Towards a Proof-of-Concept of Green Water Credits for the Sebou Basin, Morocco

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1 Introduction

1.1 Context

In Morocco, *blue water* (see Figure 2 for definitions) resources are overexploited and nearing the limit of ecologic sustainable withdrawal of ground and surface water. Population growth in the Sebou basin, Morocco, puts an increasing pressure on land and water resources. Land use and management changes that are taking place alter the overall water balance, leading to an increase in runoff, peak flows, soil erosion and sedimentation of downstream reservoirs, reducing water availability across the watershed. Flooding and pollution were indicated as the major issues in the Sebou River basin. The costs of mobilizing more blue water are becoming more and more expensive and near to the limit of economic viability.

A mind shift is necessary the way we think about water and agriculture. Instead of a narrow focus on utilization of river and ground water, it is important to be aware that precipitation is the ultimate source of water that can be managed. There is a high potential to improve the use and management of rain water in upstream rain fed agriculture, called *green water management*. Current land management practices by farmers show the wasting of rain water by (i) large surface runoff enhancing flash floods and erosion (Figure 1), and (ii) large losses by evaporation of water directly from bare soil.

Figure 1: Example of land erosion due to surface runoff.

The knowledge and the tools to improve upstream manage land uses in arable, range and forest land are available, but need to be implemented. Upstream land users can provide rain water management services to water users downstream to improve the available *blue water* resources in terms of quantity and quality.

The implementation of *Green Water Credits* (GWC) management options can enhance the water availability, but farmers need incentives to sustainably implement them. At the same time, downstream users may be unaware of the benefits they might gain through farmer implementation of these measures in upstream areas.

This report describes the current state of the proof-of-concept assessment that evaluates the possibilities of Green Water Credits in the Sebou River basin in Morocco. In the first mission to Morocco in April 2009, the interest for the proof-of-concept phase was explored on the basis of basin identification questions (Green Water Credits, Work Plan (2010)), which indicated that the Sebou River basin offered scope to implement a Green Water Credits program. The choice for the Sebou River basin was acknowledged in the Steering Management Committee meeting in Rome in July 2009. This project will be supported under the IFAD Large Grant Green Water Credits Pilot Operations.

Green water is water held in the soil and returned as vapour by plants (transpiration) and by the soil (evaporation). Green water is the largest fresh water resource but can only be used in situ.
Blue water is all liquid water and includes surface runoff, groundwater and stream flow that can be used elsewhere - for domestic and stock water, irrigation, industrial and urban use - and which supports aquatic and wetland ecosystems.
Green water management is all soil and water management activities by farmers that improve rainwater infiltration, reduce runoff and evaporation, and enhance ground water recharge.
Green Water Credits is an investment mechanism that supports rain fed agriculture farmers to improve water resources management for the benefit of water users in the catchment. The funds for these payments are coming from the extra benefits of the downstream water users. At the initial stage public funds will be required to bridge the time lag between investments and the realization of the benefits.

Figure 2: Definitions used in Green Water Credits.

1.2 Principles of Green Water Credits

Green Water Credits (GWC) is a mechanism for payments to land users in return for specified soil and water management activities that determine the water supply to stakeholders in the basin. The initiative is driven by economic, environmental and social benefits.

The implementation of GWC has the potential of enhancing overall water management by reducing damaging runoff, increase groundwater recharge, stimulate a more reliable flow regime and reduce harmful sedimentation of reservoirs. Also, GWC provides a reliable, predictable diversification of rural incomes, enabling communities to adapt to economic, social and environmental change through asset-building in the shape of stable soils, more reliable water supply and enhanced yields.

Green Water Credits is an investment mechanism for upstream farmers to practice soil and water management activities that generate benefits for downstream water users, which are currently unrecognized and unrewarded. Green Water Management enhances farm productivity and ensures food security. It further induces carbon sequestration, and thus contributes to mitigate climate change effects. Joined operations of the stakeholders in the watershed safeguard water resources for all and generate a payment mechanism to sustain the common efforts.

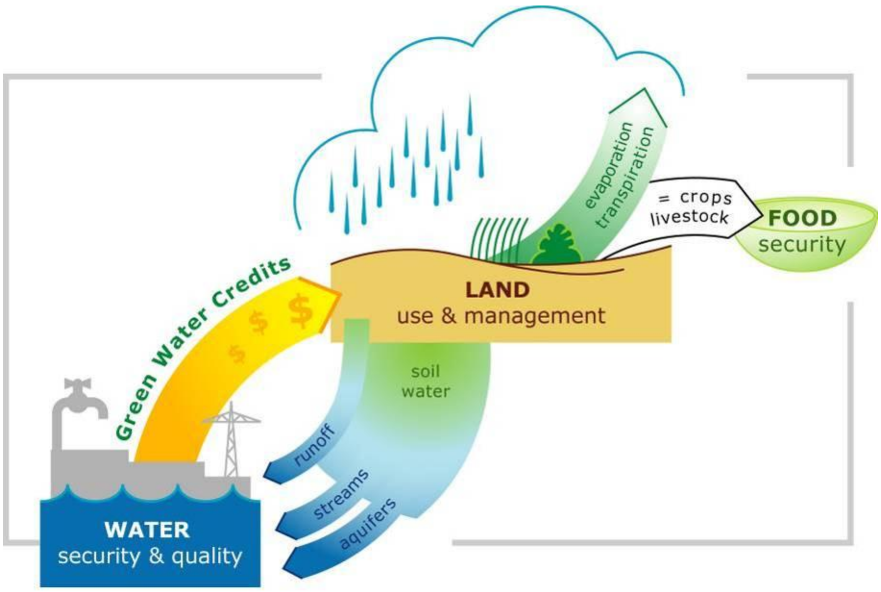

Figure 3: Green Water Credits bridging the gap in the water cycle

The overall goals of GWC are to enable rural people to better manage land and water resources such as:

- Deliver enhanced water flows;
- Reduce erosion and the siltation of reservoirs
- Mitigate the hazards of flood;
- Mitigate the hazard of drought;
- Mitigate effects from climate change.
- Improve food and water security and public health;
- Improve local resilience to economic, social and environmental change by asset building (stable soils, improved water resources, reduce the rate of poverty, and diversify rural incomes);

A study is currently being undertaken for implementation of GWC in the Tana basin in Kenya [Hunink et al., 2009]. The studies in this basin showed that the implementation of GWC significantly reduces the problems related to the growing demands for hydropower generation, municipal water utilities, and irrigators. Different green water management options were analyzed which showed that considerable improvements could be obtained in terms of water security for both upstream as downstream stakeholders.

