[221] Ibid.

[222] G. Mahé et al., “Evolution des débits et solides du Bouregreg,” in “Gestion Durable des Terres,” eds. Abdellah Laouina and Gil Mahé (Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo, 2013), 21-35.

[223] M. Chaker, A. Laouina, M. El Marbouh, “Changement Agropastoral et Dégradation des Terres dans le Plateau Sehoul," in “Gestion Durable des Terres,” eds. Abdellah Laouina and Gil Mahé (Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo, 2013), 85-102.

[224] V. Maleval, “Premiers Résulte des Mesures d’érosion Ravinaire sur les Versants Lacustres du Barrage Sidi Mohammed Ben Abdellah (Maroc) et Perspectives de Recherche," in “Gestion Durable des Terres,” eds. Abdellah Laouina and Gil Mahé (Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo, 2013), 36-58.

[225] Maleval, 36-58.

[226] Ibid.

[227] J. Al Karkouri, A. Laouina, M. Sfa, K Naimi, “Cartographie de la Gestion Durable des Terres, dans la Commune des Sehoul, (Maroc Atlantique), Approche WOCAT-LADA-DESIRE,” in “Gestion Durable des Terres,” eds. Abdellah Laouina and Gil Mahé (Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo, 2013), 58-85.

[228] El Karkouri et. Al, 58-85.

[229] Ibid.

[230] Ibid.

[231] El Karkouri et. Al, 58-85.

[232] M. Chaker, A. Laouina, M. EL Marbouh, "85-102.

[233] A. Laouina et al., "Management of Gullied Areas in the Atlantic Plateaus of the Bouregreg Watershed, Morocco," in "Gestion Durable des Terres," eds. Abdellah Laouina and Gil Mahé (Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo, 2013), 147-160.

[234] Laouina et al., "Management of Gullied Areas in the Atlantic Plateaus of the Bouregreg Watershed, Morocco," in "Gestion Durable des Terres," 147-160.

[23] Ibid.

[236] Najoua Bensalah, "Indicateurs des Risques de Ruissellement et d'érosion en Vue d'une Gestion Durable des Eaux Sols (Bassin versant de Bouregreg (s.s))," (PhD. Dissertation, Universite Mohammed V-Agdal Faculté des Lettres et des Sciences Humaines (FLSH), 2008), iv.

[237] Bensalah, iv.

[238] Ibid.

[239] Ibid.

[240] Yassin et al., "Evaluation de l'érosion au Microbassin de Sidi Sbaa: Application du Modèle MUSLE," 171-181.

[241] Ibid.

[242] Ibid.

[243] M. Yassin M. et al., "Application du modèle universel de perte en terre révisé (RUSLE) aux terrains forestiers du plateau central," Annal Recherche Pour Maroc 40 (2009) : 50-64.

[244] Ibid.

[245] Ibid.

[246] Ibid.

[247] Ibid.

[248] "Etude d'Aménagement du Bassin Versant du l'Oued Bouregreg en amont du Barrage Sidi Mohammed Ben Abdellah : Notre Méthodologique," (Le Premier Ministere de Haut-Commissariat aux Eaux et Forêts et à la Commissariat à la Lutte Contre la Désertification, 2008), 1-3.

[249] "Etude d'Aménagement du Bassin Versant du l'Oued Bouregreg en amont du Barrage Sidi Mohammed Ben Abdellah : Notre Méthodologique," 1-3.

[250] Badraoui, M. and M. Stitou, "States of Soil Survey and Soil Information System in Morocco," in Soil Resources of Southern and Eastern Mediterranean Countries, eds. P. Zdruli, P. Steduto, C. Lacirignola, and L. Montanarella, (Bari: CIHEAM, 2001), 193-201.

[251] Division of Environment and Soils, L'ONEP, Interview by Author, Rabat, Morocco, May 13, 2015.

[252] Said Ouattar et al., "Database Needs Assessment for Integrated Water Resources Management in the Souss-Massa Basin," FORWARD (2000): 38-50.

[253] Yassin, Interview with Author.

[254] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.

[255] Laouina, 21-35.

[256] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.

[257] Ibid.

[258] Ibid.

[259] Loi de l'eau 10-95

[260] Laouina, 21-35.

[261] Ibid.

[262] "Complexe de Production d'eau Potable Bouregreg," L'Office Nationale de L'eau Potable, 2013, http : // www.onep.ma/directions/drc/vue_drc.htm, paragraphs 1 and 2.

[263] Laouina, 15-16.

[264] Ibid.

[265] Laouina, 15-16.

[266] Ibid.

[267] El Hamouri, 1-5.

[268] Fry, 8.

[269] Laouina, 11-12.
[270] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.
[271] Ibid.
[272] Ibid.
[273] Berkat O. and M. Tazi, 2004 ; Ministère de l'Agriculture et de la Réforme Agraire, 1992, in A. Laouina, "Le Bassin Versant du Bouregreg, Caractéristiques Géographiques," in "Gestion Durable des Terres," eds. Abdellah Laouina and Gil Mahé (Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo, 2013), 11-12.
[274] Laouina, 11-13.
[275] Ibid.
[276] Ibid.
[277] Ibid.
[278] Ibid.
[279] Laouina, 15-16.
[280] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.
[281] Ibid.
[282] Ibid.
[283] Ibid.
[284] Skye Cooley, "Hypsometric Curves, H1, R1 Index," GIS for Geomorphology, 2014, http://gis4geomorphology.com/hypsometric-index-integral/, paragraph 5.
[285] Skye Cooley, paragraph 5.
[286] Ibid.
[287] Ibid.
[288] Ibid.
[289] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.
[290] Ibid.
[291] Ibid.
[292] Ibid.
[293] Ibid.
[294] Ibid.
[295] Ibid.
[296] Ibid.
[297] Ibid.
[298] Ibid.
[299] Ibid.
[300] Ibid.
[301] Ibid.
[302] Ibid.
[303] Ibid.
[304] Ibid.
[305] Ibid.
[306] Ibid.
[307] Ibid.
[308] Ibid.
[309] Ibid.
[310] Ibid.
[311] Ibid.
[312] "Complexe de Production d'eau Potable Bouregreg," L'Office Nationale de L'eau Potable, 2013, accessed at http : // www.onep.ma/directions/drc/vue_drc.htm, paragraphs 1 and 2.
[313] Ibid.
[314] Laouina, 11-12.

[315] Ryzak, Arthur C. “Visualizing Large Scale Changes in the Water Budget with a Custom GIS Script Tool.” (Master Departmental Report, the University of Texas at Austin, 2014). 2-3.

[316] Ryzak, 2-3.

[317] Ibid.

[318] Ibid.

[319] Ibid.

[320] Laouina, 11-12.

[321] Agence du Bassin Hydraulique du Bouregreg Et De La Chaouia, 11-72.

[322] Laouina, 11-12.

[323] Ibid.

[324] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.

[325] Ibid.

[326] Ibid.

[327] Loi de l’eau 10-95.

[328] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.

[329] Hamid Bounouira et al., "Distribution of the Rare Earth Elements in the Sediments of the Bouregreg River (Morocco) Using the Instrumental Neutron Activation Analysis (INAA)," J. Appl. Sci. Environ. Manage. 11 (2007) : 57 – 60.

[330] “Etude d’Aménagement du Bassin Versant du l’Oued Bouregreg en amont du Barrage Sidi Mohammed Ben Abdellah : Analyse des Problèmes d’Erosion et Identificateur des Zones Prioritaires," (Le Premier Ministere de Haut-Commissariat aux Eaux et Forêts et à la Commissariat à la Lutte Contre la Désertification, 2008), 1-3.

[331] Mohamed Rahdou, "Modelisation Hydrologique du Bassin Versant de Bouregreg (S.S) et Evaluation de Taux d’Envasement du Barrage Sidi Mohamed Ben Abdellah (Maroc) Par la Méthode Bathymétrique," (Project Fin d’Etudes L’Ecole Mohammedia des Ingénieurs, 2010), 6.

[332] “Complexe de Production d’eau Potable Bouregreg," paragraphs 1 and 2.

[333] Ibid.

[334] Ibid.

[335] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.

[336] Ibid.

[337] “Complexe de Production d’eau Potable Bouregreg," paragraphs 1 and 2.

[338] Ibid.

[339] Ibid.

[340] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.

[341] “Etude d’Aménagement du Bassin Versant du l’Oued Bouregreg en amont du Barrage Sidi Mohammed Ben Abdellah : Etude du Milieu Physique et des Facteurs Physiques d’Erosion" (Le Premier Ministere de Haut-Commissariat aux Eaux et Forêts et à la Commissariat à la Lutte Contre la Désertification, 2008), 2.

[342] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.

[343] Ibid.

[344] Ibid.

[345] Ibid.

[346] Ibid.

[347] Fischer, G., F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, D. Wiberg, “Global Agro-ecological Zones Assessment for Agriculture,” IIASA (Rome, FAO,2008).

[348] “Etude d’Aménagement du Bassin Versant du l’Oued Bouregreg en amont du Barrage Sidi Mohammed Ben Abdellah : Etude du Milieu Physique et des Facteurs Physiques d’Erosion," 1-3.

[349] Ibid.

[350] Ibid.

[351] Ibid.

[352] Ibid.

[353] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.

[354] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.
[355] Ibid.
[356] A. Laouina et al., "Dynamique de l'eau et Gestion des terres dans le contexte du changement global, analyse agro-hydrologique dans le bassin du Bouregreg (Maroc), » Sécheresse, 15-1 (2004) : 66-77.
[357] Laouina et al., "Dynamique de l'eau et Gestion des terres dans le contexte du changement global, analyse agro-hydrologique dans le bassin du Bouregreg (Maroc), 66-77.
[358] Ibid.
[359] Ibid.
[360] Ibid.
[361] Ibid.
[362] Renard et al., 11-19.
[363] Ibid.
[364] Ibid.
[365] Ibid.
[366] Ibid.
[367] Ibid.
[368] Ibid.
[369] Ibid.
[370] F. Fournier, "Climat et Erosion," Universitaires de France (1960).
[371] Arnoldus in Renard and Freimund, 295-297.
[372] Ibid.
[373] Ibid.
[374] Mitasova and Mitas, 4-5.
[375] Ibid.
[376] Ibid.
[377] Ibid.
[378] Ibid.
[379] Ibid.
[380] Renard et al., 11-19.
[381] Ibid.
[382] Ibid.
[383] Ibid.
[384] Ibid.
[385] Harmonized World Soil Database v1.2 in G. Fischer, F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, and D. Wiberg, "Global Agro-ecological Zones Assessment for Agriculture" (Laxenburg: IIASA and FAO, 2008), accessed August 20, 2015 at http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/#jfmulticontent_c284128-2.
[386] G Fischer et al.
[387] Ibid.
[388] Renard et al., 11-19.
[389] J.M. van der Knijff, R.J.A. Jones, and L. Montanarella, "Soil Erosion Risk Assessment in Italy," European Commission Directorate General Joint Research Centre (1999): 21-28.
[390] Van der Knijff et al., 21-28.
[391] G. Chander, B. L. Markham, and D. L. Helder, "Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors," Remote Sensing of Environment 113 (2009): 893-903.
[392] Van der Knijff et al., 21-28.
[393] Ibid.
[394] Ibid.
[395] Ibid.
[396] Van der Knijff et al., 21-28.
[397] Ibid.

[398] Van der Knijff et al., 21-28.
[399] Ibid.
[400] Berkat and Tazi, 11-12.
[401] Van der Knijff et al., 21-28.
[402] El Gaatib and Larabi, 677-689.
[403] Ibid.
[404] Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, 11-72.
[405] 30 meter Digital Elevation Model, Shuttle Radar Topography Mission, accessed August 25, 2014 and February 15, 2015, http://earthexplorer.usgs.gov/.
[406] W. H. Wirschmeier and D. D. Smith, "Predicting Rainfall Erosion Losses- A Guide to Conservation Planning," USDA Agricultural Handbook No. 537 (1978): 179-186.
[407] Mitasova and Mitas, 4-5.
[408] "It Belongs to You: Public Information in Morocco," 5-46.
[409] Ibid.
[410] Ibid.
[411] Ibid.
[412] Ibid.
[413] Ibid.
[414] Ibid.
[415] Ibid.
[416] Ibid.
[417] Ibid.
[418] Ibid.
[419] Ibid.
[420] Ibid.
[421] Ibid.
[422] Ibid.
[423] Ibid.
[424] Ibid.
[425] Ibid.
[426] Ibid.
[427] "It Belongs to You: Public Information in Morocco," 37.
[428] "Morocco Free Trade Agreement," Office of the United States Trade Representative, accessed November 12, 2015, paragraph 1, https://ustr.gov/trade-agreements/free-trade-agreements/morocco-fta.
[429] Othoman Mellouk, "Struggling to Balance Free Trade with Access to Medicines in the post-TRIPS Era, throughout the Arab World," (Proceedings of Intellectual Property Rights (IPRs), Innovation and Sustainable Development Conference, June 26-28), accessed November 12, 2015, 1, http://www.iprsonline.org/unctadictsd/docs/Mellouk_ArabRD_Health.pdf.
[430] "It Belongs to You: Public Information in Morocco," 5-46.
[431] Ibid.
[432] Ibid.
[433] Ibid.
[434] Ibid.
[435] Ibid.
[436] Ibid.
[437] "It Belongs to You: Public Information in Morocco," 16.
[1] Ibid.
[438] "UN-backed meeting in Morocco to focus on modernizing governments," UN News Center, 2002, paragraphs 1-3, http://www.un.org/apps/news/story.asp?newsid=5563&cr=&cr1.
[439] "It Belongs to You: Public Information in Morocco," 5-46.
[440] "It Belongs to You: Public Information in Morocco," 16.
[441] Ibid.

[442] Rachid Moussadek, Interview by Author, Rabat, Morocco, June 29, 2015.

Appendices

APPENDIX 1: FIGURES AND TABLES REFERENCED IN REPORT

Table 9: Land Use Classes in the Bouregreg Basin

Land Use Class	Area in kilometers^2	Percent of Basin Area
Water	40.732	0.416
Urban Built Up Areas	71.223	0.727
Forest	2,989.811	30.528
Mixed Forest and Crop Range Lands	170.556	1.742
Shrubland	461.059	4.708
Bare Soil	499.770	5.103
Sparse Vegetation	251.797	2.571
Croplands and Rangelands	5,308.685	54.205

Source: Generated by Madeline Clark using data from Landsat 5 TM Images 2021037, 2022036, 2022037, September 5 and 14, 2011, Shuttle Radar Topography Mission, accessed May 23, 2015 at http://earthexplorer.usgs.gov/.

Table 10: Station Information for Bouregreg Stations and Cheikh Reguig

Station Name	Elevation (30 meter)	Average Annual Precipitation (mm)	Average Monthly Precipitation (mm)	Maximum Monthly Precipitation (mm)	Minimum Monthly Precipitation (mm)
Aguibat Ezziar	180	469.27	39.11	159.82	0.08
Ain Loudah	168	378.96	31.58	120.00	0.03
Barrage SMBA	59	464.19	38.68	145.82	0.05
Cheikh Reguig	89	461.30	38.44	143.79	0.01
Lalla Chafia	266	375.09	31.26	113.15	0.01
Ouljet Haboub	556	338.95	28.25	95.22	0.10
Ras El Fatiha	232	412.38	34.36	131.72	0.11
Roumani	316	364.63	30.39	113.74	0.06
Sidi Amar	329	392.14	32.68	113.99	0.00
Sidi Jabeur	764	325.19	27.10	94.07	0.01
Sidi Moh Cherif	324	386.28	32.19	118.54	0.12
Tsalat	659	493.14	41.09	140.48	0.32

Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Table 13: Dominant Soil Types in the Bouregreg Basin

FAO Class Name	USDA TEXTURE	Area in kilmeters^2	Percent of Basin Area
Chromic Luvisols	loam	372.74	3.81
Calcic Kastanozems	loam	233.71	2.39
Eutric Planosols	loam	1855.70	18.95
Chromic Luvisols	loam	4473.63	45.68
Vertisols	clay light	724.18	7.39
Chromic Luvisols	loam	2084.814366	21.29
Calcic Cambisols	loam	48.45505114	0.49

Source: Generated by Madeline Clark using data from the Harmonized World Soil Database v1.2 in G. Fischer, F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, and D. Wiberg, "Global Agro-ecological Zones Assessment for Agriculture" (Laxenburg: IIASA and FAO, 2008), accessed August 20, 2015 at http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/.

APPENDIX 2: TREATMENT AND PROCESSING OF DATA USED IN STUDY

A. DEM: Hydrologic Boundaries Used in Study

1. STRM 90 meter DEM data was downloaded from USGS's EarthExplorer and loaded into ESRI's ArcMap 10.3 GUI. To delineate catchments, the Hydrology toolset within ArcMap's Spatial Analyst Extension was used. The Sink tool was used to determine if there were any extraneous depressions or sinks in the DEM that would affect flow direction. The Fill tool was then used to create a depressionless DEM.
2. The next step in processing involved executing the Flow Direction tool in ArcMap, which is necessary to both derive catchments, be they sub-basins or watersheds, and the topographical calculations necessary to derive the LS factor.
3. Flow Direction in ArcMap was executed using the 8 direction pour point method used as a default in the ArcGIS framework.
4. From this point, the Flow Accumulation tools was used to derive maximum flows within the drainage network- this tool is essential for determining channel networks, and consequently catchments.
5. From this point, the output drainage network calculated by the Flow Accumulation tool was re-classed to 100,000 due to the fact that a balance had to be struck between detail and comprehension in a large-basin scale, though It is possible to re-class to 10,000, 100,000- the choice is usually based on the nature of the study area and the scale of analysis.
6. From this point, the Stream Order tool was used to determine the order of stream links in the drainage network, using the Strahler Order method.
7. Stream link was then used to assign values to the ordered links and their junctions within the drainage network, which is necessary for creating a representation of catchments via the watershed tool later.
8. Stream to feature was then used to create a representation of waterways within the drainage network. This processes, importantly, was repeated using a 10,000 threshold for sub-basin delineation.
9. The Basin tool was used to create a representation of the Bouregreg basin as according to the DEM used, with flow direction as the input.
10. The Watershed tools was used to create a representation of sub-basins at 10,000 and micro-catchments at the watershed level using the 100,000 threshold using flow direction, the linear network created from steps 4-8, in order to determine the contributing area for points of high flow, represented by the junctions created by the stream link tool.
11. The resulting sub-basin and watershed (micro-catchment) layers are derived only using the DEM, and so are only an approximation of the way that the Bouregreg Basin is subdivided. Methods for creating sub-basins vary widely among agencies, and usually involve using stations as pour points, which are considered to be high points of flow accumulation in deriving catchment areas.
12. The final boundaries are displayed in Figure 8 as a comparison between hydrologically defined boundaries and Bouregreg drainage basin boundaries defined for study

Source: Compiled by Madeline Clark.

B. Precipitation Data from Agence du Bassin de Bouregreg-Chaouia

The Agence du Bassin de Bouregreg-Chaouia provided the conductor of this study with 37 years of daily precipitation data for 19 stations with the Bouregreg-Chaouia River Basin system. This data was formatted into agricultural years from 1976-2013 in multi-tab excel workbooks.