1.3 Basin characterization

1.3.1 Basin selection

The choice for the Sebou River basin for the implementation of GWC was acknowledged in the Steering Management Committee meeting in Rome in July 2009. The GWC objectives are in line with Morocco's Green Plan (Plan Maroc Vert), as the plan seeks a balance between irrigated and dry land agriculture, the latter being the target of GWC. The plan aims at boosting market-oriented agriculture that should improve the livelihood of smallholders and subsistence farmers, which is also the GWC target.

1.3.2 Basin overview

The Sebou River Basin (Figure 7), with a total area of 37,000 km^2, is one of Morocco's most important river basins. The Sebou River begins amongst scattered lakes in the cool oak and cedar forests of Morocco's Middle Atlas range. The basin contributes with 30% of the national potential of surface water resources and 20% of the ground water resources. Sometimes this basin is referred to as Oued Sebou or River Sebou. The river runs north through overgrazed scrub and grasses of the Atlas foothills to meet its tributary, Oued Fes, near the historic city of Fes. From there, it winds through one of the most populated areas of Morocco, supplying water to irrigate fields of rice, wheat and sugar-beet as well as supporting olive groves and vineyards. This lower course of the river is artificially connected by the Nador canal to one of the most important wetlands of North Africa: the Merja Zerga lagoon.

The basin can be divided into three distinct geomorphic regions: the upper, mid, and lower Sebou [Snoussi et al., 2002]. The upper Sebou rises over 2,800 m in the Middle Atlas Mountains and is underlain mainly by calcareous rocks. Mean annual precipitation is above 1,000 mm, and at high elevations winters are snowy. The mid-Sebou basin is located in the Rif and Prerif mountains, which are characterized by an average altitude of 2,000 m, very steep slopes, and a strong rainfall gradient across the basin. Ouerrha and Inaouene are the major tributaries of the Sebou draining the Rif and Pre-rif mountains. At the lower basin, the Sebou opens into a wide valley where it meanders through a floodplain. The mean annual rainfall is about 600 mm in the west and 450 mm in the southeast.

The Sebou basin is the most important agricultural region of Morocco. It has relatively well-developed social and economic infrastructure. Only 25% of the basin's drainage area is covered with natural vegetation. Since the lower basin consists of a coastal plain, large-scale irrigation schemes have been developed in Rharb Plain. The main crops grown are cereals, vegetables, olive, sugar beet, citrus, and grapes [Snoussi et al., 2002]. The upstream part of the basin supports a large population of rain-fed farmers (Figure 4), offering significant opportunities for improved land and water management in rainfed agriculture and forest land.

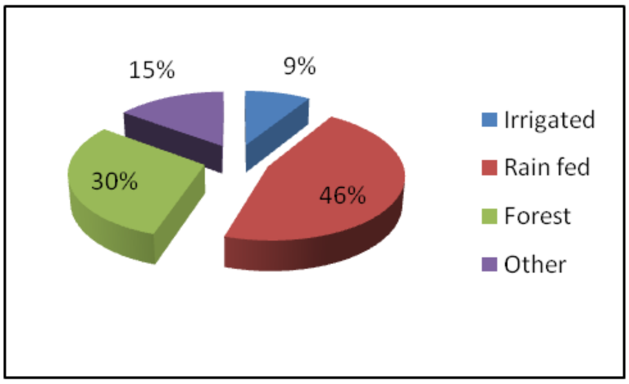

Figure 4: Percentage of land use (Green Water Credits, Work Plan (2010)).

A total of 6.7 million people live in the basin (23% of total Morocco), of which 57% living in rural areas. Most of the population is concentrated in the urban centers of Fès, Meknés, Kénitra, Taza, in the agricultural plains of Saïs, Gharb and Mnasra, and to a minor extent, in the forestry and pastoral areas of the Middle Atlas, the Rif and the Pré-rif.

Faced with a rapidly growing urban population of 3.0% per year, the Moroccan authorities, along with local actors and the international community, is searching for innovative approaches to address the interrelated issues of water scarcity, poverty and environmental degradation in the Sebou basin. The pressure to secure the growing demands for water for domestic consumption, industry and agriculture is particularly high in the densely populated river basin of the Sebou River.

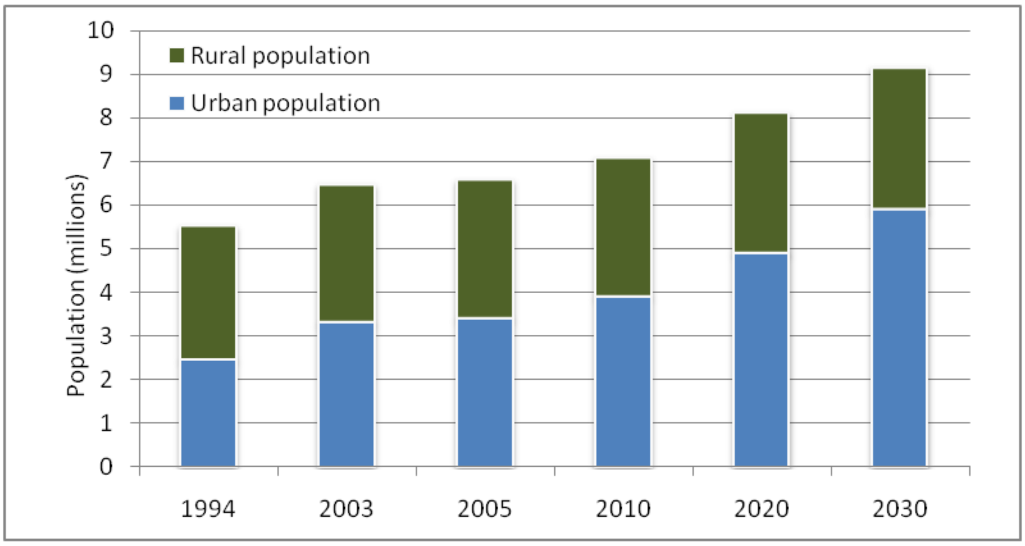

Figure 5: Past and future population growth (data source: PDAIRE, 2005).

Another major recognized problem in the basin is the massive deforestation and land degradation which has several negative impacts as the siltation of dams, loss of arable land and flooding. Especially in the high mountain areas of the Middle Atlas and the Piedmont area these problems are relevant. Very local intense precipitation storms, especially in summer or fall, can cause damage to agricultural fields in small catchments, erosion of fertile land, and hazardous flood levels in the rivers. Also prolonged floods occur, affecting more downstream areas. The occurrence of these harmful events has most likely increased during recent years due to the continuing land use changes in the mountain areas.

- The Sebou River Basin in northern Morocco runs roughly 500 kilometers in length, from Middle Atlas Mountains in the east to the Atlantic Ocean in the west. The area of the basin is 40,000 square kilometer.

- The Sebou water resources potential is about 5.6 billions of cubic meters representing 28% of the national potential. This basin includes also a large agricultural potential (useful agricultural area = 1.8 million of hectares) from which 357.000 ha are irrigated. The Sebou basin holds several industrial, touristic and handicraft activities.

- The Sebou Basin Hydrological Agency (ABHS) faces many challenges:
    - Droughts which are becoming a structural component and not a conjuncture phenomenon
    - Flooding
    - Groundwater depletion and overexploitation
    - Pollution
    - Watershed erosion and dams silting up
    - Weak efficiency of the water distribution systems
    - Weak economic valorization (difference between areas dominated by dams and equipped areas with irrigation systems)

Figure 6: The Sebou River basin in a nutshell.

1.3.3 Water balance

A rough estimate of the water balance of the Sebou River basin is shown in Table 1, coming from previous studies, which shows that runoff to rivers and reservoirs is 18% of the annual rainwater, and groundwater recharge is 5%. So far, efforts for improved water management were mainly directed to harness blue water in reservoirs that currently have a storage capacity of 24% of the annual rainfall. The total amount of green water (evapotranspiration) is 77% of the total annual rainfall, which is an improved management target of the GWC program.

Table 1: The Sebou water balance (ABHS and WWF, 2009)[1]

Water flux	*Quantity [Mm^3]*	*Quantity [%]*
Precipitation	24,000	100
Green Water (ET)	18,500	77
Runoff	4,160	18
Groundwater	1,300	5

Figure 7: The Sebou River Basin (red line) in Morocco.

[1] ABHS and WWF (2009) SPI-Water: Etat des lieux du basin du Sebou

2.1 Model selection

The circulation of water throughout the earth and atmosphere is a complex mechanism of energy exchange and different ways of transportation. A schematization of the different processes involved in the water cycle is shown in Figure 8. Hydrological models are a tool to simulate these paths of water movement under different conditions. They are used as a tool to study, for example, the impact of climate change on water availability, the impact of land use change on river discharges, and the impact of (agricultural) management strategies on the water availability and sediment yield.

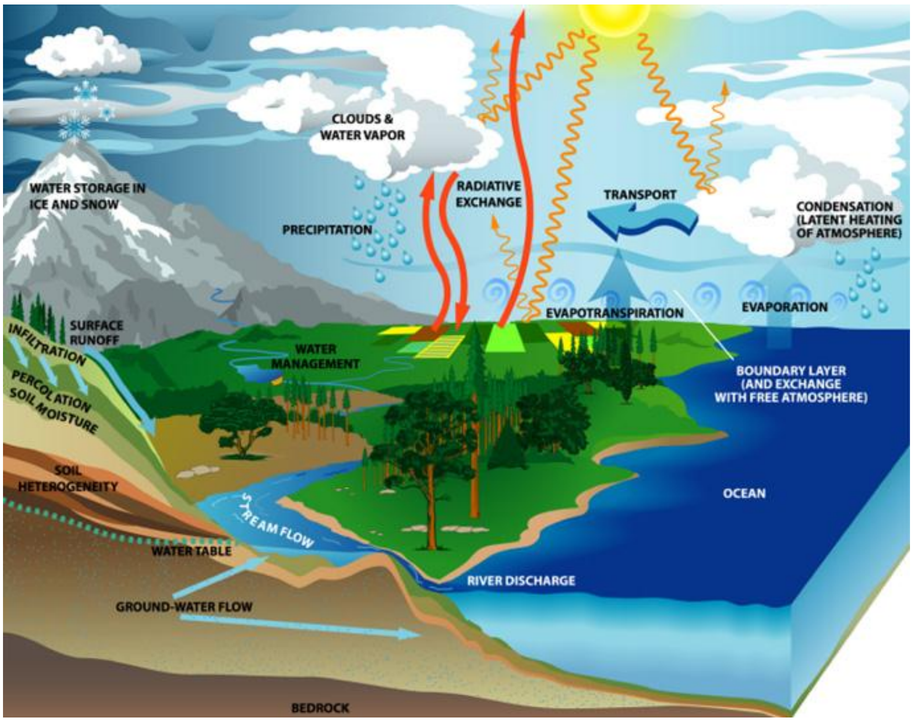

Figure 8: Schematization of the global water cycle.