1. To create a longitudinal dataset of all 19 stations by station, year, month, and day. Visual basic coding was employed in Excel using the developer tab.
2. After data were compiled, they were analyzed to check for baseline equivalence across stations and across years, months, and days.
3. Categorical variables were created to denote blank, error, missing, taste, and unusable records.
4. These records were compiled and the dataset was analyzed to determine what subset of stations and years to use. Stations and years with more than 40 percent of values missing were dropped from the dataset. For a summary table describing data quality characteristics, see Appendix 1. The resulting subset of data was for 26 years and 11 stations in the Bouregreg Basin, and 1 station in the Chaouia Basin. Years ranged from 1984-1989, 1991-2005, and 2009-2013. Stations included Aguibat Ezziar, Aid Loudah, Barrage Sidi Mohammad Ben Abdellah, Cheikh Reguig, Lalla Chafia, Ouljet Haboub, Ras El Fatiha, Roumani, Sidi Amar, Sidi Jabeur, Sidi Moh Cherif, and Tsalat.
5. To fill or approximate missing and error values, the Simple Average Mean Method was used. The Simple average mean involves using at least the 3 nearest stations to estimate missing rainfall. In order to estimate the proximity of stations to one another for this method, the near tool was used in ArcMap to create a table of stations and their relative proximity to one another.
6. After these steps were completed, sums of precipitation by month and by year were derived using Excel's pivot table tool for input into the Arnoldus modified Fournier equation. The modified Fournier index was then computed using the relation listed in methods, and then rasterized using ArcMap's polygon to raster tool.

Source: Compiled by Madeline Clark.

C. Landsat 5 TM Pre-processing
(Radiometric Calibration, Atmospheric Correction, Data Resizing, Noise Reduction)

The conductor of this study used Envi 5.2 for radiometric calibration and atmospheric correction. Landsat 5 TM panels 2021037, 2022036, and 2022073 were acquired for September 5th and 14th 2011, respectively. It should be noted that only this date was used, and for this sensor, due to the scarcity of cloud-free images for the northwest central coastline of Morocco. Equation # demonstrates the algorithm used in radiometric calibration. This day was at a 30 meter resolution, or more precisely 33, which was resampled to 28 to match the STRM DEM data.
A scaling factor of 0.10 was used. Radiometrically corrected images are necessary for input into ENVI's FLAASH algorithm. This is an expression for correcting for radiance at the sensor at time of image capture.
Images are then input into flash, which then corrects for reflectance at the sensor. The parameters necessary to determine surface reflectance are time of capture at the date in month/year, and then time in hours, minutes, seconds; sensor information including latitudinal/longitudinal position, altitude, elevation, to derive the azimuth. A scale factor of 1 was used. The output is a surface reflectance corrected images.
FLAASH multiplies images by a factor of 10,000 to eliminate decimals and reduce output image size. After these radiometrically and atmospherically corrected images were obtained, ENVI's Bandmath function was used to scale the images back down.
Following this, images were processed in ENVI's Forward Minimum Noise Fraction noise reduction tool. Eigenvalues were determined to be normal.
Images were then loaded into ArcMap for mosaicking using ArcMap's Mosaic to Raster tool. After being mosaicked, the resulting raster was processed in ArcMap's' image analysis toolbar NDVI tool.
Image classification was then performed using ArcMap's image classification toolbar using a supervised classification technique, which involved collecting samples of the 8 land use types. The maximum likelihood classification equation was used. SIGMED's vegetation dataset for Bouregreg and the Global Land Cover Facility's Land Cover dataset were used as references.

Source: Compiled by Madeline Clark.

D. eMODIS Pre-Processing

1. eMODIS data were downloaded using EarthExplorer and accessed through ArcMap's GUI. Each panel downloaded was for the whole of Africa. This dataset is for 10-day averages at 250 meter resolution. Dates included the 26th of every month for agricultural years 2009-2013 for a total of 60 images. These data are pre-processed by USGS radiometrically and atmospherically and for cloud cover and errors. A Quality file is included to guide users with codes for good data, cloud, snow, etc.
2. Each panel was accessed and then the shapefile for the Bouregreg Basin delineated was used to extract a subset for the data. These images were then examined for inconsistencies. Images with significant cloud cover (removed) had no data parts of images removed using the re-class toolset in ArcMap. Averages for at least 3 good months were used for the no data sections of these images in an adaptation of the methodology proposed by Alaska lab. NDVI was then derived for each image.
3. The resulting Landsat image and eMODIS images were then put through the C Factor algorithm. Values above 1 were analyzed visually and determined to be water. These parts of the images were extracted from each image re-classed to 1 and then combined with the rest of the data.
4. For eMODIS images. Each resulting image was grouped by year and the 12 months were averaged to obtain an average for each year. This was repeated by month, but due to the fact that the R factor is annual and not monthly, these images were not used.

Source: Compiled by Madeline Clark.

E. FAO data

The Harmonized World Soil Database in Microsoft Access format, the Digital Soil Map of the World in vector or shapefile format, and the Harmonized World Soil Database Viewer were downloaded from the FAO website. Morocco's dataset is still linked to the FAO 74 dataset. Moroccan administrative boundaries obtained from ONEE's GIS division were used to extract a subset of this data DSMW, as with Bouregreg Basin. The Morocco subset was linked to the HWSD. This subset was examined with reference from the HWSD viewer to extract the parameters needed to compute the K Factor, including percent organic matter/ carbon, particle size in the form of percent silt, sand, clay, texture, and permeability. These parameters were then used to compute K, and displayed using the field. The resulting K factor was rasterized for processing in the RUSLE model using ArcMap's polygon to raster toolset.

Table 23: Precipitation Data Quality, by Station

Station Name	Unusable Value	Percent
Aguibat Ezziar	166	1.52
Ain Loudah	69	0.63
Barrage El Mellah	345	3.15
Barrage Mazer	646	5.9
Barrage SMBA	140	1.28
Cheikh Reguig	46	0.42
El Gara	761	25
El Mers	160	1.46
Feddan Taba	70	0.64
Lalla Chafia	8	0.07
Ouljet Haboub	379	3.46
Ras El Fatiha	39	0.36
Roumani	58	0.53
Sidi Amar	941	8.59
Sidi Jabeur	156	1.42
Sidi Moh Cherif	10	0.09
Skhirat	50	0.46
Tamdrost	314	2.87
Tsalat	37	0.34
Grand Total	4395	2.19

Source: Compiled by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

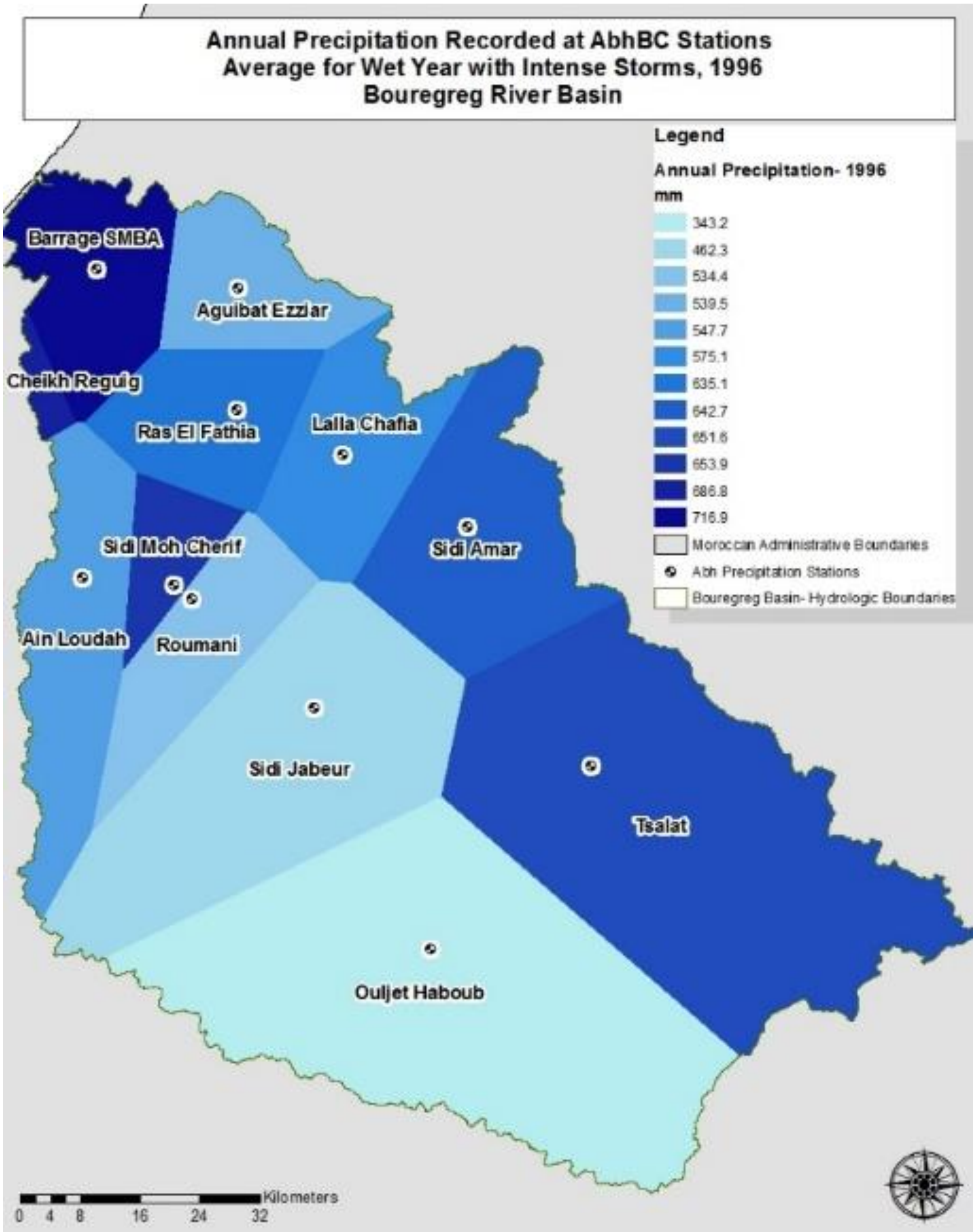
Table 24: Precipitation Data Quality, by Year

Year	Unusable Value	Percent
1984	219	9.97
1985	244	3.71
1986	26	0.4
1987	1	0.02
1988	25	0.38
1989	218	3.32
1990	40	0.61
1991	1	0.02
1992	63	0.96
1993	49	0.75
1994	16	0.24
1995	46	0.7
1996	28	0.43
1997	45	0.68
1998	40	0.61
1999	83	1.26
2000	97	1.47
2001	28	0.43
2002	246	3.74
2003	274	4.17
2004	210	3.19
2005	119	1.81
2006	337	5.04
2007	399	5.75
2008	476	6.84
2009	303	4.37
2010	126	1.82
2011	214	3.09
2012	177	2.55
2013	0	0
2014	245	5.17
Grand Total	4395	2.19

Source: Compiled by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

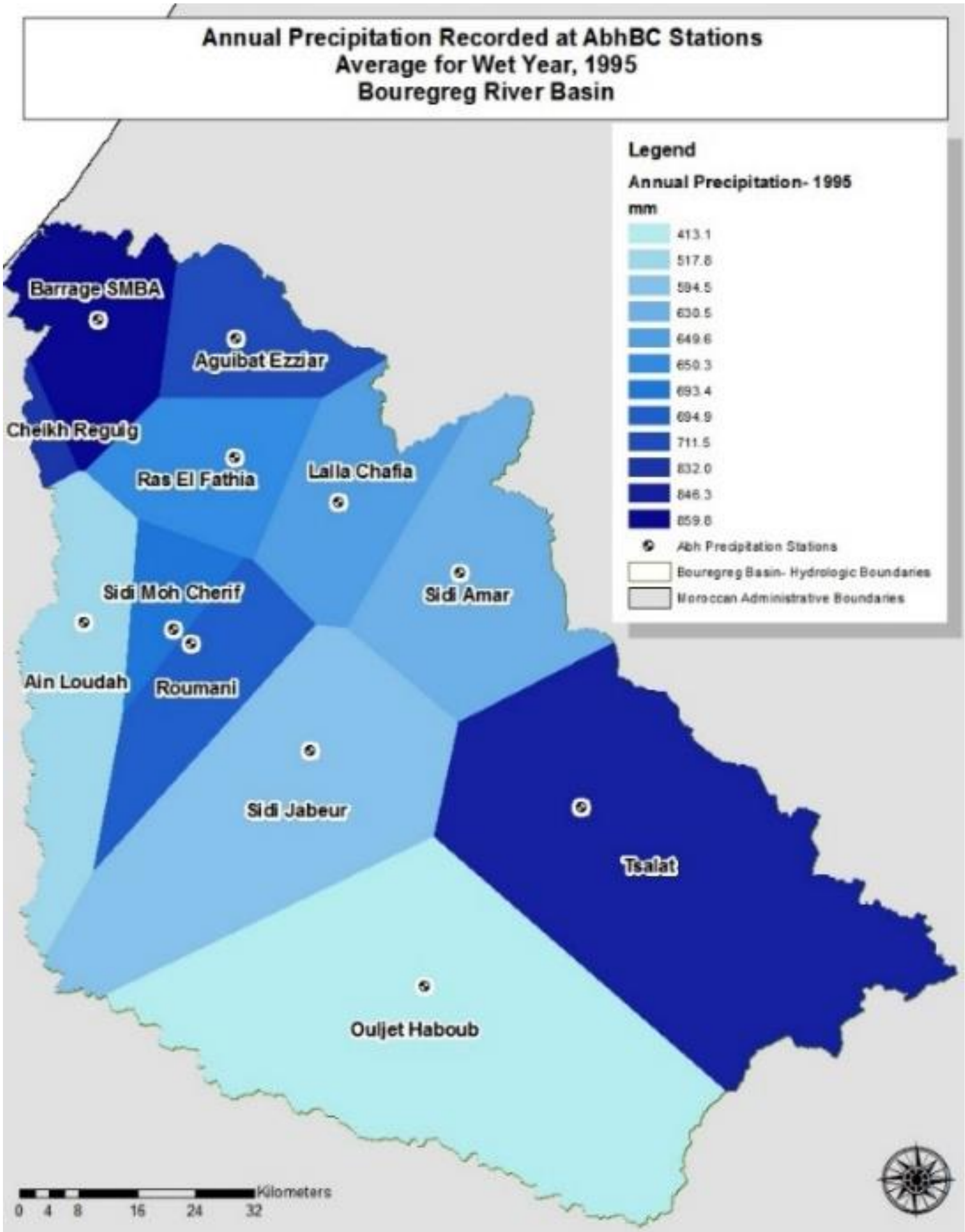
APPENDIX 3: VARIATION IN PRECIPITATION

Figure 55: Annual Precipitation for the Bouregreg Basin, 1994



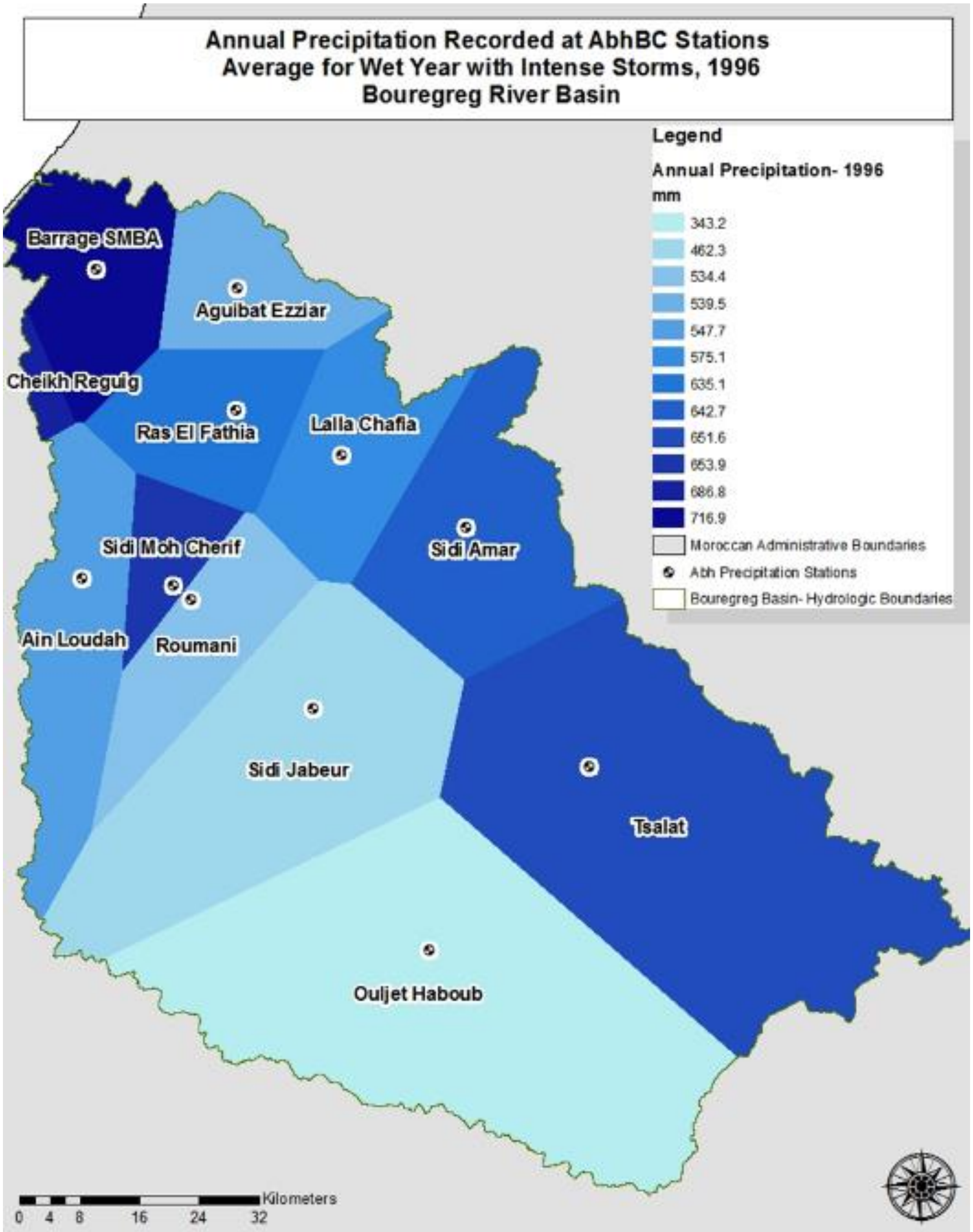
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 56: Annual Precipitation for the Bouregreg Basin, 1995