Currently, a huge number of hydrological models are available to analyze the soil-water relationships at the field and basin level. For the current study the Soil and Water Assessment Tool (SWAT) [Gassman et al., 2007] was chosen to evaluate the impact of crop-land-soil management on downstream water and sediment flows. SWAT was chosen because it is a basin-scale model, which is able to quantify the impact of land management practices in large, complex watersheds.

The main advantage for the exploration of GWC in the Sebou basin is that SWAT uses a physical based rainfall-runoff scheme, instead of a purely data-based statistic or conceptual scheme. This guarantees more reliable scenario simulations and better performance in poorly gauged catchments, which is essential for a study on this scale. Besides, the model is primarily focused on the interaction between land management versus water- and erosion processes. This makes the tool adequate for this study, as it will be able to represent and simulate the impact of land management practices on basin-scale water and sediment yields.

Shortly, strong aspects of the SWAT model to make it suitable for the current project can be summarized as:

- Physical based rather than parametric based rainfall-runoff scheme to ensure more reliable scenario simulations.
- Focus on water-erosion-land management processes.
- Public domain, including source code.
- User-friendly interface.
- Large user-group worldwide.
- Excellent documentation, including training materials.
- Consortium extensive experiences in application as well as training.
- Modeling experience with previous Green Water Credits assessments [Kauffman et al., 2007; Hunink et al., 2009]. The relevant components of SWAT for this study will be described in the following paragraphs.

2.2 The agro-hydrological model SWAT

SWAT is a river basin model developed originally by the USDA Agricultural Research Service (ARS) and Texas A&M University and is currently one of the world's leading spatially distributed hydrological models.

A distributed rainfall-runoff model – such as SWAT – divides a catchment into smaller discrete calculation units for which the spatial variation of the major physical properties are limited and hydrological processes can be treated as being homogeneous. The total catchment behaviour is a net result of manifold small sub-basins. The soil map and land cover map within sub-basin boundaries are used to generate unique combinations, and each combination will be considered as a homogeneous physical property, i.e. Hydrological Response Unit (HRU). The water balance for HRU's is computed on a daily time step. Hence, SWAT will distribute the river basin into units that have similar characteristics in soil, land cover and that are located in the same sub-basin.

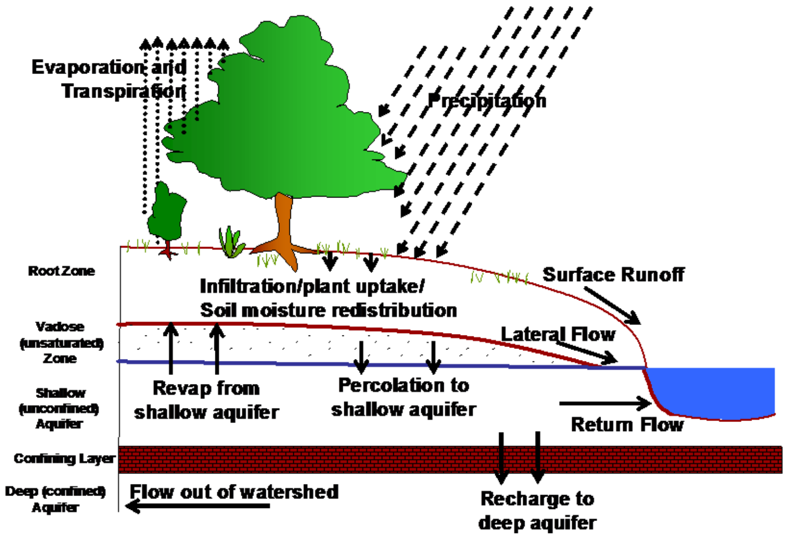

Figure 9: Main processes as implemented in the SWAT model.

Irrigation in SWAT can be scheduled by the user or automatically determined by the model depending on a set of criteria. In addition to specifying the timing and application amount, the source of irrigation water must be specified, which can be: canal water, reservoir, shallow aquifer, deep aquifer, or a source outside the basin.

SWAT can deal with standard groundwater processes (Figure 9). Water enters groundwater storage primarily by infiltration/percolation, although recharge by seepage from surface water bodies is also included. Water leaves groundwater storage primarily by discharge into rivers or lakes, but it is also possible for water to move upward from the water table into the capillary fringe, i.e. capillary rise. As mentioned before, water can also be extracted by people for irrigation purposes. SWAT distinguishes recharge and discharge zones.

Recharge to unconfined aquifers occurs via percolation of excessively wet root zones. Recharge to confined aquifers by percolation from the surface occurs only at the upstream end of the confined aquifer, where the geologic formation containing the aquifer is exposed at the earth's surface, flow is not confined, and a water table is present. Irrigation and link canals can be connected to the groundwater system; this can be an effluent as well as an influent stream.

After water is infiltrated into the soil, it can basically leave the ground again as lateral flow from the upper soil layer – which mimics a 2D flow domain in the unsaturated zone – or as return flow that leaves the shallow aquifer and drains into a nearby river (Figure 10). The remaining part of the soil moisture can feed into the deep aquifer, from which it can be pumped back. The total return flow thus consists of surface runoff, lateral outflow from root zone and aquifer drainage to river.

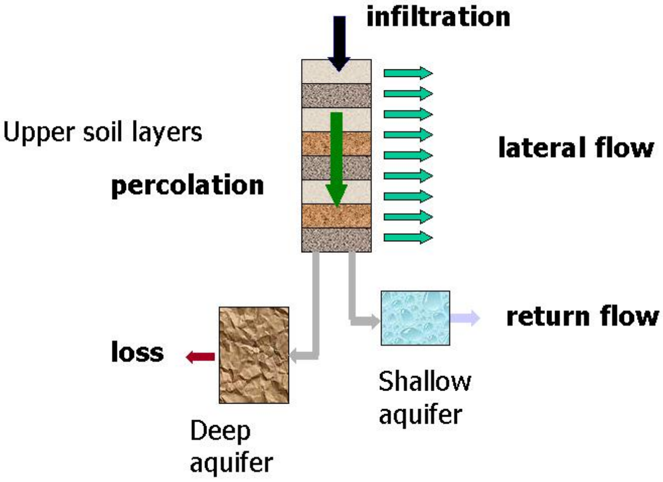

Figure 10: Schematization of the SWAT sub-surface water fluxes.

For each simulation day, potential plant growth, i.e. plant growth under ideal growing conditions is calculated. Ideal growing conditions consist of adequate water and nutrient supply and a favourable climate. First the Absorbed Photosynthetical Radiation (APAR) is computed from intercepted solar radiation, followed by a Light Use Efficiency (LUE) that is in SWAT essentially a function of carbon dioxide concentrations and vapour pressure deficits. The crop yield is computed as the harvestable fraction of the accumulated biomass production across the growing season (Figure 11).

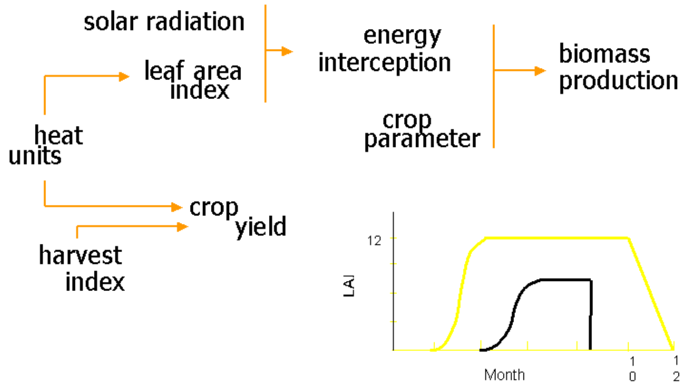

Figure 11: Parameterization of crop production in SWAT

2.3 Data needs

An overview of the required data to perform the biophysical assessment is provided in Figure 12. The datasets were requested and obtained from the Morrocan counterparts and evaluated, as described in the following sections. In addition, the remainder of the necessary data for the schematization of the model has been obtained from global public domain datasets.

It was stressed to the local counterparts that the time resolution of the climate-data needs to be daily data. These data needs to be from various weather stations, well distributed throughout the basin, both from mountain areas as well as downstream locations.

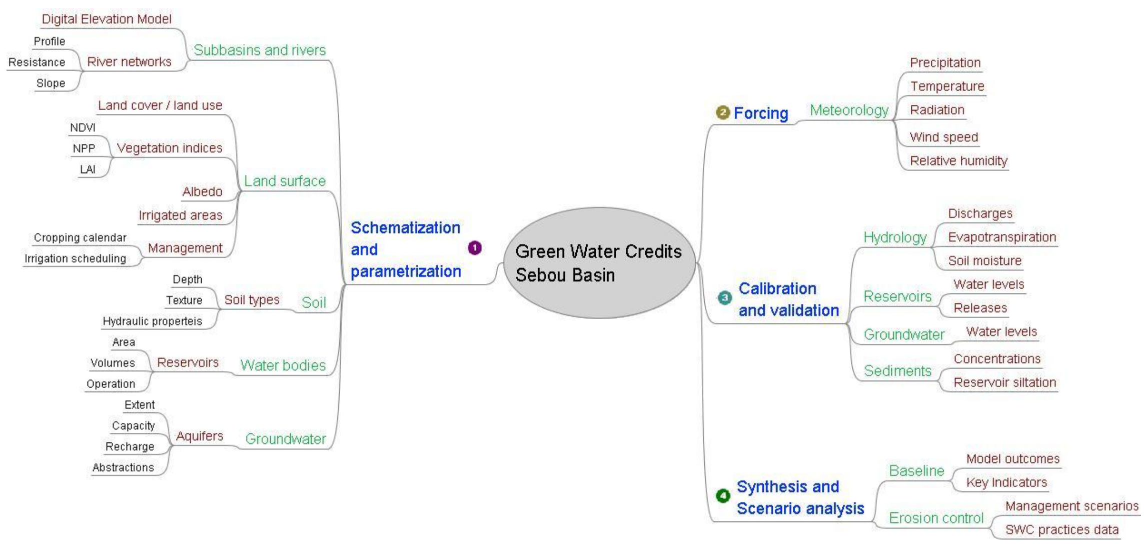

Figure 12: Diagram of required data and modeling components for the GWC Biophysical Assessment for the Sebou basin.

The following sections will describe the datasets that have been evaluated and prepared for the assessment. The main datasets that are discussed are:

- Digital elevation model
- Climate
- Land use and management
- Soils
- Streamflow
- Reservoirs

3 Baseline Datasets

For the Green Water Credits concept it is crucial to fully understand and quantify the up- and downstream interactions in terms of water flows and sediment transport. Consequently good data on the interfering variables of the current situation are needed and have to be analyzed with the appropriate tool. As was mentioned before, the SWAT model will be used in this study to analyze the impacts of land use management strategies on the water and sediment dynamics in the Sebou River basin.

The current chapter describes the available datasets which are used to build-up the distributed hydrological model SWAT in the Sebou River basin. Different datasets are available, which are compared and evaluated in order to make an appropriate dataset selection to obtain optimal accuracy in the quantification of the interactions relevant for the scope of Green Water Credits.