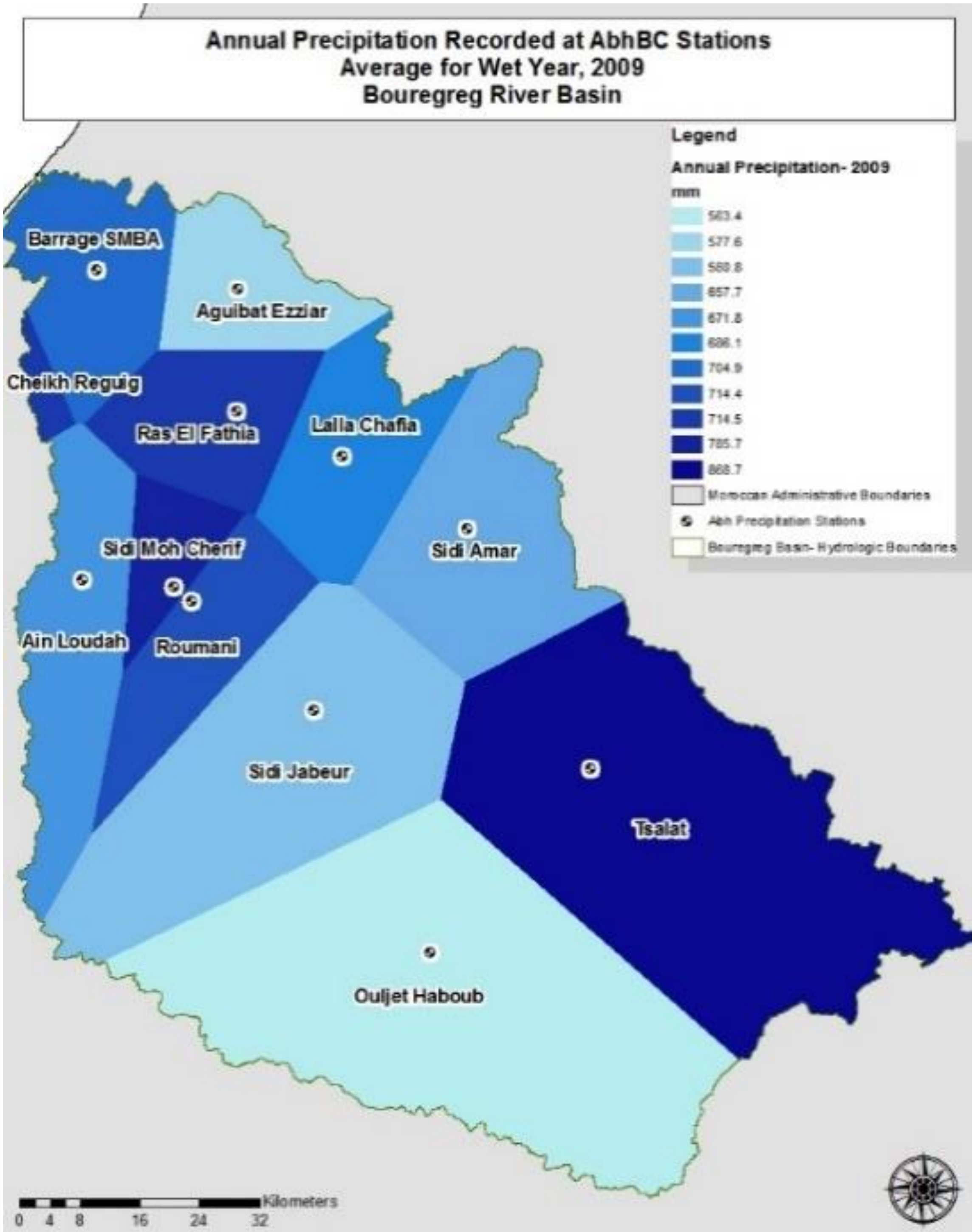
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 57: Annual Precipitation for the Bouregreg Basin, 1996



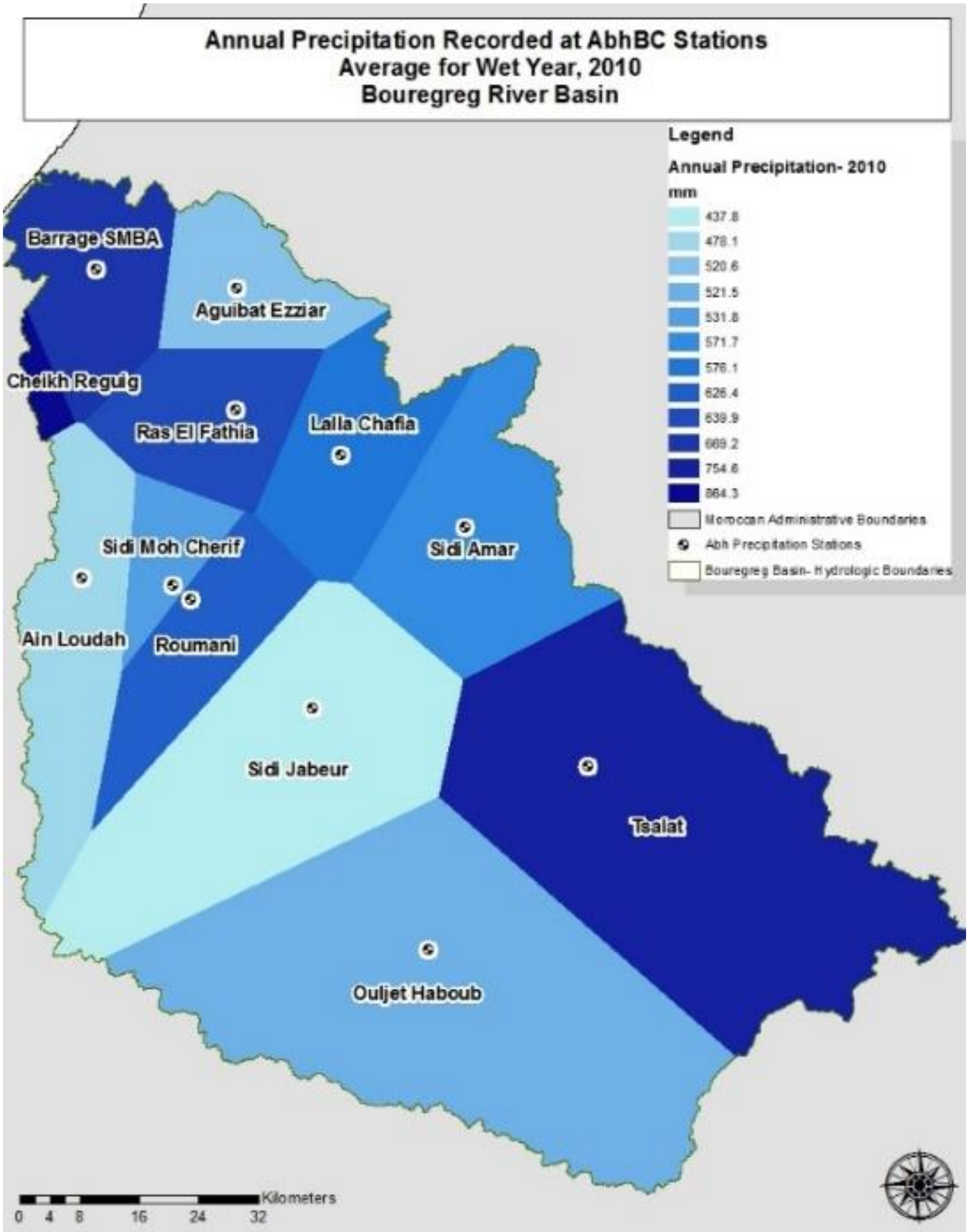
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 58: Annual Precipitation for the Bouregreg Basin, 2009



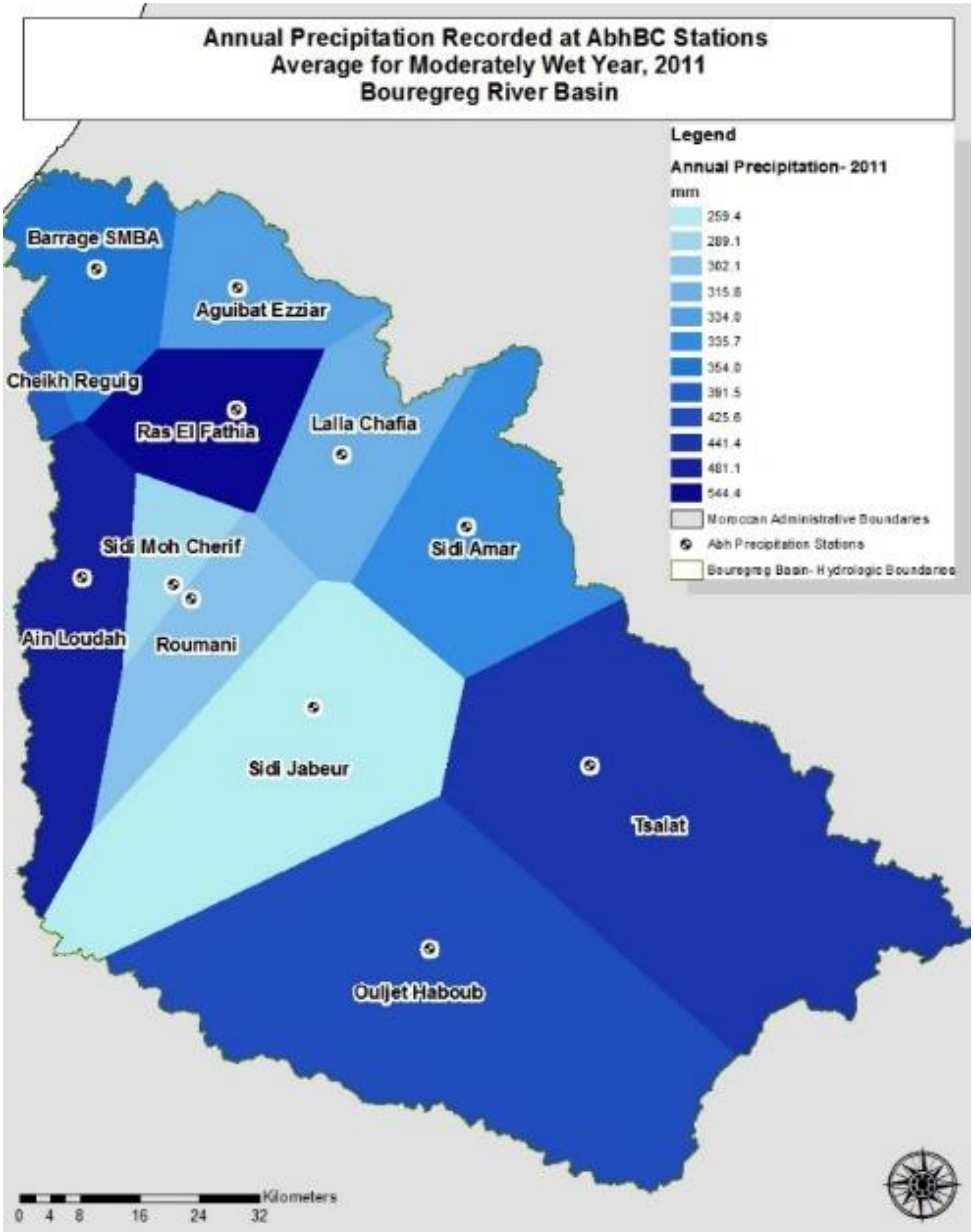
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 59: Annual Precipitation for the Bouregreg Basin, 2010



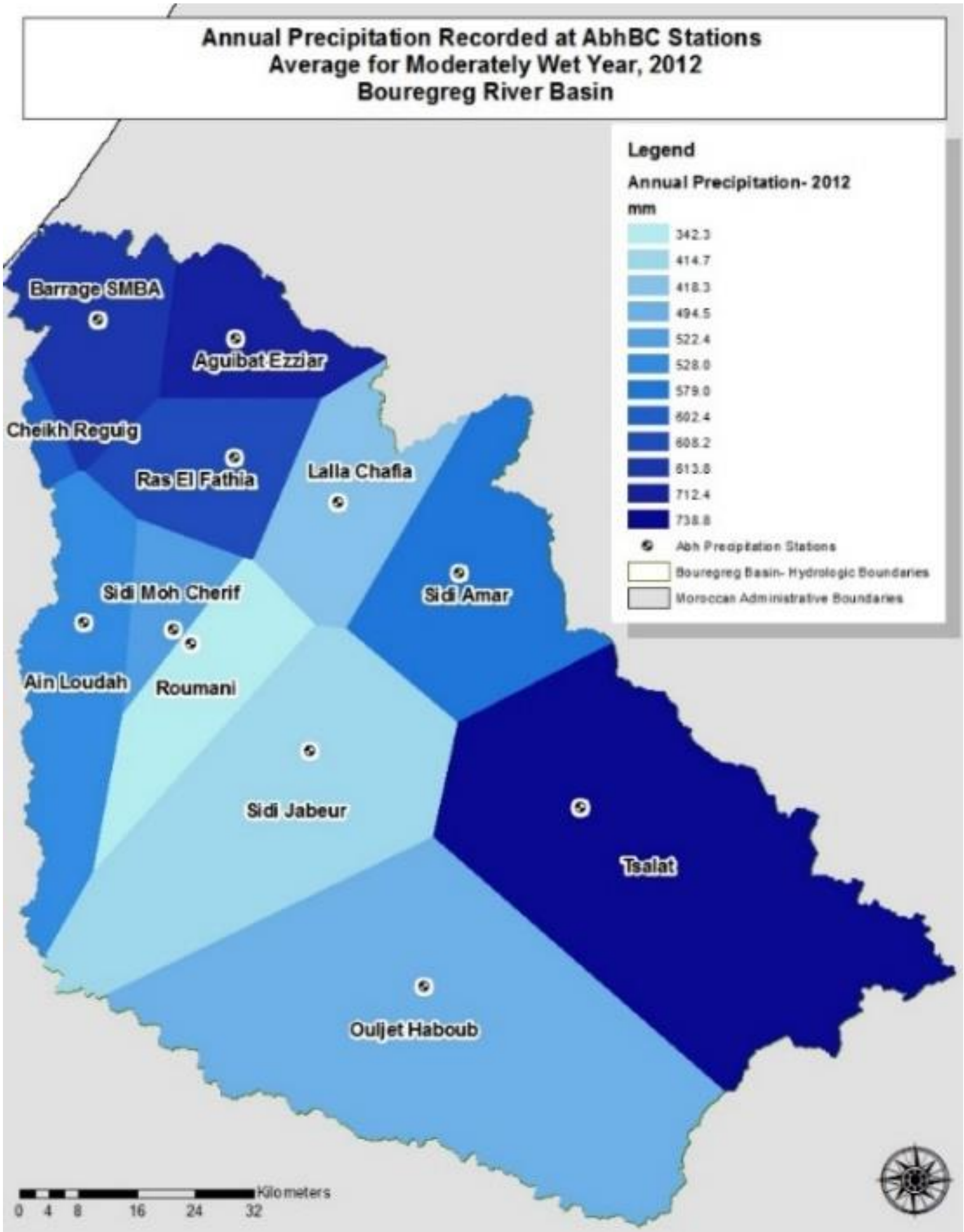
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 60: Annual Precipitation for the Bouregreg Basin, 2011



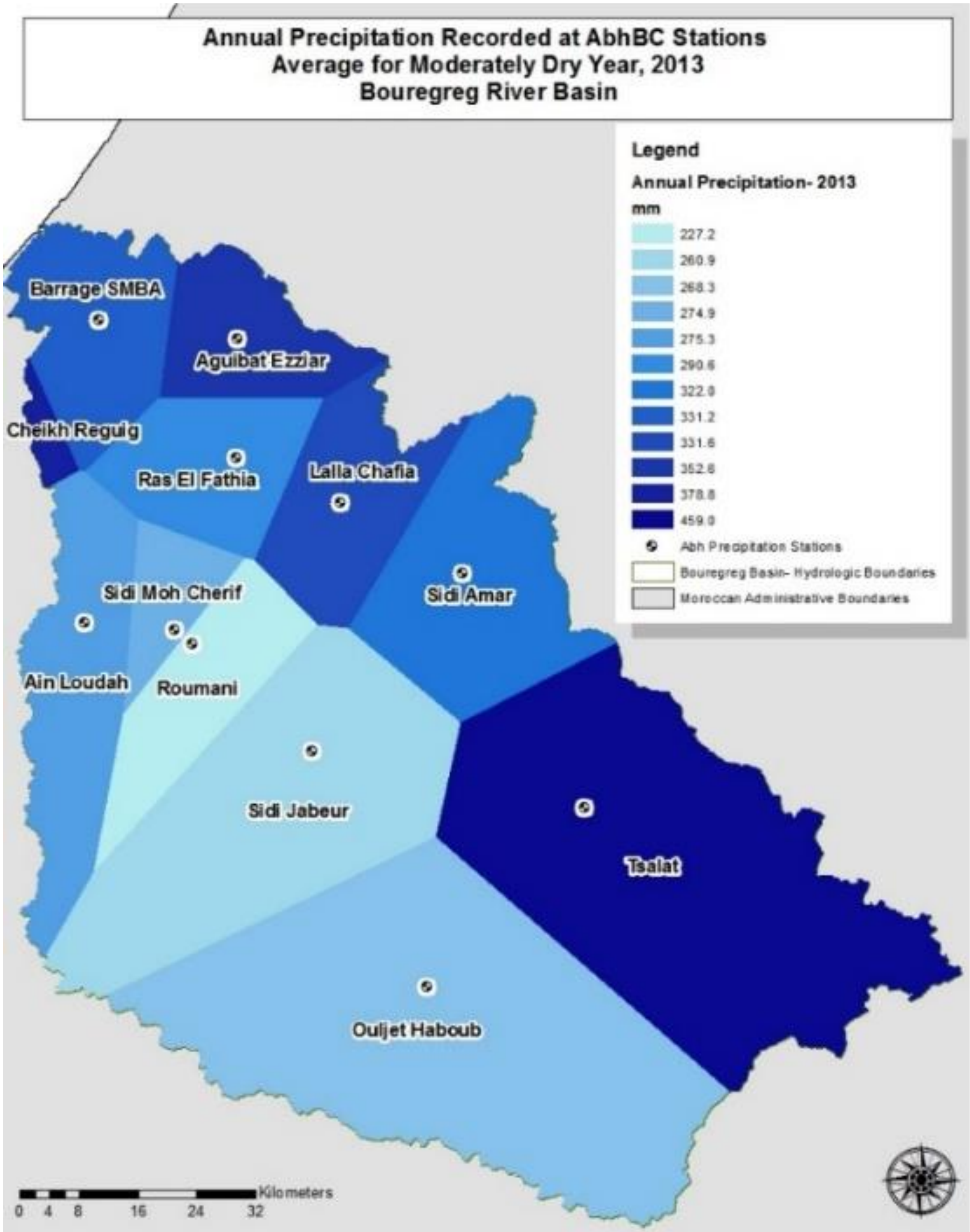
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 61: Annual Precipitation for the Bouregreg Basin, 2012



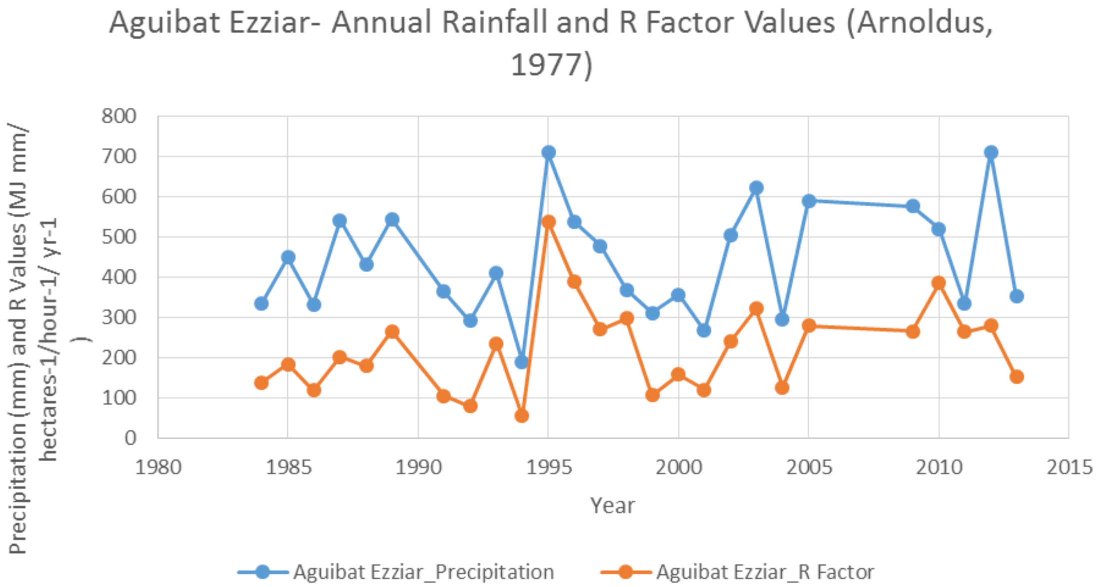
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 62: Annual Precipitation for the Bouregreg Basin, 2013



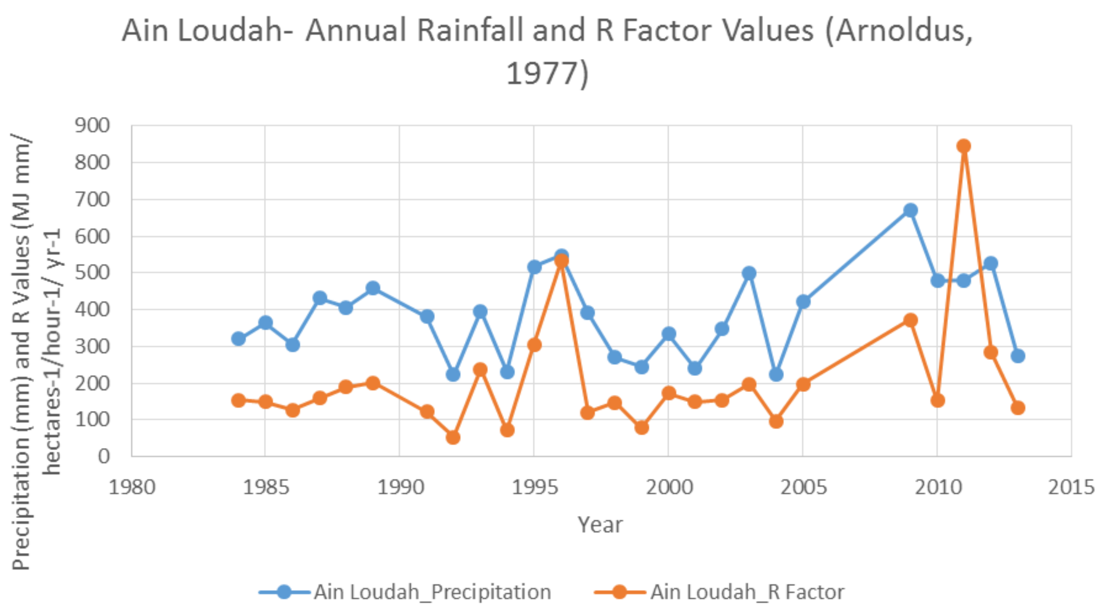
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

.Figure 63: Average Annual Precipitation and R-Values, Aguibat Ezziar



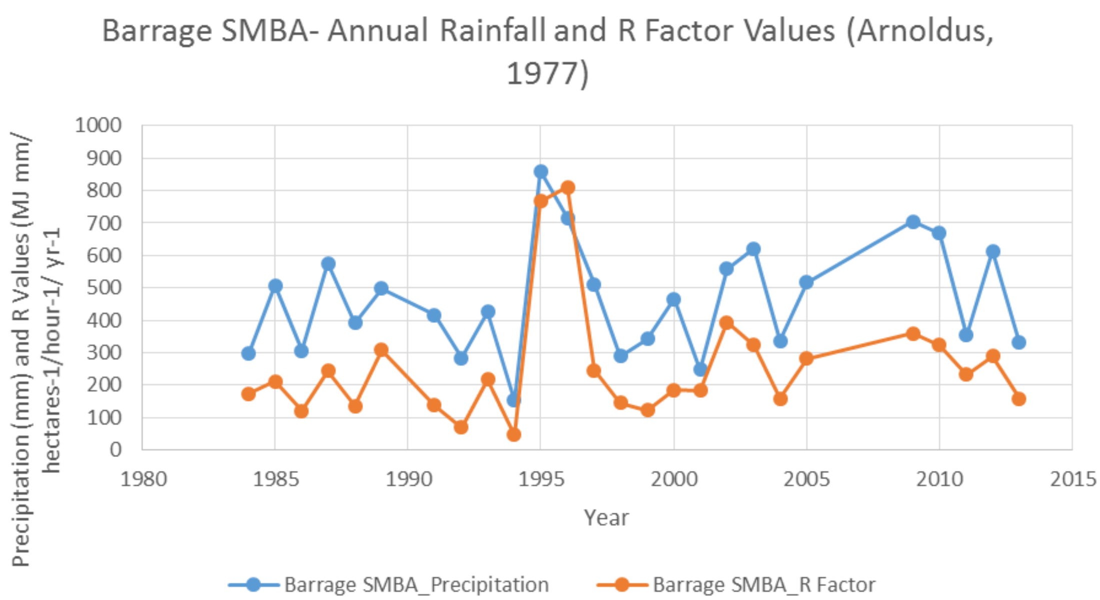
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 64: Average Annual Precipitation and R-Values, Ain Loudah



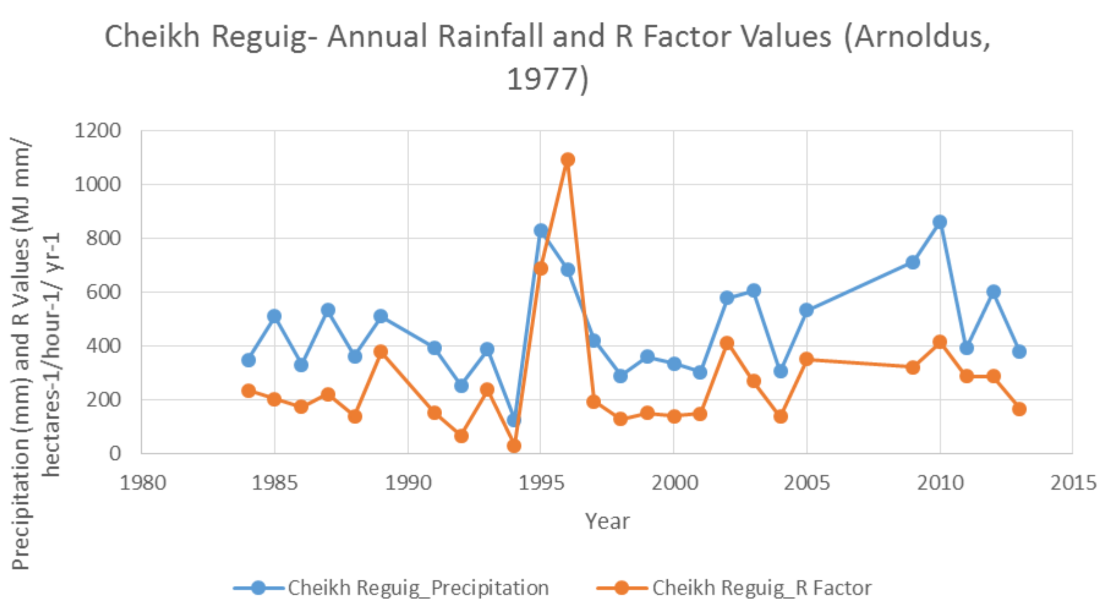
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 65: Average Annual Precipitation and R-Values, SMBA Dam



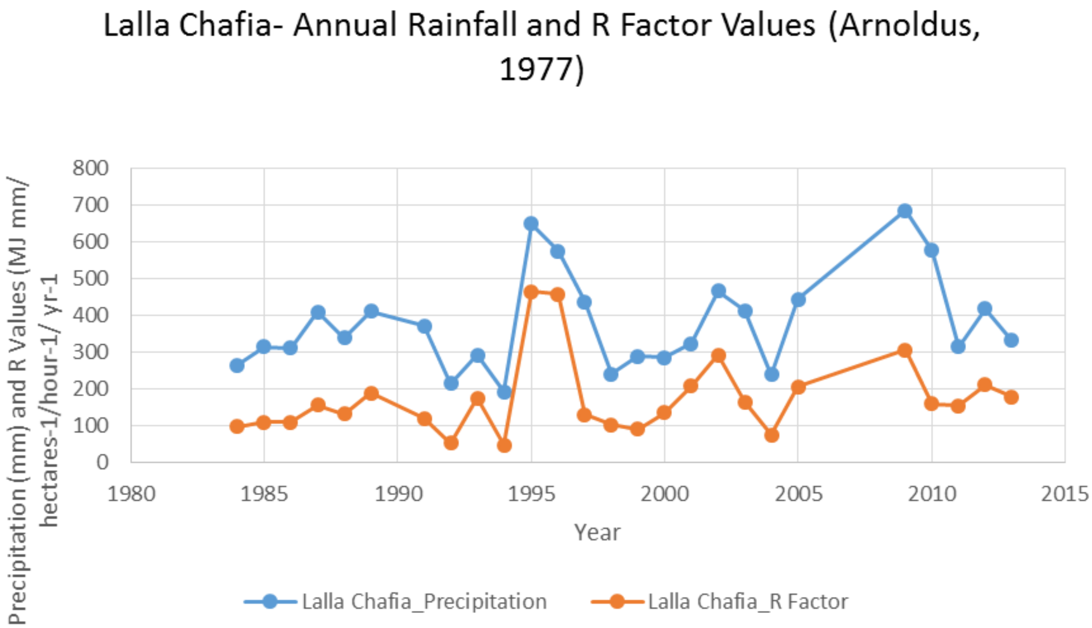
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 66: Average Annual Precipitation and R-Values, Cheikh Reguig



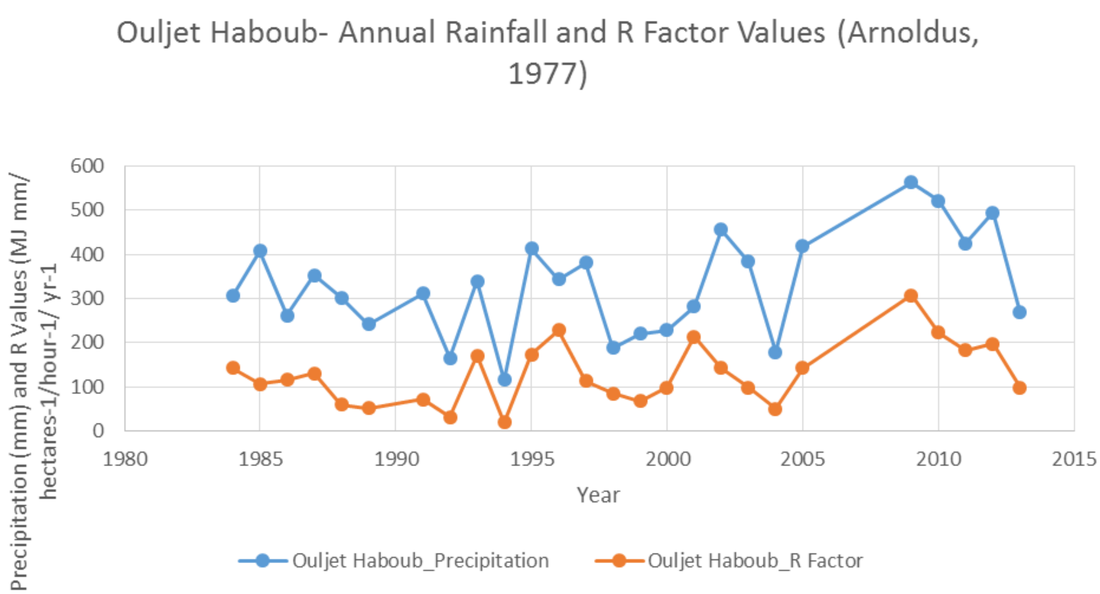
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 67: Average Annual Precipitation and R-Values, Lalla Chafia



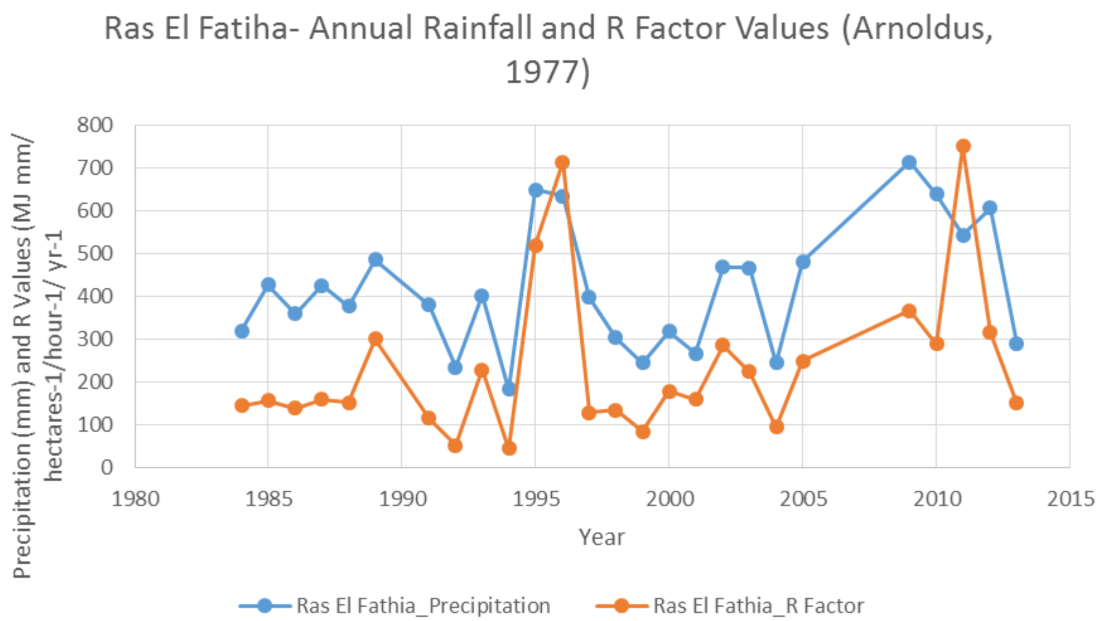
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 68: Average Annual Precipitation and R-Values, Ouljet Haboub



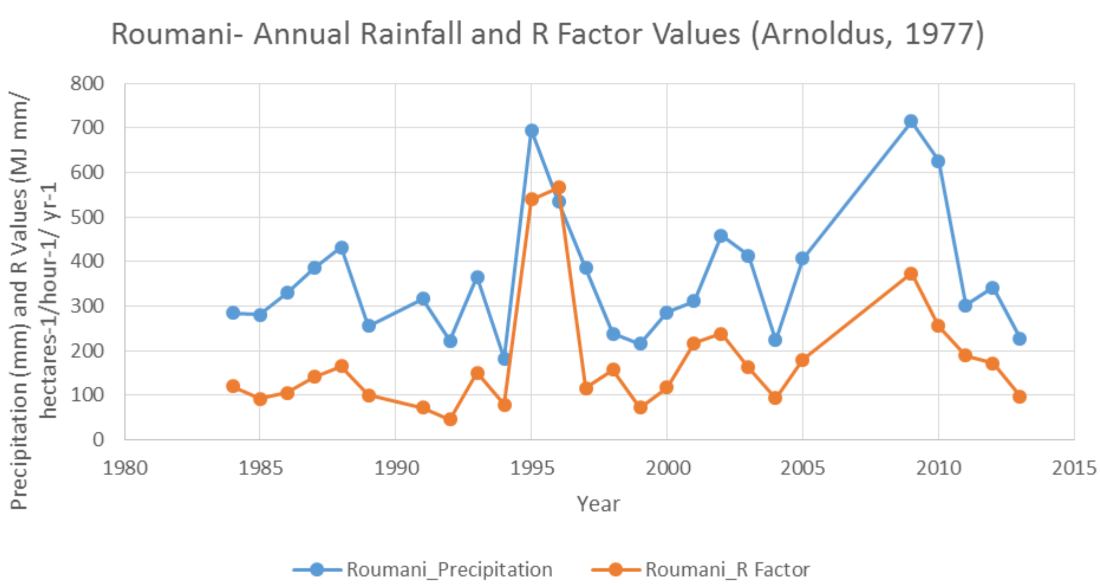
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 69: Average Annual Precipitation and R-Values, Ras El Fatiha



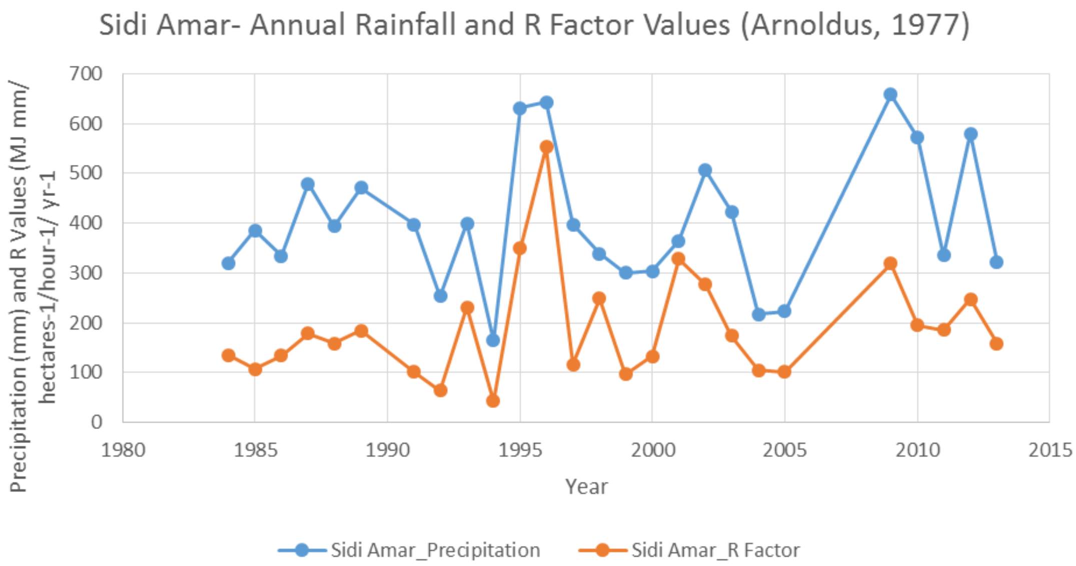
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 70: Average Annual Precipitation and R-Values, Roumani



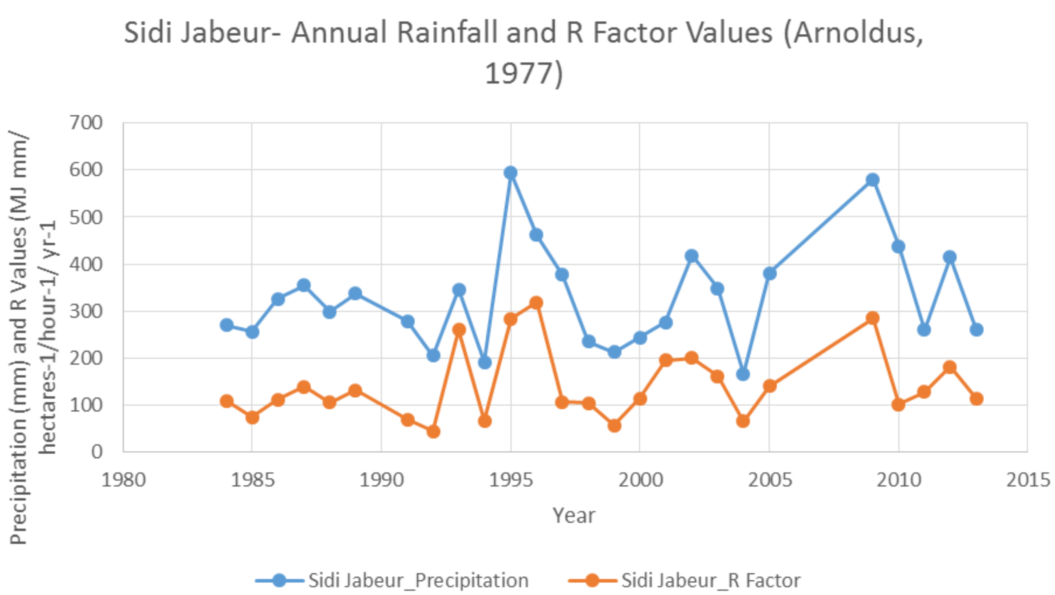
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 71: Average Annual Precipitation and R-Values, Sidi Amar