3.1 Digital Elevation Model

The basis for the delineation of a watershed in SWAT is a Digital Elevation Model (DEM). Digital Elevation data were obtained from the Shuttle Radar Data Topography Mission (SRTM) of the NASA's Space Shuttle Endeavour flight on 11-22 February 2000. SRTM data were processed from raw radar echoes into digital elevation models at the Jet Propulsion Laboratory[2] (JPL) in California.

Currently, SRTM data at a spatial resolution of 3 arc-second (90 meters) are available for global coverage between 60 degrees North and 56 degrees South latitude. This product consists of seamless raster data and is available in geographic coordinates (latitude/longitude) and is horizontally and vertically referenced to as the EGM96 Geoid (NASA 1998). The SRTM-DEM data have been obtained using the Data Distribution System of CIAT (http://srtm.csi.cgiar.org/) where the original DEMs were further processed to fill in these no-data voids. This involved the production of vector contours and points, and the re-interpolation of these derived contours back into a raster DEM. These interpolated DEM values are then used to fill in the original no-data holes within the SRTM data. These processes were implemented using Arc/Info and an AML script. The DEM was resampled to the Lambert Conformal Conic[3] projection with a resolution of 250 m using a bilinear algorithm. Finally it was clipped to the boundary of the basin, and sink were filled using the method of Tarboton et al., (1991) with a threshold of 20 m.

This DEM is shown in Figure 13 for the Sebou River basin in Morocco. Based on this DEM, we note that the elevations in the basin range between 0 and 2921 MASL (Meters Above Sea Level). Large elevations are found in the southeastern and northeastern part of the basin, which belong to the Atlas mountain range.

[2] http://www2.jpl.nasa.gov/srtm/

[3] http://en.wikipedia.org/wiki/Lambert_conformal_conic_projection

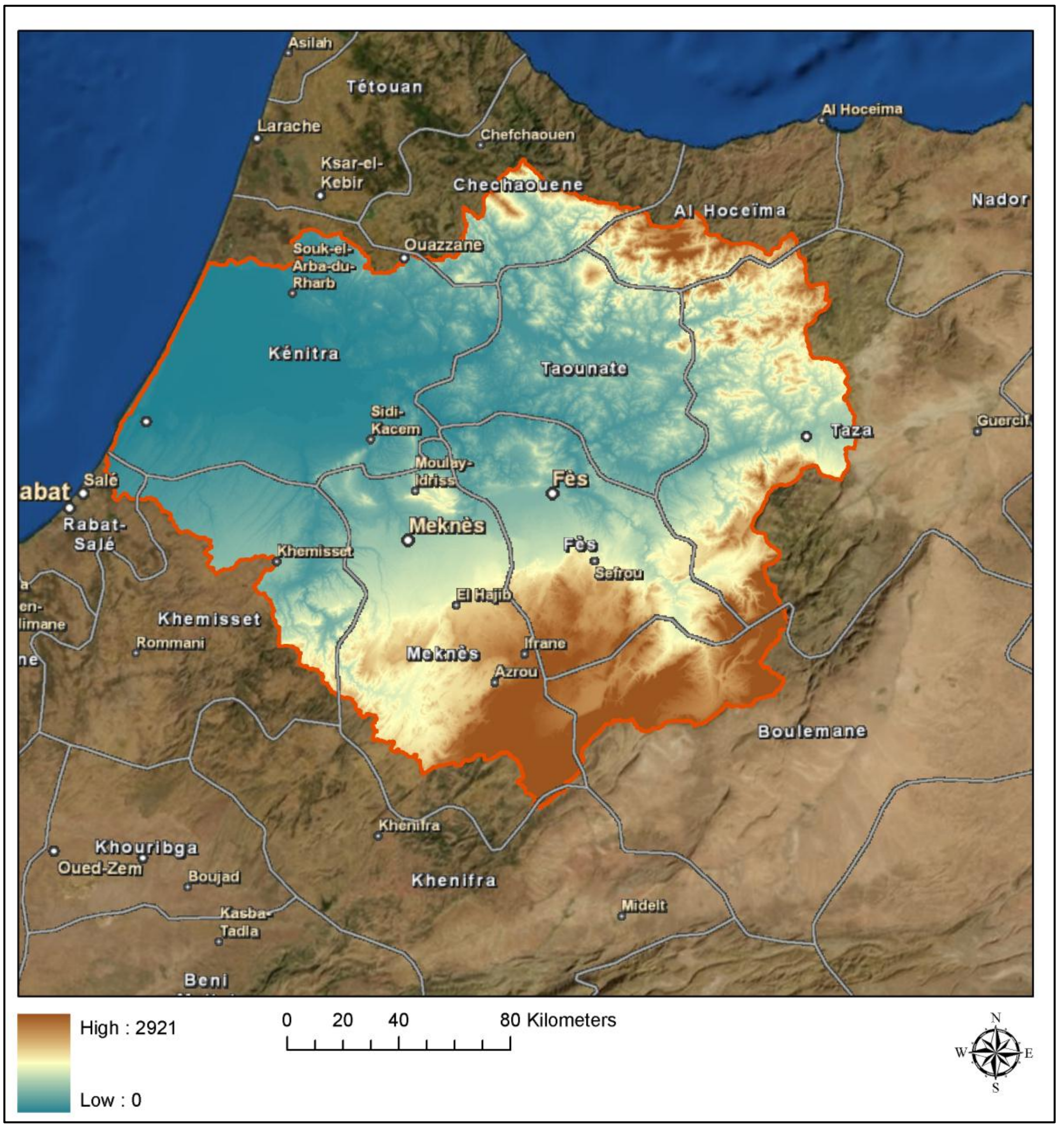

Figure 13: Digital Elevation Model (DEM) of the Sebou River Basin at a spatial resolution of 250 m.