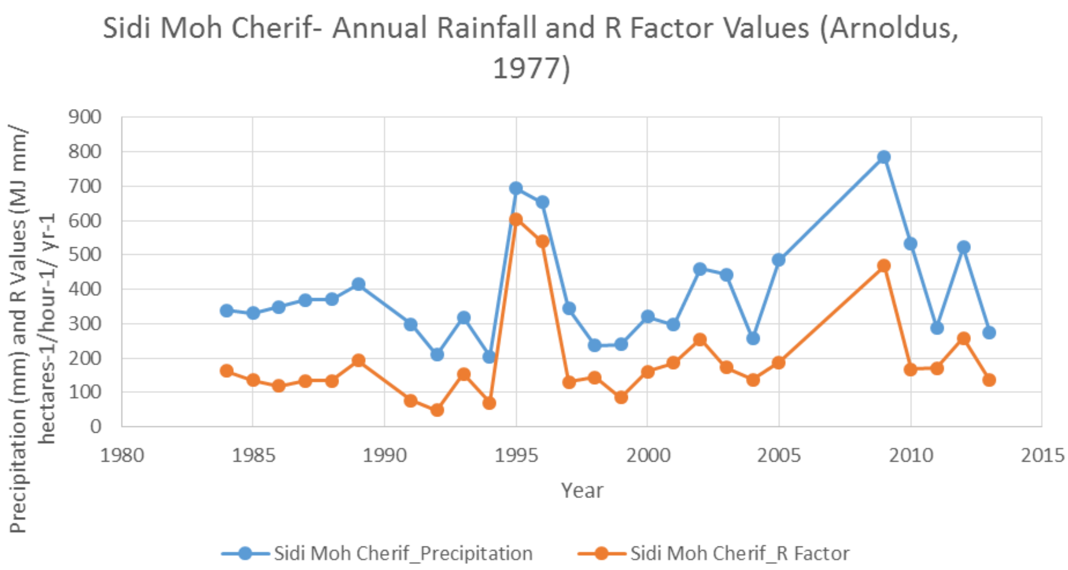
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 72: Average Annual Precipitation and R-Values, Sidi Jabeur



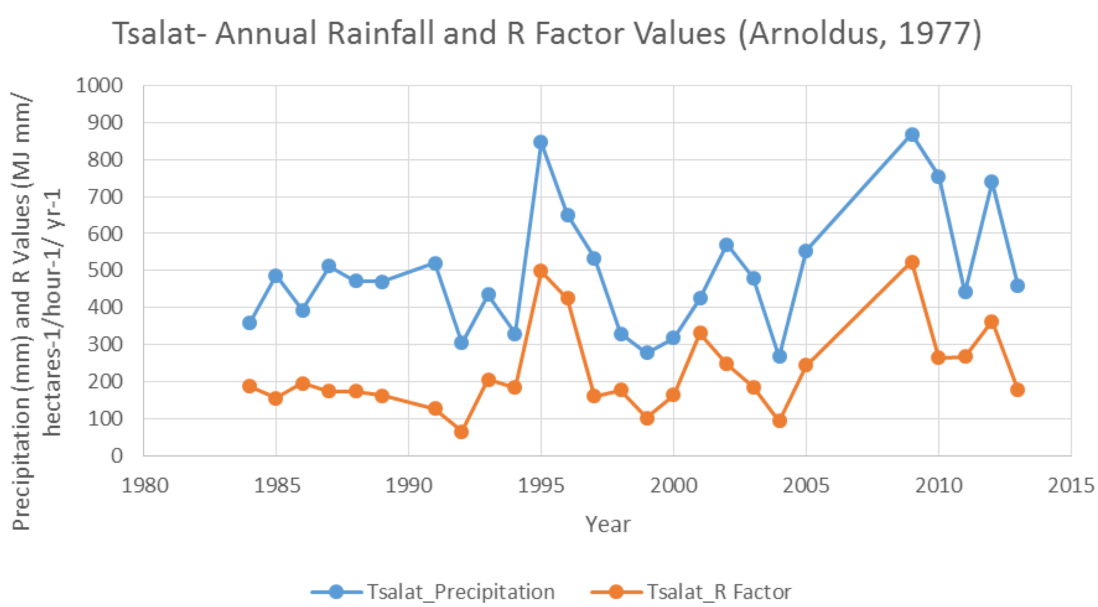
Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 73: Average Annual Precipitation and R-Values, Sidi Moh Cherif



Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

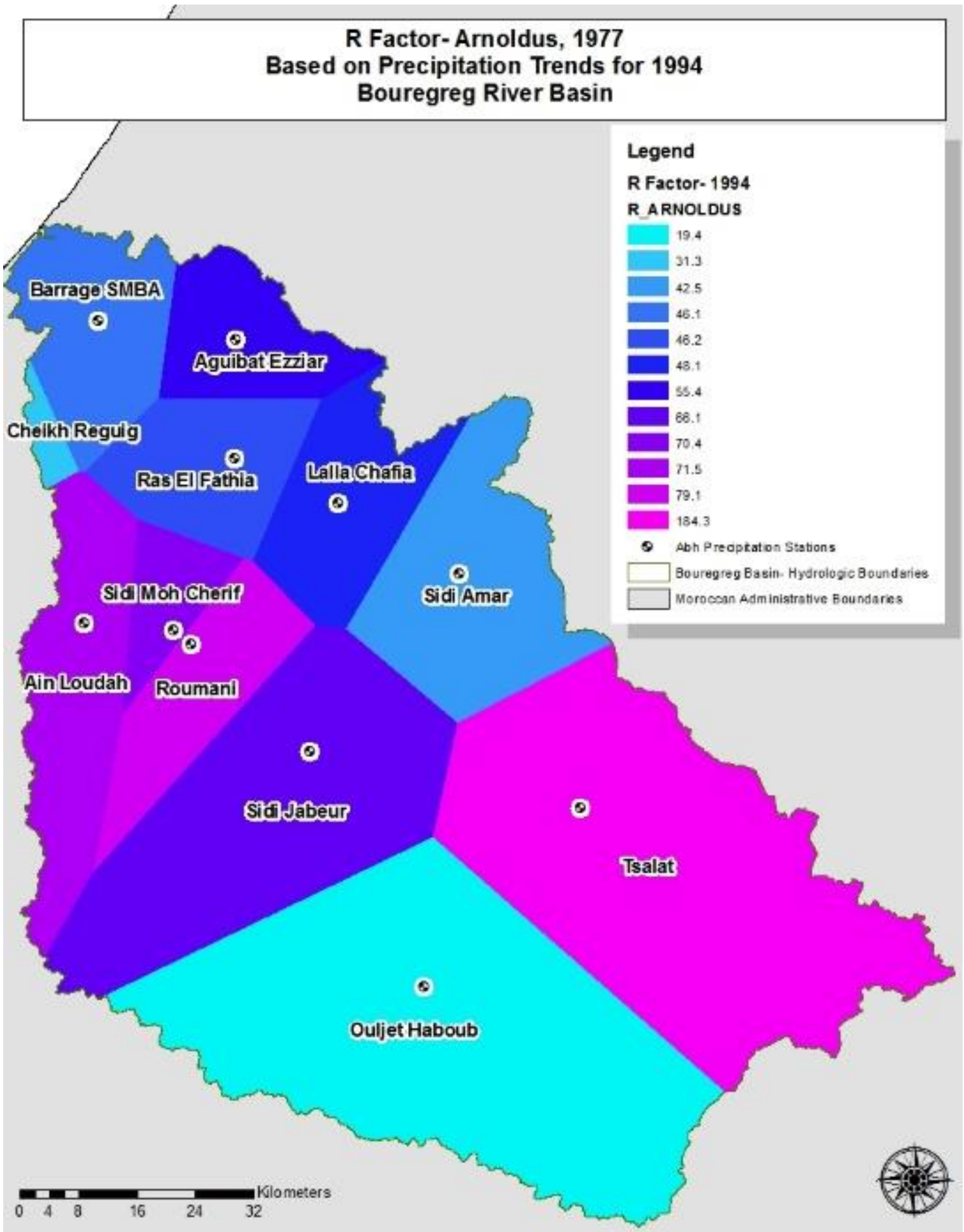
Figure 74: Average Annual Precipitation and R-Values, Tsalat



Source: Generated by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

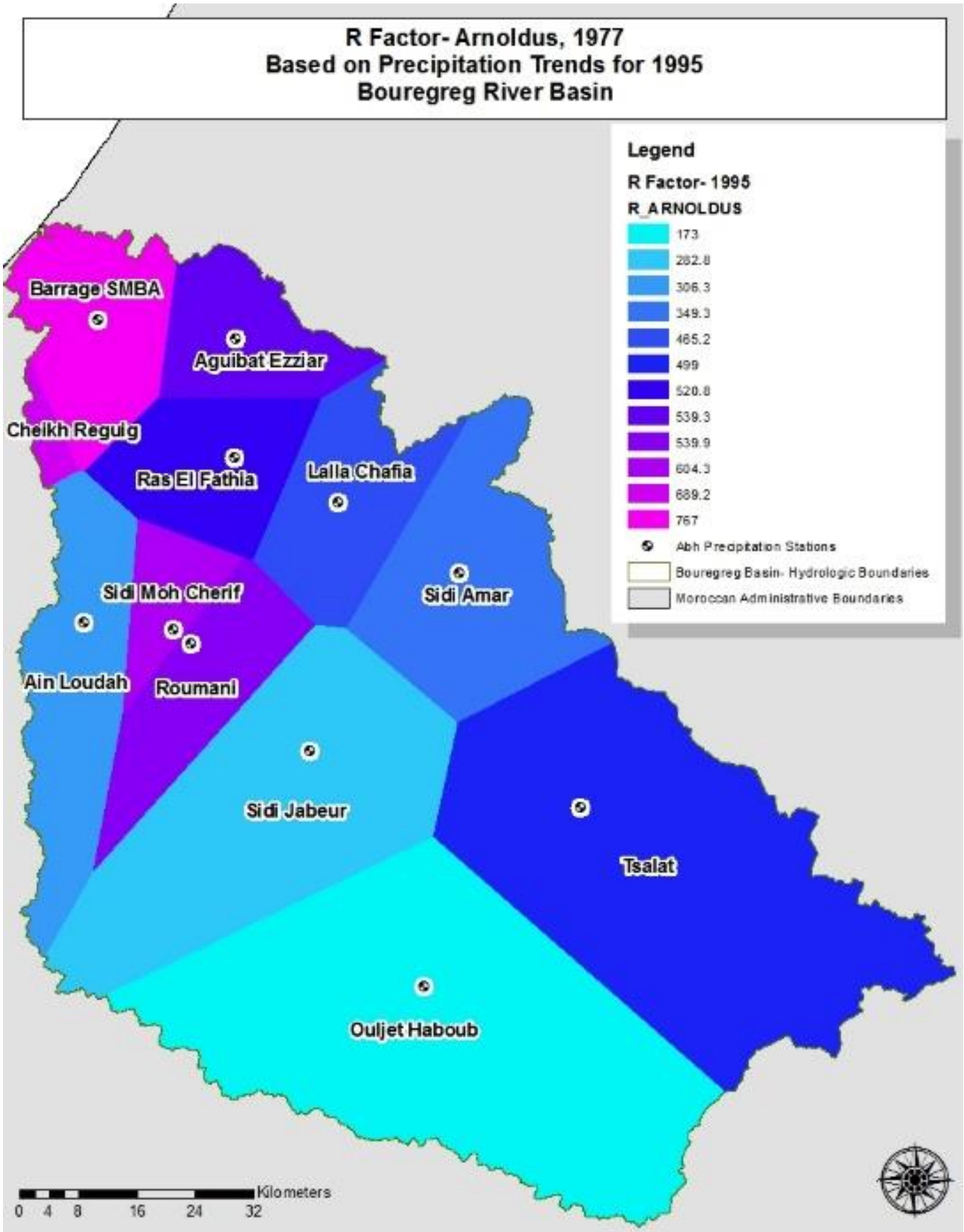
APPENDIX 4: VARIATION IN R FACTOR (1994-1996, 2009-2013)

Figure 75: Bouregreg Basin R Factor Values for 1994



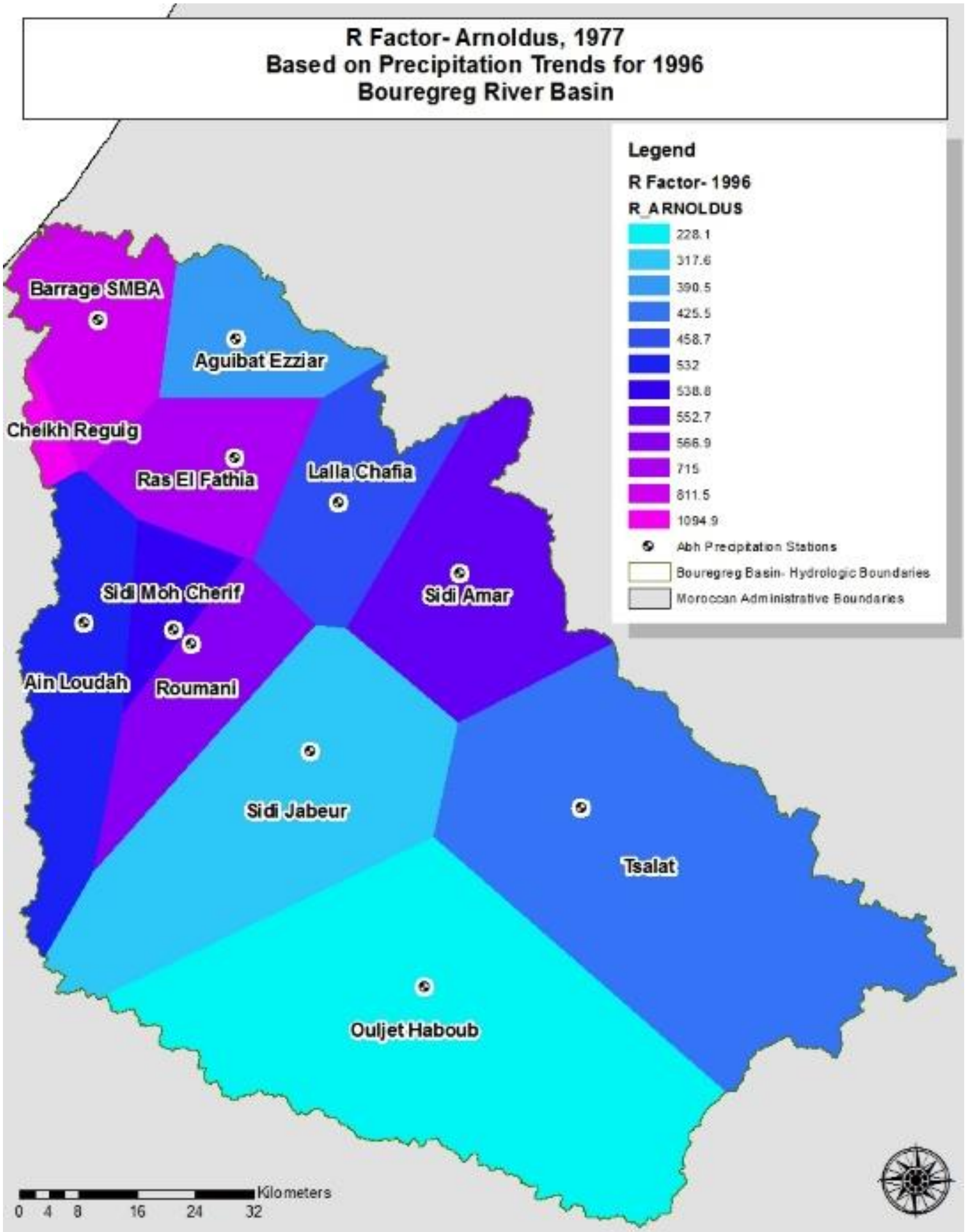
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 76: Bouregreg Basin R Factor Values for 1995



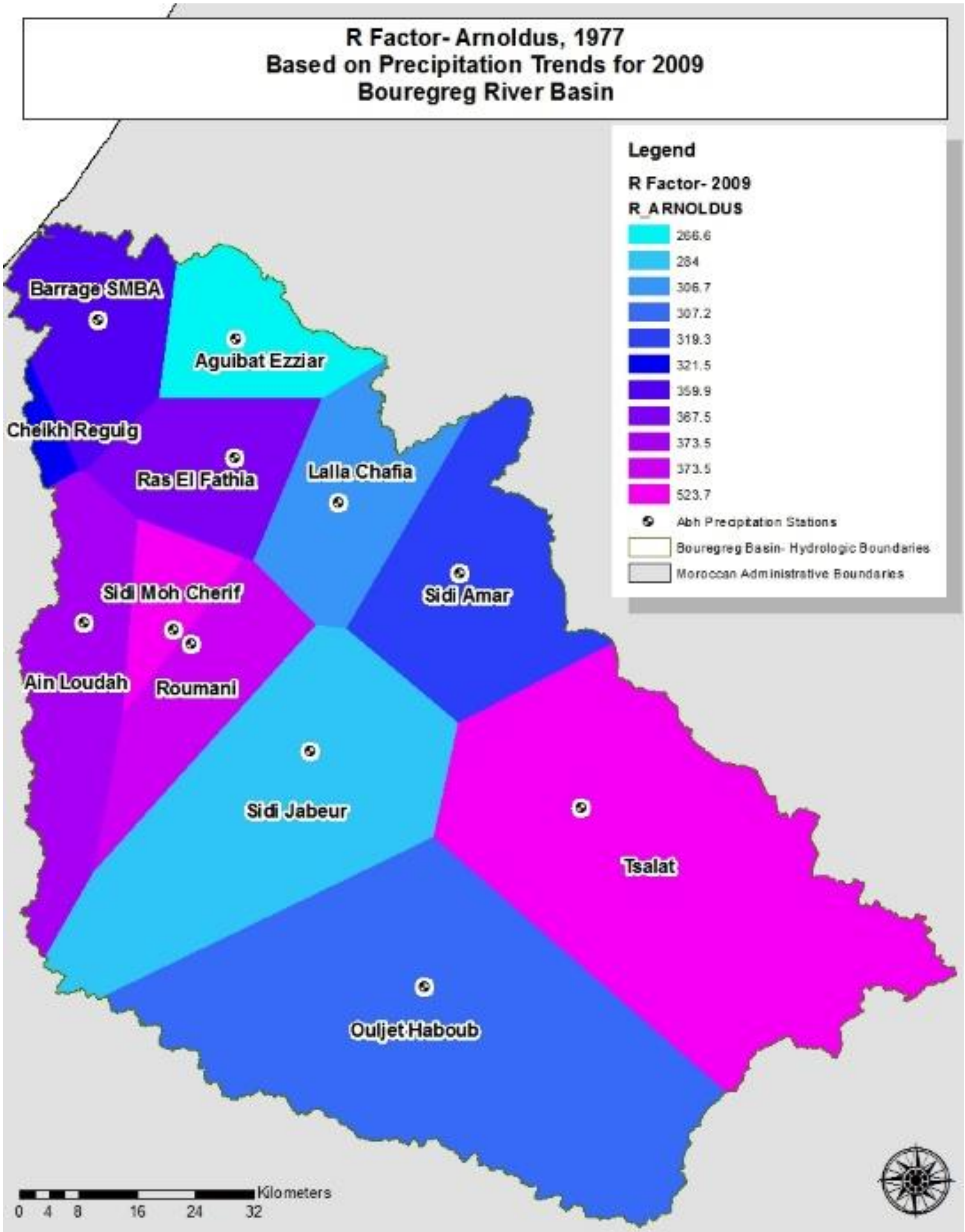
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 77: Bouregreg Basin R Factor Values for 1996



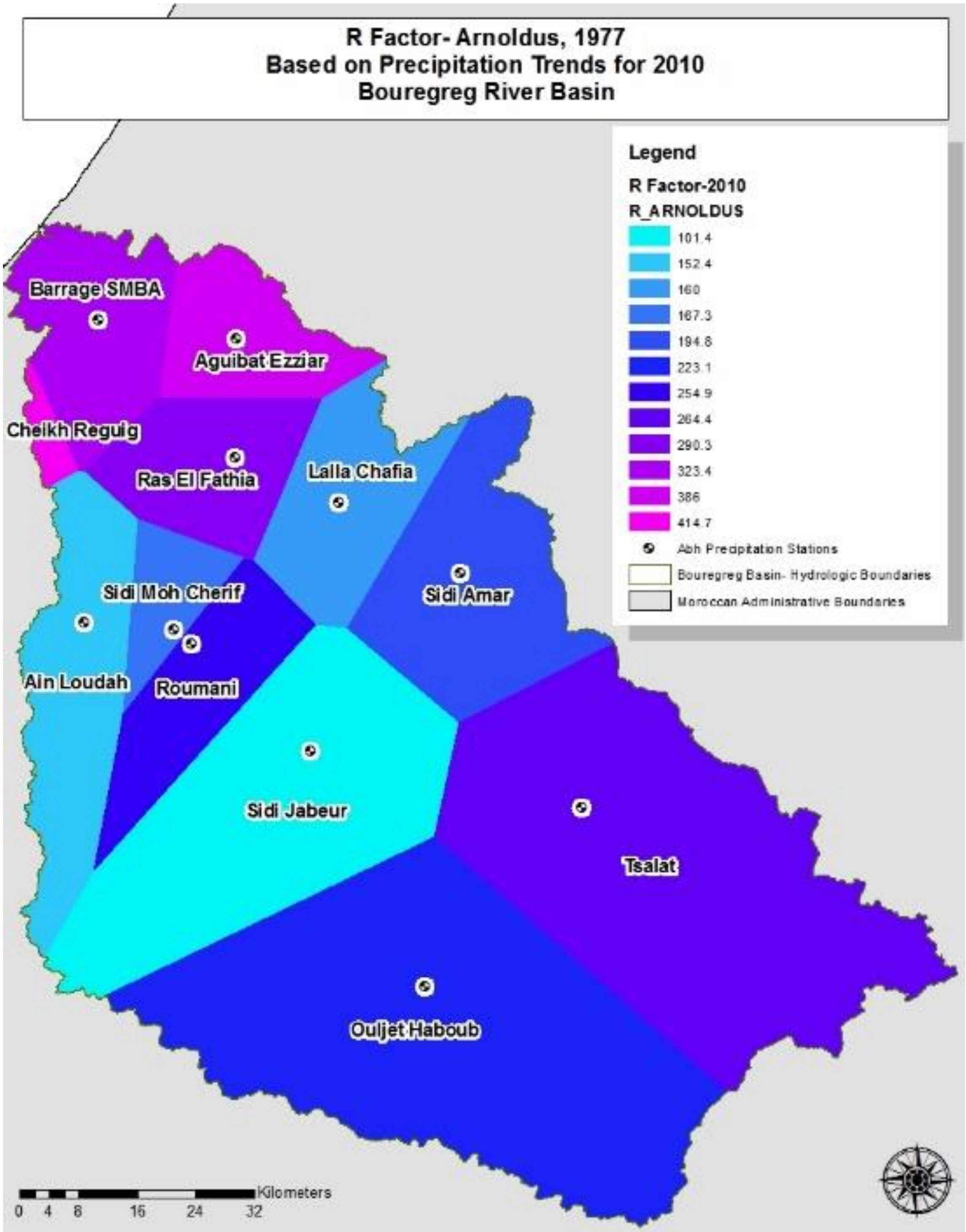
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 78: Bouregreg Basin R Factor Values for 2009



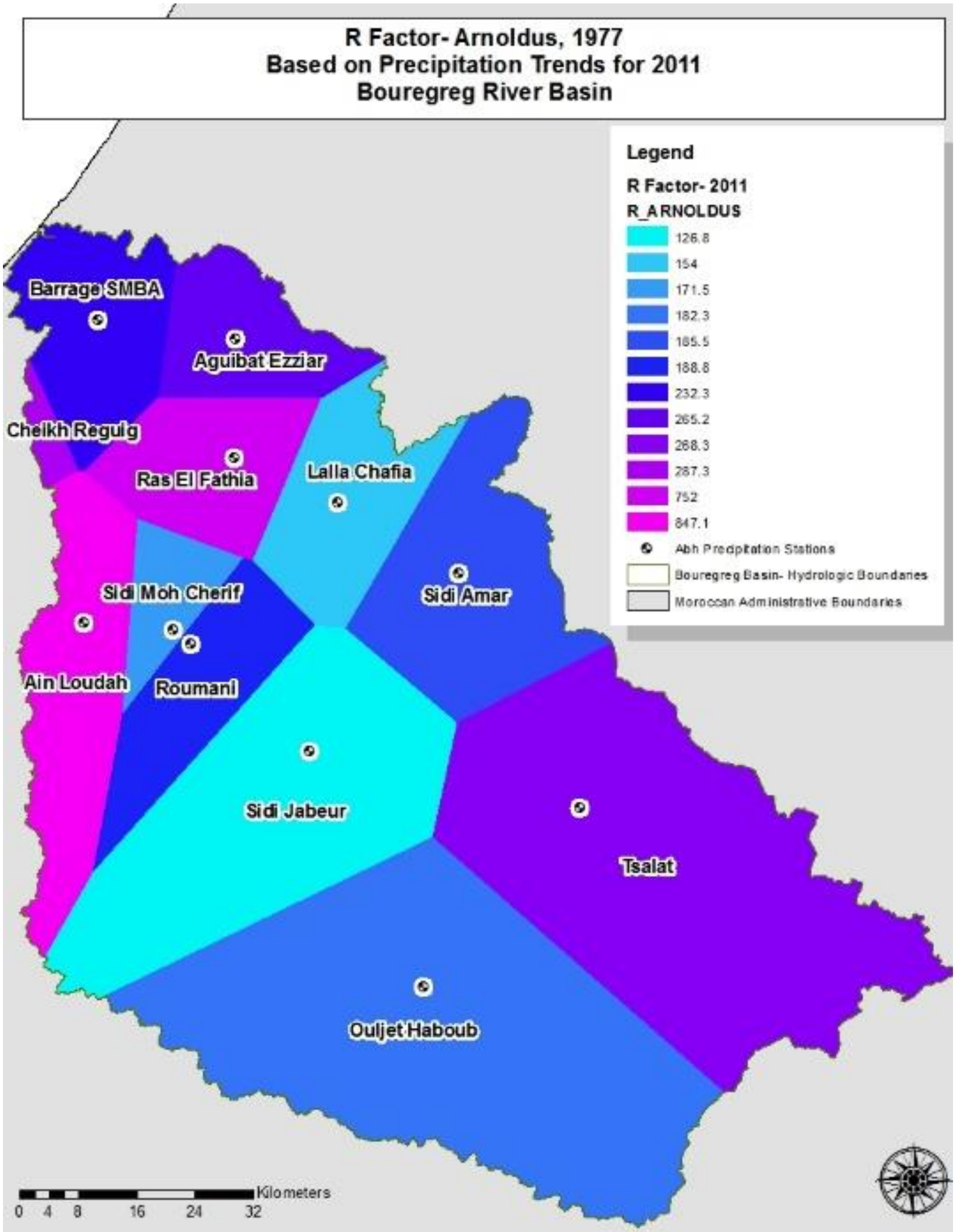
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 79: Bouregreg Basin R Factor Values for 2010



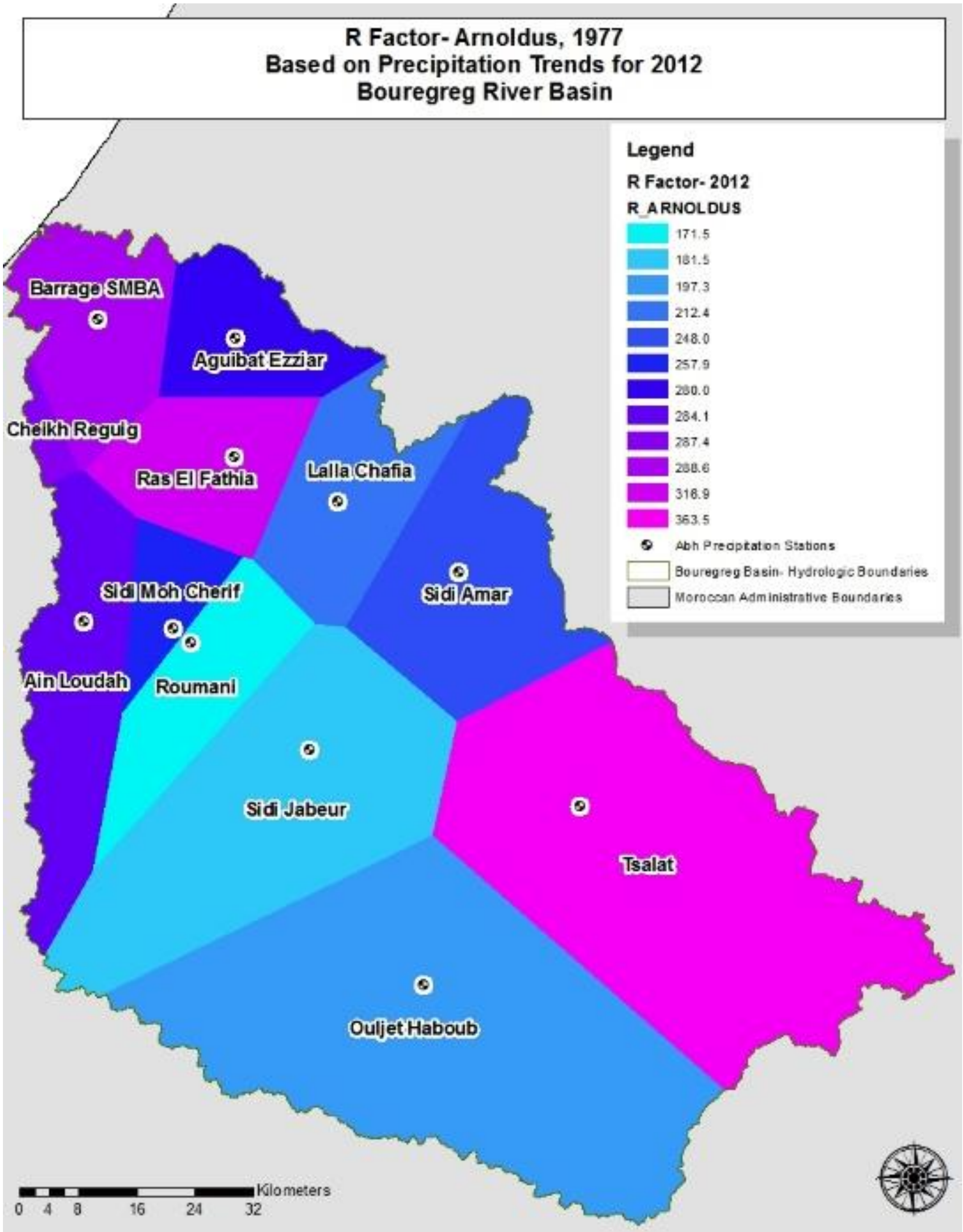
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 80: Bouregreg Basin R Factor Values for 2011



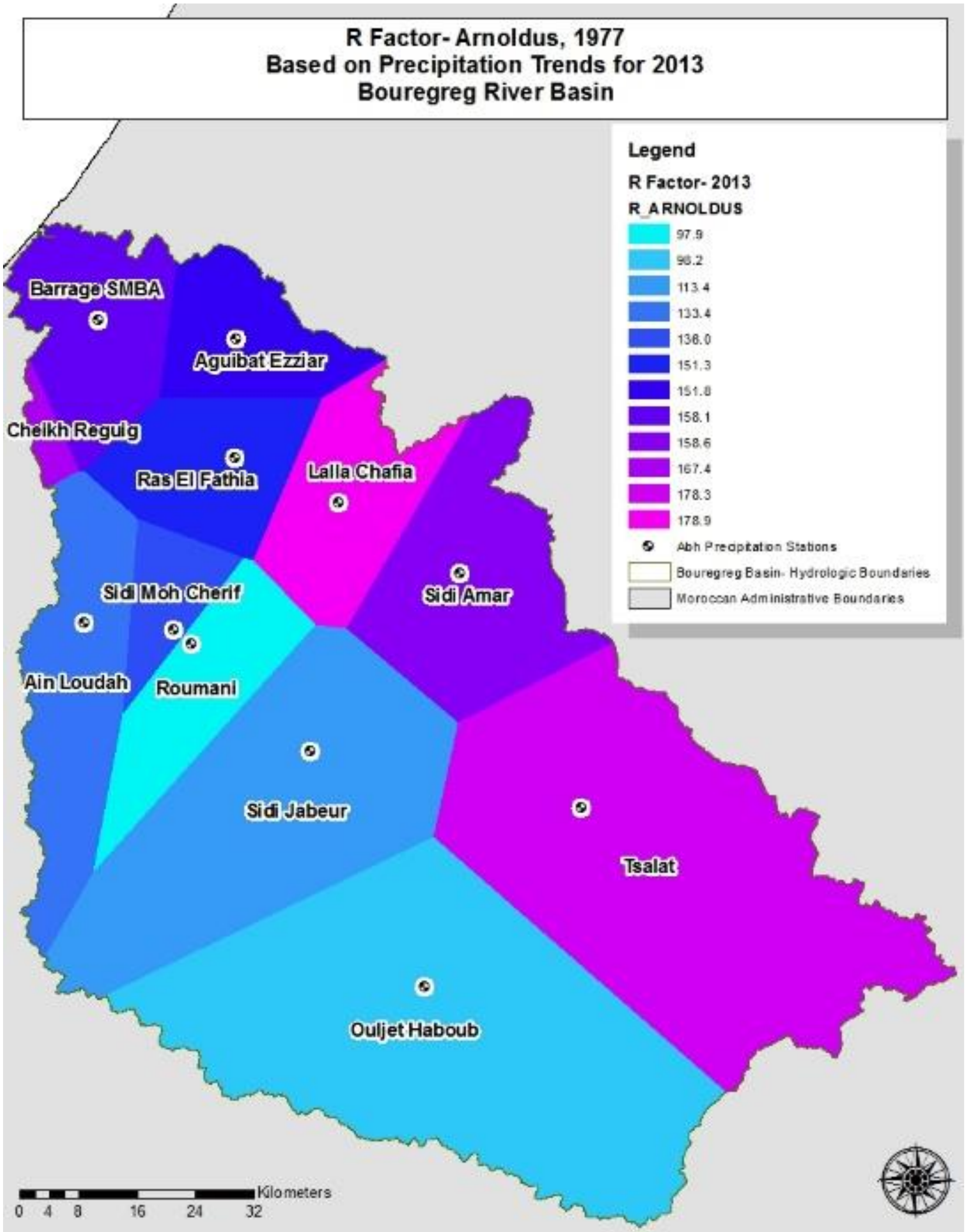
Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

Figure 81: Bouregreg Basin R Factor Values for 2012



Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

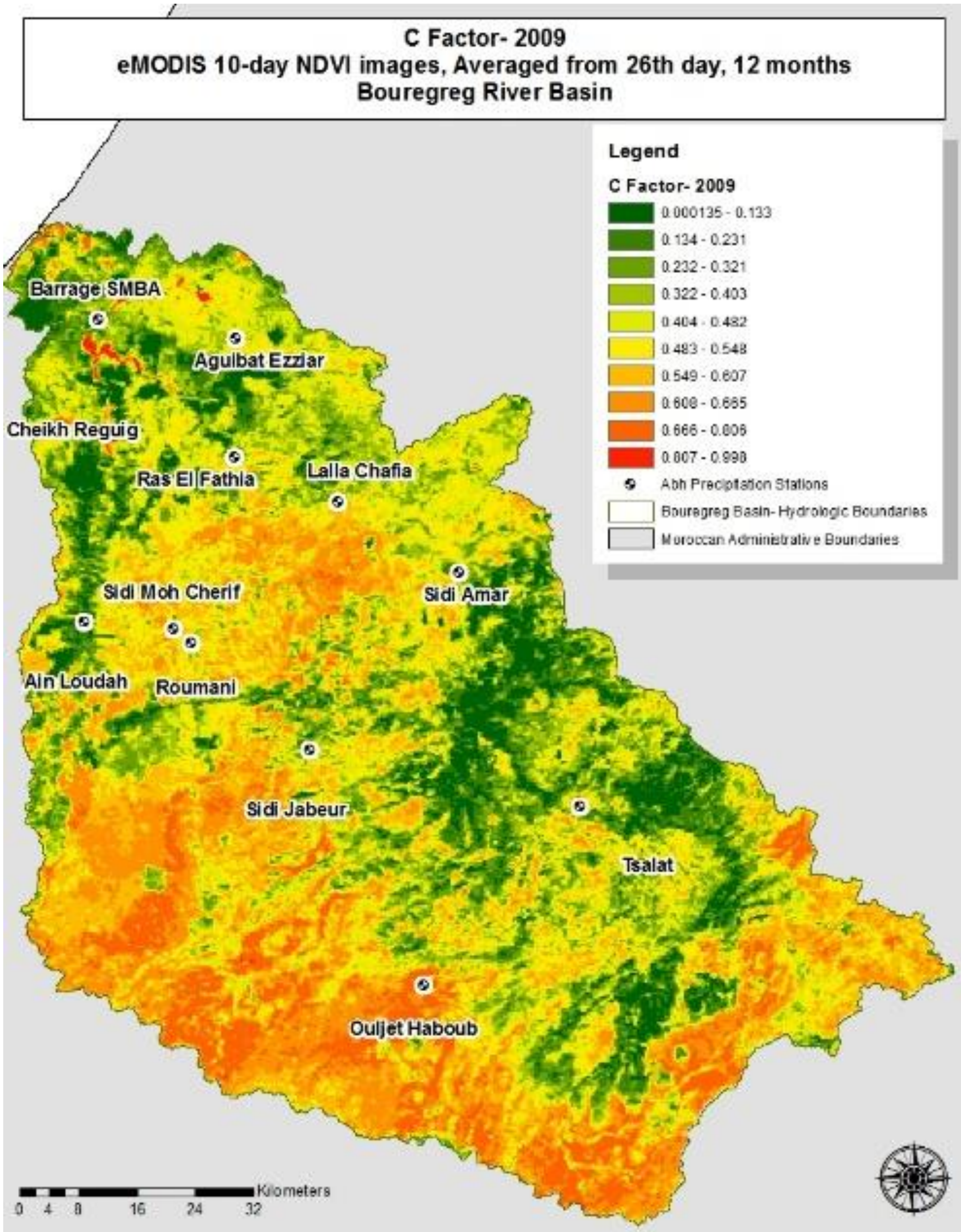
Figure 82: Bouregreg Basin R Factor Values for 2013



Source: Map created by Madeline Clark using data from Historical Precipitation Data, Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane, Morocco, January 14, 2015.