3.2 Climate

3.2.1 Data needs

SWAT requires daily rainfall data as well as other metrological input data that depend on the evapotranspiration method used. Several methods are available to calculate the potential evapotranspiration. The most advanced method available, which is the Penman-Monteith method, requires data on temperature, solar radiation, wind speed, and humidity for the calculation of the spatially distributed potential evapotranspiration rates. For this phase, the Hargreaves method [Hargreaves et al., 1985] was used for the calculation of the potential evapotranspiration.

The SWAT model requires meteorological data to be available at a daily time step. SWAT requires the following variables:

- Cumulative daily rainfall
- Minimum and maximum daily temperature

- Solar radiation
- Wind speed
- Relative humidity

Various sources for these data were evaluated, as described in the following section.

3.2.2 Data sources

3.2.2.1 Locally obtained climate data

For the Proof of Concepts phase of Green Water Credits, local data were obtained from 18 meteorological stations in the basin provided by ABHS. These data are on a monthly basis. Daily data for these stations have been requested but until now it is unclear whether they will come available. The locations of these stations are shown in Figure 14. The coverage throughout the basin is fair; however, no station data is available in the north-eastern part of the basin, which is a mountainous area where rainfall amounts tend to be higher than in the lower areas.

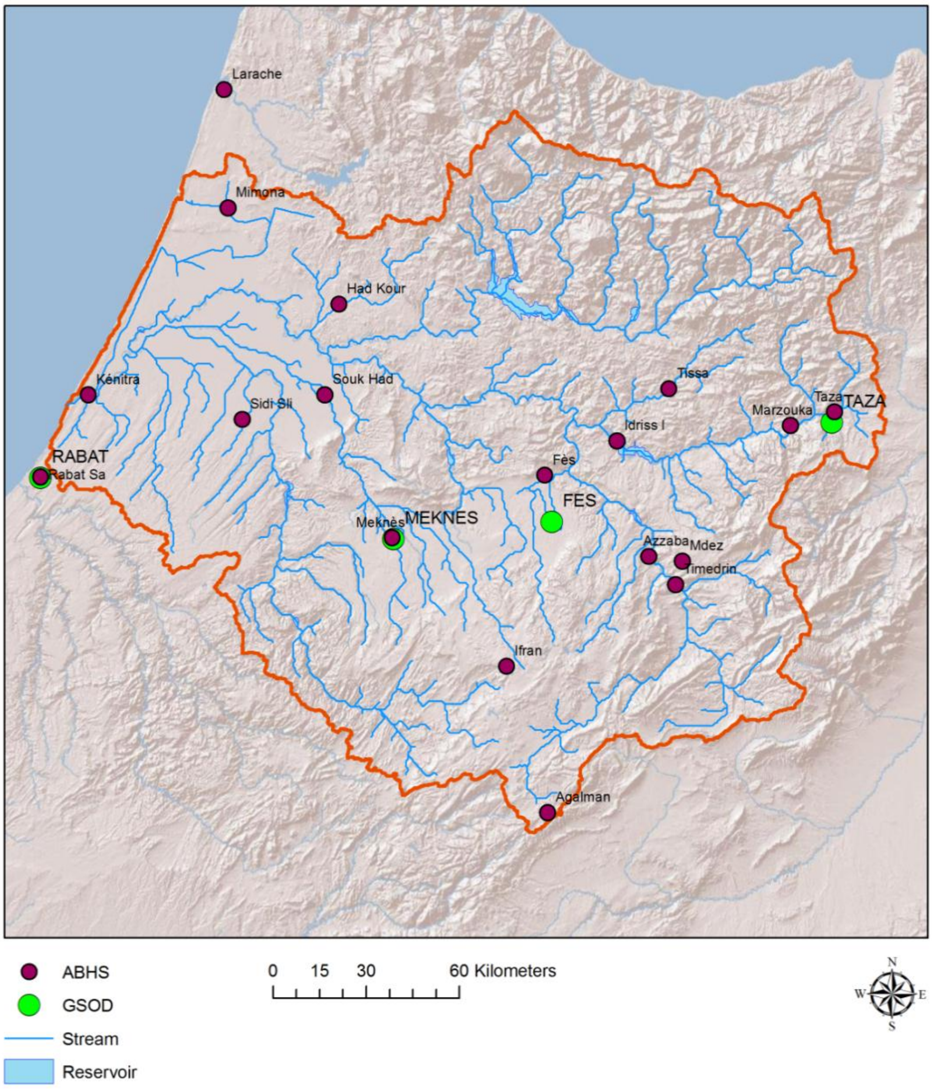

Figure 14: Locations of the active meteorological weather stations from GSOD and ABHS.

3.2.2.2 GSOD

Meteorological data from weather stations all over the world can be found at the public domain Global Summary of the Day (GSOD[4]) database archived by the National Climatic Data Center (NCDC[5]). This database offers a substantial number of stations with long-term daily time-series. The GSOD database submits all series (regardless of origin) to extensive automated quality control. Therefore, it can be considered as a uniform and validated database where errors have been eliminated. For the current study, four active stations located within the Sebou River basin were extracted from the GSOD database. The characteristics of these four stations are described in Table 2. The locations of these meteorological stations are presented in Figure 14. A shortcoming of these 4 active stations is that their location is more or less in the same climatic zone, while no weather stations can be found in the higher mountain areas.

Table 2: Characteristics of the GSOD meteorological stations.

Station name	*Elevation*	*Data*
Fes	510	01/01/1980 to 20/10/2010
Taza	79	01/01/1980 to 20/10/2010
Rabat	579	01/01/1980 to 20/10/2010
Meknes	560	01/01/1980 to 20/10/2010*

* From 26/10/1984 to 27/01/1988 filled with Rabat data.