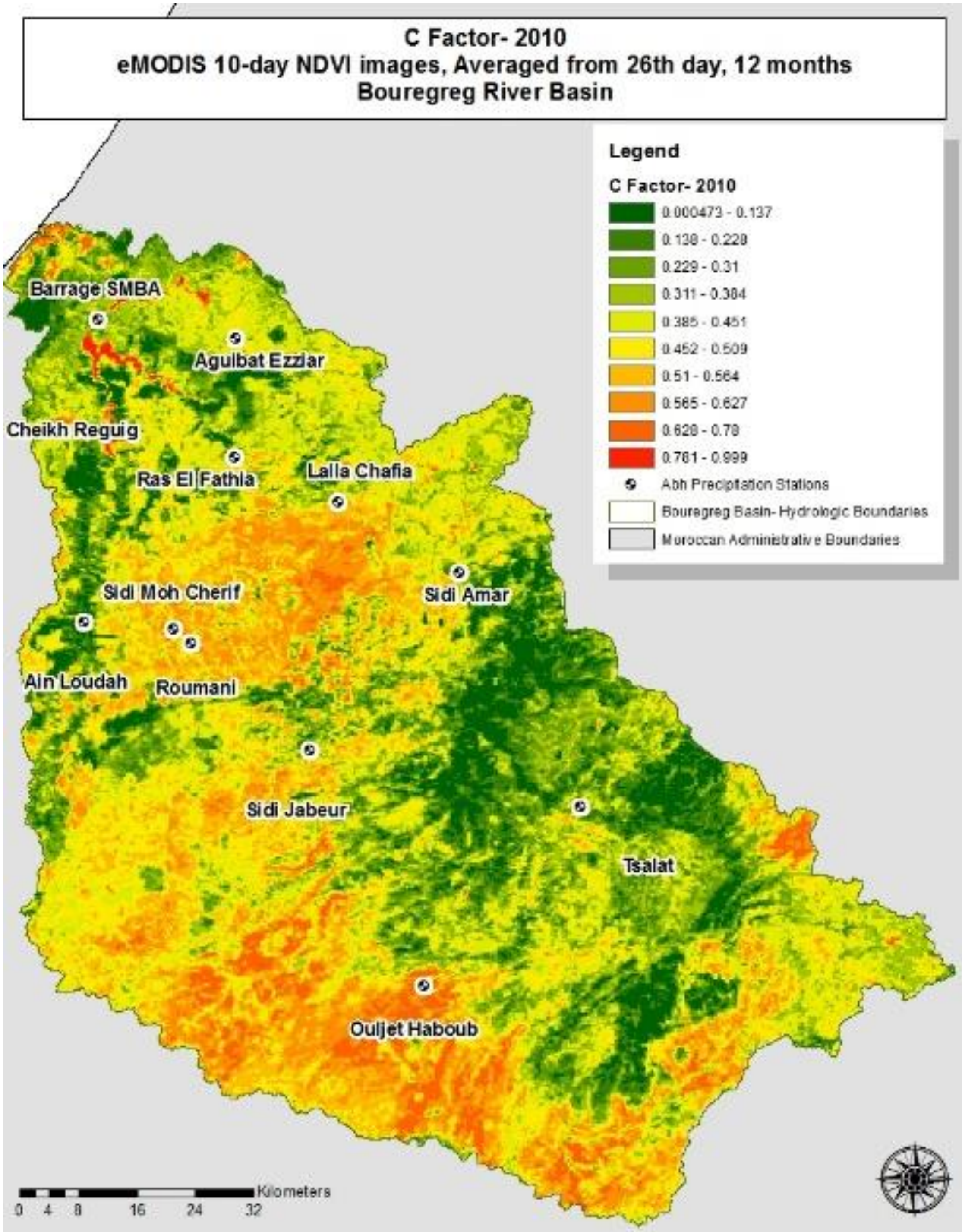
APPENDIX 5: VARIATION IN C FACTOR (2009-2013)

Figure 83: Bouregreg Basin C Factor Values for 2009



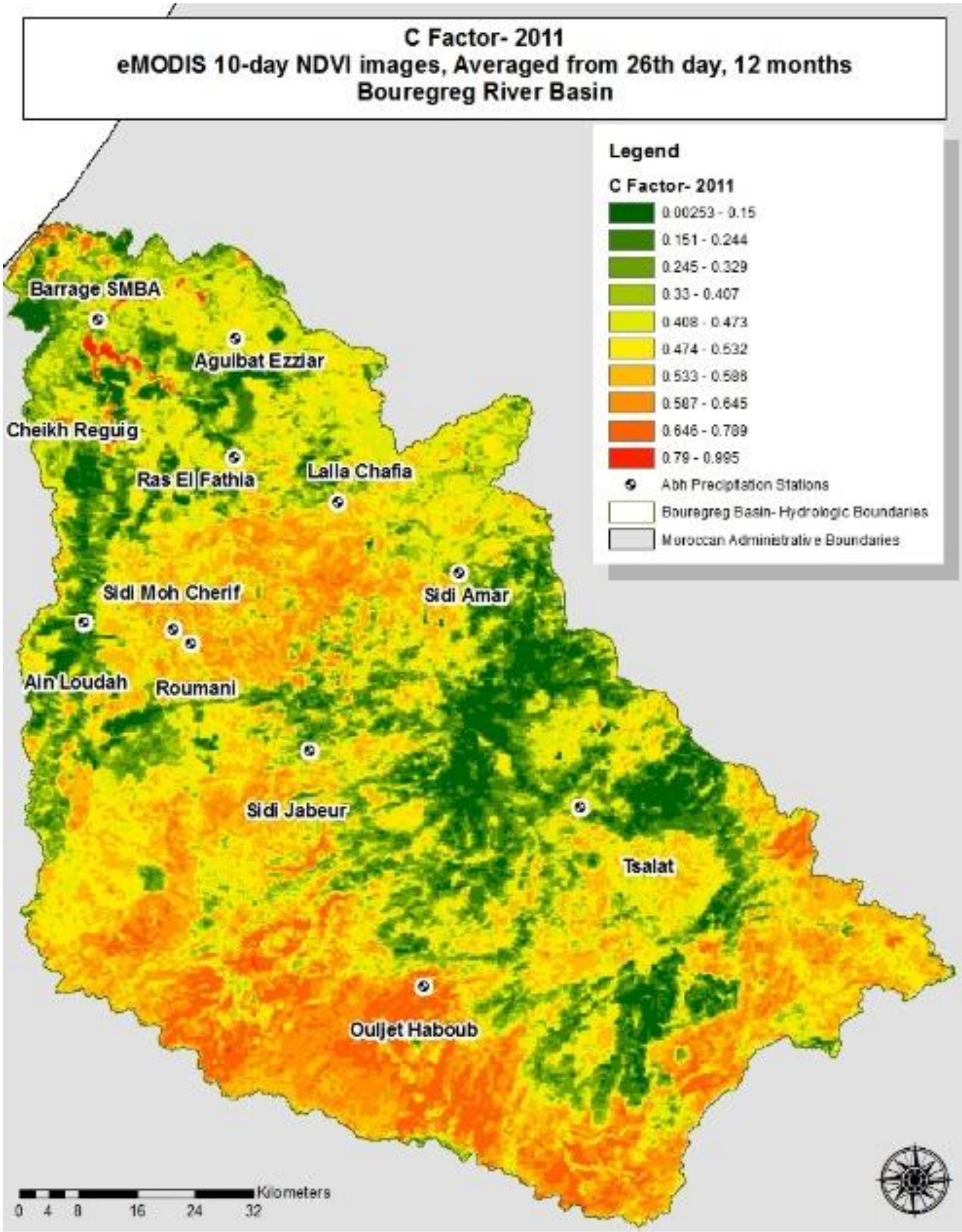
Source: Map created by Madeline Clark using data from eMODIS 10-day averaged NDVI, 12 months for Agricultural Years 2009-2013, Africa, Shuttle Radar Topography Mission, accessed March 31, 2015 at http://earthexplorer.usgs.gov/.

Figure 84: Bouregreg Basin C Factor Values for 2010



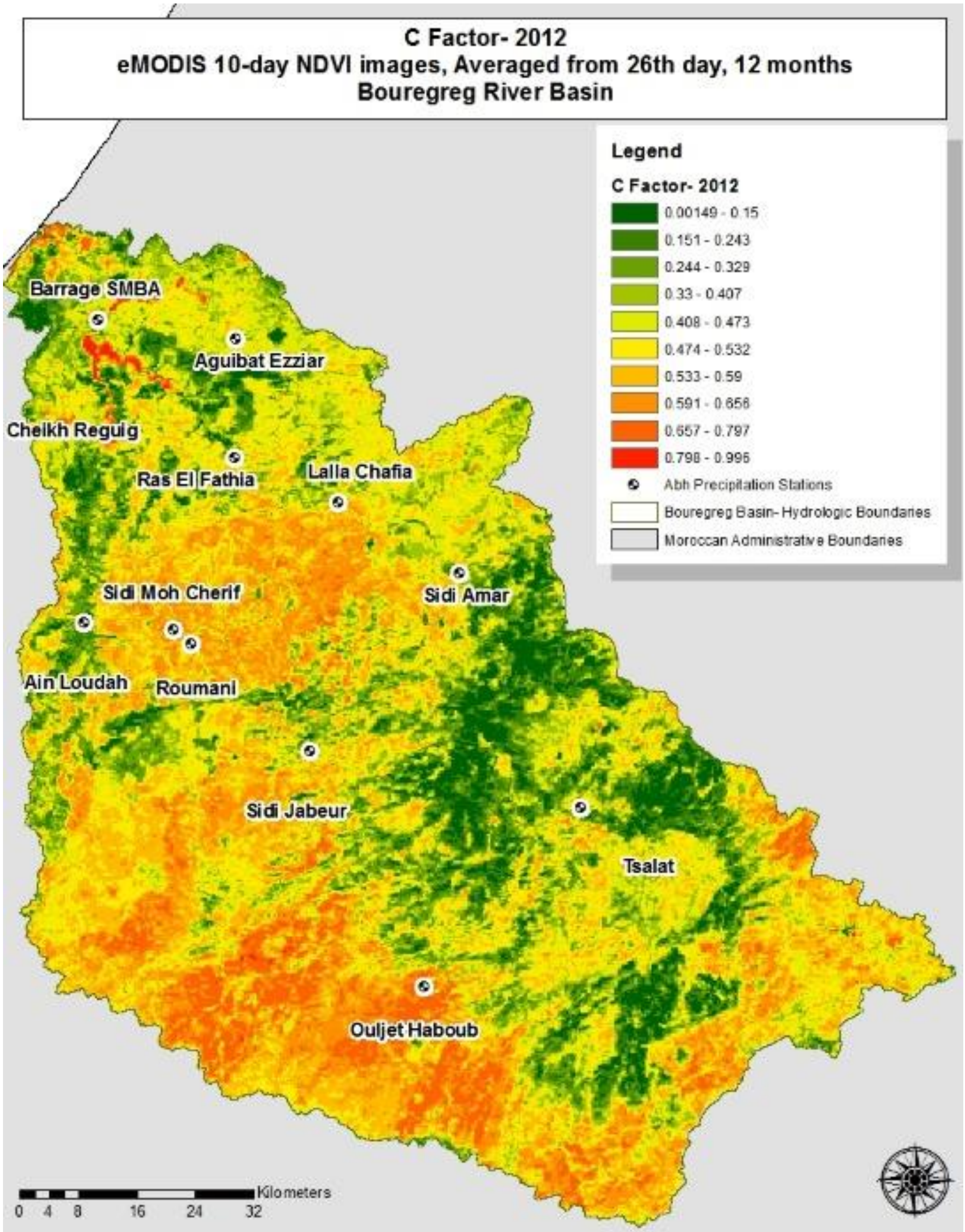
Source: Map created by Madeline Clark using data from eMODIS 10-day averaged NDVI, 12 months for Agricultural Years 2009-2013, Africa, Shuttle Radar Topography Mission, accessed March 31, 2015 at http://earthexplorer.usgs.gov/.

Figure 85: Bouregreg Basin C Factor Values for 2011



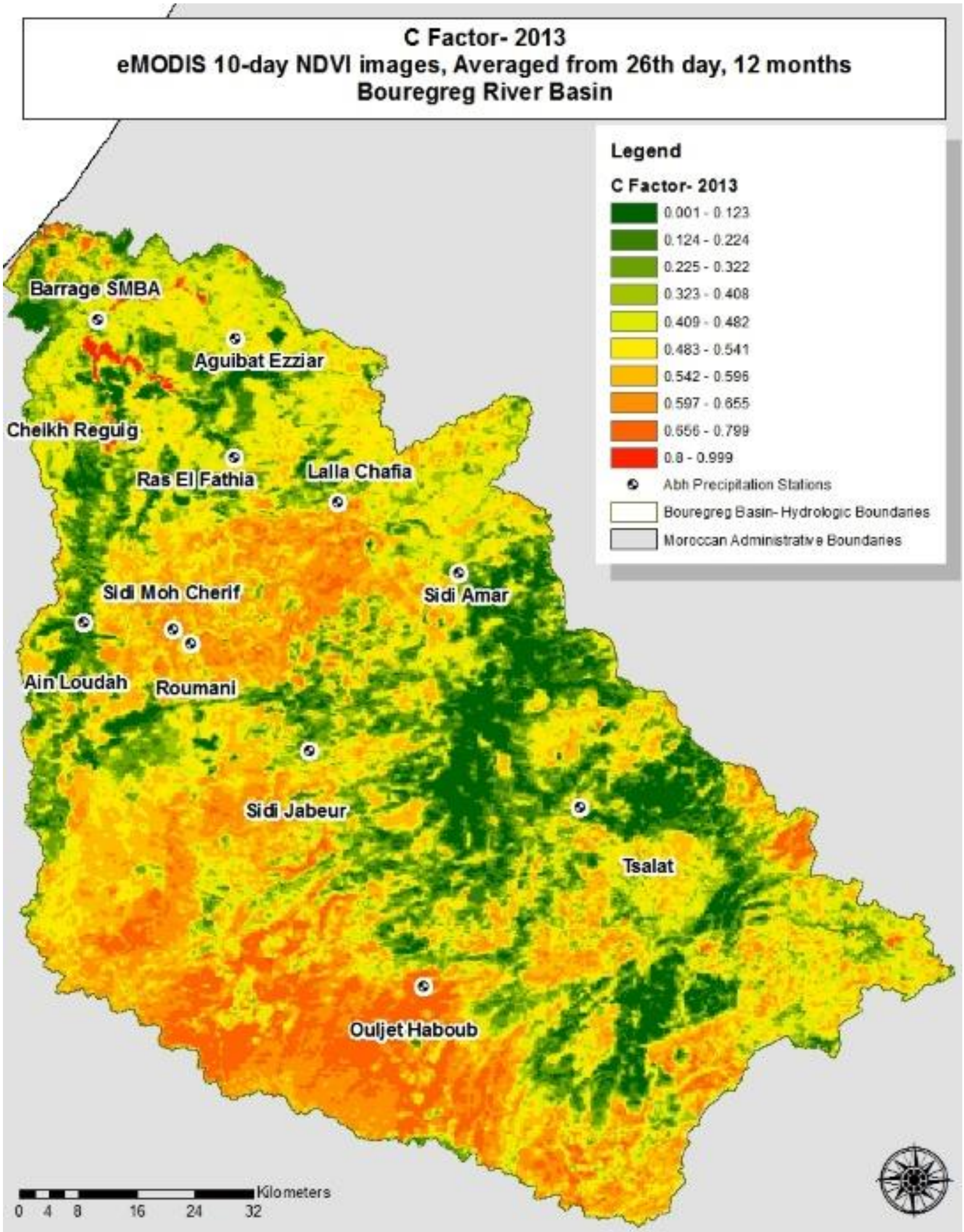
Source: Map created by Madeline Clark using data from eMODIS 10-day averaged NDVI, 12 months for Agricultural Years 2009-2013, Africa, Shuttle Radar Topography Mission, accessed March 31, 2015 at http://earthexplorer.usgs.gov/.

Figure 86: Bouregreg Basin C Factor Values for 2012



Source: Map created by Madeline Clark using data from eMODIS 10-day averaged NDVI, 12 months for Agricultural Years 2009-2013, Africa, Shuttle Radar Topography Mission, accessed March 31, 2015 at http://earthexplorer.usgs.gov/.

Figure 87: Bouregreg Basin C Factor Values for 2013



Source: Map created by Madeline Clark using data from eMODIS 10-day averaged NDVI, 12 months for Agricultural Years 2009-2013, Africa, Shuttle Radar Topography Mission, accessed March 31, 2015 at http://earthexplorer.usgs.gov/.

Bibliography

"4: Deforestation- Environment. Mafia Maâmora." 2005. TelQuel Magazine. April 28. Accessed May 8, 2015. http://geres-asso.org/article_deforestation4.html.

"30 and 90 meter Digital Elevation Model." 2000. Shuttle Radar Topography Mission. Accessed August 25, 2014 and February 15, 2015. http://earthexplorer.usgs.gov/.

Abdellah Laouina and Gil Mahé. 2013. "Gestion Durable des Terres," Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo.

"Administrative Boundaries of Bouregreg-Chaouia." 2015. Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane. Morocco.

"Administrative Boundaries of Morocco." 2015. Obtained in person from the GIS Department of L'office nationale de l'eau Potable. Morocco.

Agence du Bassin Hydraulique du Bouregreg Et De La Chaouia. 2012. Le Plan Directeur d'Aménagement Intégré des Ressources en eau Du Bassin Hydraulique Du Bouregreg et de La Chaouia, Rapport De Synthèse. 11-72.

"Agriculture, value added." 2014. The World Bank. Accessed October 12, 2014. http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS/countries.

Al Karkouri, J., A. Laouina, M. Sfa, K Naimi. 2013. "Cartographie de la Gestion Durable des Terres, dans la Commune des Sehoul, (Maroc Atlantique), Approche WOCAT-LADA-DESIRE." In "Gestion Durable des Terres." Edited by Abdellah Laouina and Gil Mahé, Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo: 21-35.

ArcMap. 2015. ArcGIS Desktop Release 10.3. Environmental Systems Research Institute.

Arnoldus, H.M.J. 1977. "Methodology Used to Determine the Maximum Potential Sheet and Rill Erosion in Morocco." FAO Soils Bulletin 34: 39-51.

Arnoldus, H.M.J. 1977. "Methodology Used to Determine the Maximum Potential Sheet and Rill Erosion in Morocco." FAO Soils Bulletin 34: 39-51. In Kenneth, G. Renard and Jeremy R. Freimund. 1994. "Using Monthly Precipitation Data to Estimate the R-Factor in the Revised USLE." Journal of Hydrology 154: 295-297.

Badraoui, M. and M. Stitou. 2001. “States of Soil Survey and Soil Information System in Morocco.” in Soil Resources of Southern and Eastern Mediterranean Countries. Edited by P. Zdruli, P. Steduto, C. Lacirignola, and L. Montanarella. Bari: CIHEAM. 193-201.

BasKem. 2013. "Products." e-SOTER. ISRIC World Soil Information. Accessed March 29, 2015. http://www.esoter.net/.

Bensalah, Najoua. 2008. “Indicateurs des Risques de Ruissellement et d’érosion en Vue d’une Gestion Durable des Eaux Sols (Bassin versant de Bouregreg (s.s))." PhD Diss, Universite Mohammed V- Agdal. iv.

Berkat, O. and M. Tazi. Ministère de l’Agriculture et de la Réforme Agraire. 1992. in A. Laouina, "Le Bassin Versant du Bouregreg, Caractéristiques Géographiques." In “Gestion Durable des Terres.” 2013. Edited by Abdellah Laouina and Gil Mahé. Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg. CERGéo: 11-12.

Bounouira, Hamid, Abdelmajid Choukri, Elmoursli Cherkaoui, Hakam Rajaa, Oum Keltoum Hakam, and Said Chakiri. 2007. "Distribution of the Rare Earth Elements in the Sediments of the Bouregreg River (Morocco) Using the Instrumental Neutron Activation Analysis (INAA).” J. Appl. Sci. Environ. Manage. 11: 57 – 60.

Cables, Rick, Mary Peterson, Mike Cheveas, and Melissa Outhman. 2007. Technical Assistance Scoping Mission to the US Agency for International Development and the Moroccan Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification: Mission Dates: May 5 – 19. 2007. USAID: 3-10.

"Cartes." MeteoMaroc. Accessed October 14, 2014. http://www.meteomaroc.com/cartes.

Chaker, M., A. Laouina, M. EL Marbouh. 2013. “Changement Agropastoral et Dégradation des Terres dans le Plateau Sehoul." In “Gestion Durable des Terres.” Edited by. Abdellah Laouina and Gil Mahé. Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo: 85-102.

G. Chander, B. L. Markham, and D. L. Helder. 2009. "Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors," Remote Sensing of Environment 113: 893-903.

Chikhaoui, M. and M. Naimi. 2011. "Dégradation des Sols dans Le Rif Marocain." HTE 149/150: 56-60.

Choukr-Allah, R. 2011. “Comparative study between Moroccan water strategies and WFD.” In Dialogues on Mediterranean Water Challenges: Rational Water Use, Water Price Versus Value and Lessons Learned from The European Water Framework Directive. Edited by S. Junier, M. El Moujabber, G. Trisorio-Liuzzi, S. Tigrek, M. Sernegu, R. Choukr-Allah, M. Shatanawi, and R. Rodríguez. Bari : CIHEAM. 181 -188.

“Complexe de Production d’eau Potable Bouregreg." 2013. L’office Nationale de L’eau Potable. 2013. Accessed January 15, 2015. http://www.onep.ma/directions/drc/vue_drc.htm.

Cooley, Skye.2014. “Hypsometric Curves, H1, R1 Index.” GIS for Geomorphology. http://gis4geomorphology.com/hypsometric-index-integral/, paragraph 5.

Dahan, Rachid, Mohamed Boughala, Rachid Mrabet, Abdelali Laamari, Riad Balaghi, and Lahcan Lajouad. 2012. A Review of Available Knowledge on Land Degradation in Morocco. Aleppo: ICARDA. 10-18.

"Dahir du 20 hija 1335 (10 Octobre 1917) sur la Conservation et l'exploitation des Forêts." 1917. Haut-Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification, Royaume du Maroc.

Division of Environment and Soils, L’ONEP. Interview by Author. Rabat, Morocco. May 13, 2015.

d’Ostiani, Luca Fé. 2004. “Watershed Management Case Study: Mediterranean Watershed Management: a Key Component of Rural Development in the Mediterranean Region.” Rome: FAO: 12-15, 22-27.

El Gaatib, Rabii and Abdelkader Larabi. 2014. "Integrated Evaluation of Soil Erosion Hazard and Risk Management in the Oued Beht Watershed Using Remote Sensing and GIS Techniques: Impacts on El Kansra Dam Siltation (Morocco)." Journal of Geographic Information Systems 4: 677-689.

El Hamouri, Bouchaib. 2007. Water resources in Morocco: Potential, Exploitation and Handicaps. Rabat: Institute Agriculturale et Vétérinaire. 1-5.

eMODIS 10-day averaged NDVI for Africa. Shuttle Radar Topography Mission. Accessed March 31, 2015. http://earthexplorer.usgs.gov/.

“Employment in agriculture (% of total employment).” 2012. The World Bank. Accessed October 14, 2014. http://data.worldbank.org/indicator/SL.AGR.EMPL.ZS.

ENVI Release 5.2. Exelis Visual Information Solutions, 2015.

“Etude d’Aménagement du Bassin Versant du l’Oued Bouregreg en amont du Barrage Sidi Mohammed Ben Abdellah : Analyse des Problèmes d’Erosion et Identificateur des Zones Prioritaires." 2008. Le Premier Ministere de Haut-Commissariat aux Eaux et Forêts et à la Commissariat à la Lutte Contre la Désertification. 1-3.

“Etude d’Aménagement du Bassin Versant du l’Oued Bouregreg en amont du Barrage Sidi Mohammed Ben Abdellah : Etude du Milieu Physique et des Facteurs Physiques d’Erosion."2008. Le Premier Ministere de Haut-Commissariat aux Eaux et Forêts et à la Commissariat à la Lutte Contre la Désertification. 2.

“Etude d’Aménagement du Bassin Versant du l’Oued Bouregreg en amont du Barrage Sidi Mohammed Ben Abdellah : Notre Méthodologique." 2008. Le Premier Ministere de Haut-Commissariat aux Eaux et Forêts et à la Commissariat à la Lutte Contre la Désertification. 1-3.

Ex-Ante Evaluation, Watershed Management Project Loan to the Kingdom of Morocco. 2007. JICA, 104.

Fischer, G., F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, D. Wiberg, “Global Agro-ecological Zones Assessment for Agriculture,” IIASA (Rome, FAO, 2008).

Fournier, F. 1960. “Climat et Erosion,” Universitaires de France.

Fry, Al. “Facts and Trends: Water.” 2005. World Business Council for Sustainable Development. 8. Accessed October 14, 2015. http://www.unwater.org/downloads/Water_facts_and_trends.pdf.

Gardner, Edward P. and Julie L. Myer. 2001. “Sensitivity of RUSLE to Data Resolution: Modeling Sediment Delivery in the Upper Little Tennessee River Basin.” University of Georgia. Edited by Kathryn J. Hatcher. 1-5.

"Global Climatology." 2000. Global Land Cover Facility. Accessed January 15, 2015. http://landcover.usgs.gov/global_climatology.php.

Guidelines for Soil Description. 2006. Rome: Food and Agricultural Organization of the United Nations. 46-52.

Hajji, Mustapha. Interview by Author. Rabat, Morocco. May 13, 2015.

Harmonized World Soil Database version 1.2. 1974. In Global Agro-ecological Zones Assessment for Agriculture." Edited by G. Fischer, F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, and D. Wiberg. Laxenburg: IIASA and FAO. Accessed August 20, 2015. http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/.

Heusch, B. 1970. "L'Erosion Hydraulique au Maroc: Son Calcul et Son Contrôle." Al Awamia 36: 39-63.

Historical Precipitation Data. Obtained in person from Agence du Bassin de Bouregreg-Chaouia in Benslimane. Morocco. January 14, 2015.

"Institution." 2009. Haut-Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification. Accessed May 10, 2015. http://www.eauxetforets.gov.ma/fr/institution.aspx, paragraphs 2-3.

"It Belongs to You: Public Information in Morocco." 2013. Transparency Maroc and Transparency International. USAID. 5-46.

Khaled, Abuzeid. 2008. "Policy Analysis of National Water Plans in Selected Arab Countries." Proceedings of 3rd Regional Workshop on Water Governance in the Arab Region, Water Governance Forum, Water Council, and Inwent, Marrakesh).

Lahlou, Abdelhadi. 1996. "Environmental and Socioeconomic Impacts on Erosion and ' Sedimentation in North Africa." Erosion and Sedimentation Yields: Global and Regional Perspectives IAHS: 491-500.

Lahlou, Abdelhadi. "The Silting of Moroccan Dams." Sediment Budgets IAHS 174 (1988): 71-77.

Landerer, F.W. and S. C. Swenson. 2012. "Accuracy of scaled GRACE terrestrial water storage estimates." Water Resources Research, 48, no. W04531, 11. Accessed February 15, 2015. doi:10.1029/2011WR011453.

"Landsat 5 TM Images 2021037, 2022036, 2022037 for September 5 and 14, 2011." Shuttle Radar Topography Mission. Accessed May 23, 2015, http://earthexplorer.usgs.gov/.

Laouina, A. 2013. "Le Bassin Versant du Bouregreg, Caractéristiques Géographiques." In "Gestion Durable des Terres." Edited by Abdellah Laouina and Gil Mahé. "Gestion Durable des Terres." Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo: 5-20.

Laouina, A., C. Coelho, C. Ritsema, M. Chaker, R. Nafaa, I. Fenjiro, M. Antari, A. Ferreira and S. Van Dijck. 2004. "Dynamique de l'eau et Gestion des terres dans le contexte du changement global, analyse agro-hydrologique dans le bassin du Bouregreg (Maroc)." Sécheresse 5-1: 66-77.

Laouina, A., M. Chaker, M. Aderghal, J. Al Karkouri, M. Machouri, and M. Sfa. "Management of Gullied Areas in the Atlantic Plateaus of the Bouregreg Watershed, Morocco." In "Gestion Durable des Terres." Edited by Abdellah Laouina and Gil Mahé (Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo, 2013), 147-160.

Loi d'leau 10-95. 1995. Ministere de l'Energie et les Mines et l'Eau et l'Environment, Royaume Du Maroc.

Loi n° 12-03 relative aux études d'impact sur l'environnement. 1995. Ministere de l'énergie et les Mines et l'eau et l'environment, Royaume Du Maroc.

Mahé, G., H. Benabdelfadel, C. Dieulin, M. Elbaraka, M. Ezzaouini, K. Khomsi, N. Rouche, M. Sinan, M. Snoussi, and A. Zérouali. 2013. "Evolution des Débits et Solides du Bouregreg." In "Gestion Durable des Terres." Edited by Abdellah Laouina and Gil Mahé. Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo: 21-35.

Major Cities of Morocco. 2014. Obtained in person from the GIS Department of L'office Nationale de l'eau Potable. Morocco.

Majoudi, Abdelkrim. 2009. "Session 1 : L'Aménagement des Bassins Versants Composante Incontournable Pour La Gestion Durable des Ressources en eau." Communication of the Haute Commissariat des Eaux et Forêts et la Lutte Contre le Désertification. 1-5.

Maleval, V. 2013. "Premiers Résulte des Mesures d'érosion Ravinaire sur les Versants Lacustres du Barrage Sidi Mohammed Ben Abdellah (Maroc) et Perspectives de Recherche." In "Gestion Durable des Terres." Edited by Abdellah Laouina and Gil Mahé, "Gestion Durable des Terres," Proceedings de la Réunion Multi-Acteurs, sur le Bassin Bouregreg, CERGéo. 21-35.

MAPM. 2012. Programme d'action national de lutte contre la désertification. Ministry of Agriculture and Marine Fisheries. In Rachid Dahan et al. A Review of Available Knowledge on Land Degradation in Morocco. Aleppo: ICARDA. 10-11.

Mellouk, Outhmane. "Struggling to Balance Free Trade with Access to Medicines in the Post-TRIPS Era throughout the Arab World." Intellectual Property Rights (IPRs), Innovation and Sustainable Development Conference, June 26-28. Accessed November 12, 2015. http://www.iprsonline.org/unctadictsd/docs/Mellouk_ArabRD_Health.pdf.

Microsoft Office Excel. Microsoft. Windows, 2013.

Mitasova, Helena and Lubos Mitas. 2009. "Modeling soil detachment with RUSLE 3d using GIS." University of Illinois at Urbana Champaign. http://www4.ncsu.edu/~hmitaso/gmslab/denix/usle.html/. Paragraphs 4-5.

"Morocco Free Trade Agreement." Office of the United States Trade Representative. Accessed November 12, 2015. Paragraph 1. https://ustr.gov/trade-agreements/free-trade-agreements/morocco-fta.

"Morocco Watershed Protection and Management Project: Final Report." 2005. Washington D.C.: USAID. 5-16.

Moussadek, Rachid. Interview by Author. Rabat, Morocco. June 29, 2015.

Nash, Maliha S., Deborah J. Chaloud, William Kepner, and Samuel Sarri. 2008. "Regional Assessment of Landscape and Land Use Change in the Mediterranean Region: Morocco Case Study (1981-2003)." In "Environmental Change and Human Security: Recognizing and Acting on Hazard Impacts. Science for Peace and Security Series." Edited by P. Liotta, D. Mouat, W.G. Kepner, and J.M. Lancaster. Netherlands, Springer. 143 – 165.

National Human Development Initiative (INDH) Project. 2012. Washington, DC: World Bank. Accessed October 14, 2015. http://documents.worldbank.org/curated/en/2012/01/16420886/morocco-national-human-development-initiative-indh-project.

Nearing, Mark. 2013. "Soil Erosion and Conservation." Publications from USDA-ARS / UNL Faculty. Paper 1290" 365-376.

Ouassou, A., H.A. Tayeb, and L. Lajouad. 2006. "State of natural resource degradation in Morocco and plan of action for desertification and drought control." In Desertification in the Mediterranean Region: a Security Issue. Springer: 251-268. In A Review of Available Knowledge on Land Degradation in Morocco. Rachid Dahan et al. Aleppo: ICARDA. 10-18.

Ouassou, A, T. Ameziane, M. Belghiti, A. Ziyad, and A. Belhamd. 2007. "Application of the drought management guidelines in Morocco (Part 2. Examples of application)." In Drought Management Guidelines Technical Annex, edited by A. Iglesias, M. Moneo, A. López-Francos, 343-372. Zaragoza: CIHEAM / EC MEDA Water.

Ouattar, Said, Driss Messaho, John Huyler, Rachida Youmouri, Driss Ouazar, and Salwa Bennani. 2000. "Database Needs Assessment for Integrated Water Resources Management in the Souss-Massa Basin." FORWARD: 38-50.

Omerani, A. "Watershed management." In "Institutional implications of participatory approaches." Decentralization and Rural Development 20. Rome: FAO.

Ostrum, Elinor. 2011. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge: Cambridge University Press. 1-5.

"Plan Maroc Vert: Strategy." 2014. Ministère de l'agriculture et de la Pêche Maritime. Accessed October 14, 2015. http://www.agriculture.gov.ma/pages/la-strategie. Paragraphs 1-15.

Rahdou, Mohamed. 2010. « Modelisation Hydrologique du Bassin Versant de Bouregreg (S.S) et Evaluation de Taux D'Envasement du Barrage Sidi Mohamed Ben Abdellah (Maroc) Par la Méthode Bathymétrique." Master's thesis, L'Ecole Mohammedia des Ingénieurs. 6.

"Regions." l'Office National de l'Electricité et de l'Eau Potable. Accessed August 5, 2015. http://www.onep.ma/.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, D.C. Yoder. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Equation (RUSLE). Washington: USDA. 11-19.

Rivas, Todd. 2006. Erosion Control Treatment Selection Guide. Washington: USDA. 1-7.

Rodell, Matthew and Hiroko Kato Beaudoing. 2013. NASA/GSFC/HSL. GLDAS Noah Land Surface Model L4 monthly 0.25 x 0.25 degree Version 2.0. Maryland, USA: Goddard Earth Sciences Data and Information Services Center (GES DISC). Accessed February 15, 2015. doi:10.5067/9SQ1B3ZXP2C5

Ryzak, Arthur C. 2014. "Visualizing Large Scale Changes in the Water Budget with a Custom GIS Script Tool." Master's thesis, the University of Texas at Austin. 2-48.

Ryzak, Arthur C. 2015. "Hydrologic Trend Analysis Tool." Center for Research in Water Resources, the University of Texas at Austin. Accessed on April 3, 2015. http://tools.crwr.utexas.edu/HTAT/index.html.

Sediment Committee. 2009. "Sedimentation and Sustainable Use of Reservoirs and River Systems." Draft Bulletin, ICOLD. 31.

"Services." L'Agence du Bassin Hydraulique du Bouregreg et de la Chaouia. Accessed September 7, 2014. http://www.abhbc.com/index.php/services.

Shen, Hsieh Wen and Pierre Y. Julien. 1993. "Erosion and Sediment Transport." In Handbook of Hydrology. Edited by David Maidment. New York: McGraw-Hill. 12.1.

Stata Statistical Software: Release 13. StataCorp LP, 2013.

"State of the Environment." Ministre de l'Energie, des Mines, de l'Eau et de l'Environnement. Accessed October 14, 2014. http://www.environnement.gov.ma/index.php/en/etat-env-en.

"Statistiques & Veille Économique." Ministère de l'Agriculture et de la Pêche Maritime. Accessed October 14, 2014. http://www.agriculture.gov.ma/rapports-statistiques.

"Strategy." 2009. Ministere d'Agriculture et Pêche Maritime. Paragraph 1. Accessed October 14, 2015. http://www.agriculture.gov.ma/pages/la- strategie.

Tetrimap. 2013. "Carte de fertilité des sols cultivés au Maroc." Fertimap. Ministère de l'Agriculture et de la Pêche Maritime et le Groupe Office Chérifien des Phosphates. Accessed November 15, 2014. http://www.fertimap.ma/map.phtml.

"The Green Morocco Plan- What is it exactly?" 2014. Economia. http://www.economia.ma/fr/numero-07/wp/le-plan-maroc-vert-c-est-quoi-au-juste.

Turabian, Kate L. 2013. A Manual for Writers of Term Paper, Theses, and Dissertations. 8th ed. Chicago: University of Chicago Press.

"UN-backed meeting in Morocco to focus on modernizing governments." 2002. UN News Center. Paragraphs 1-3. http://www.un.org/apps/news/story.asp?newsid=5563&cr=&cr1.

Van der Knijff, J.M., R.J.A. Jones, and L. Montanarella. 1999. “Soil Erosion Risk Assessment in Italy.” European Commission Directorate General Joint Research Centre: 21-28.

Vegetation in Bouregreg River Basin. 2013. SIGMED. Accessed November 30, 2015. http://labo.um5a.ac.ma/sigmed/index.php/fr/joomlaorg/carte.

Wagdy, Ahmed & Khaled AbuZeid. 2006. “Challenges of Implementing IWRM in the Arab Region.” Proceedings of WWF4, Mexico City.

Wirschmeier, W.H. and D. D. Smith. 1978. “Predicting Rainfall Erosion Losses- A Guide to Conservation Planning.” USDA Agricultural Handbook No. 537: 179-186.

"World Population Prospects: The 2012 Revision." 2012. United Nations, Department of Economic and Social Affairs. Accessed on Nov 15, 2014. http://esa.un.org/wpp/unpp/panel_indicators.htm.

Yadari, Hanaa. 2012. “Evolution spatio-temporelle des conditions de surface dans le bassin versant Tleta (Rif Occidental)." Master's thesis, Institute Agronomique et Vétérinaire de Hassan II: iv.

Yassin M., S. El Bahi, K. Renard, and M. El Wartiti. 2009. "Application du modèle universel de perte en terre révisé (RUSLE) aux terrains forestiers du plateau central." Annal Recherche Pour Maroc 40: 50-64.

Yassin, M., Y. Pépin, S. El Bahi, and P. Zante. 2011. "Evaluation de l’érosion au Microbassin de Sidi Sbaa : Application du Modèle MUSLE." Annales de la Recherche Forestière au Maroc 42: 171-181.

Yassin Mohammed. Interview by Author. Rabat, Morocco. June 30, 2015.

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