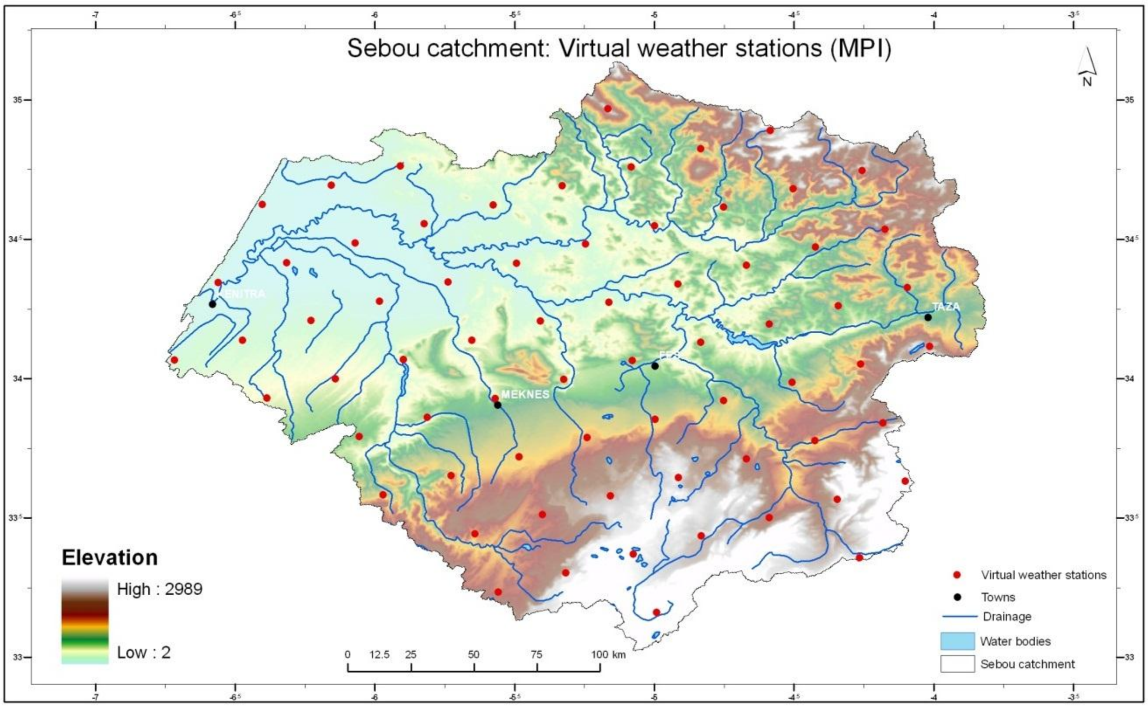

Figure 15: Locations of the virtual MPI model stations.

3.2.2.3 MPI model data

The MPI dataset (FP5-FP7) provided by the European Center for Medium Range Weather Forecast[6] (ECMWF) covers a timespan of over 40 years. The goal of MPI is to promote the use

[4] http://climate.usurf.usu.edu/products/data.php?tab=gsod

[5] http://www.ncdc.noaa.gov/oa/ncdc.html

[6] http://www.ecmwf.int/

of global analyses of the state of the atmosphere, land and surface conditions, while using three dimensional variation techniques, using the T159L60 version of the Integrated Forecasting System. According to the documentation, the analysis involves comprehensive use of satellite data, starting from the early Vertical Temperature Profile Radiometer data in 1972. Later also TOVS[7], SSM/I, ERS and ATOVS were included. Cloud Motion Winds are used from 1979 onwards.

The MPI dataset was used in the ENSEMBLES project (FP6) to simulate climatology for Europe, while still encompassing the northern part of the African continent (including Morocco). The ENSEMBLES project's aim was:

"Develop an ensemble prediction system for climate change based on the principal state-of-the-art, high resolution, global and regional Earth System models developed in Europe, validated against quality controlled, high resolution gridded datasets for Europe, to produce for the first time, an objective probabilistic estimate of uncertainty in future climate at the seasonal to decadal and longer timescales".

Daily meteorological variables for SWAT have been extracted from the http://ensemblesrt3.dmi.dk/ data service for model runs of the Max Planck Institute für Meteorology[8] (MPI-M), which were sub-setted in time (1970-2000) and space (Morocco), using CDO tools available from the MPI-M in Hamburg. Based on the GDAL library, a custom made converter has been developed in python to generate DBF location files as well as DBF weather record for each location point over the 30 years.

The MPI model grid points are shown as virtual stations in Figure 15.

3.2.2.4 WMO and TRMM

Droogers and Immerzeel (2008) evaluated multiple meteorological data sources for the Sebou Basin in Morocco. They analyzed precipitation and temperature data from the World Meteorological Organisation[9] (WMO). A disadvantage of this dataset is that there is no quality control, and that it contains many gaps. Therefore, this dataset is not used in the current study. This dataset, however, can be used for comparison reasons with our meteorological datasets.

Another important and world-wide used source of meteorological data is the Tropical Rainfall Measuring Mission[10] (TRMM). The advantage of this dataset is that it has a high spatial resolution (0.25 degrees, approx. 25 km), and that recent data is available. A disadvantage is that data is available from 1998 onwards, only.

3.2.2.5 Data availability

The characteristics of the different available meteorological data sources are shown in Table 3. Especially the temporal and spatial resolutions of the datasets are of importance for a reliable model implementation. As can be seen from Table 3, only GSOD, MPI, and FEWS (rainfall only) data provide data on a daily basis. Unfortunately, until now, no discharge data has come available for the period 2002 onwards. Therefore, the FEWS data cannot be used to force the

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[7] http://www.ozonelayer.noaa.gov/action/tovs.htm

[8] http://www.mpimet.mpg.de/en/home.html

[9] http://worldweather.wmo.int/

[10] http://trmm.gsfc.nasa.gov/data_dir/data.html

SWAT model at the moment and carry out a proper calibration procedure. If in a later stage more recent discharge data becomes available, then FEWS would be a favorable option to be used in SWAT. For now GSOD and MPI would be the first choice to be used in the SWAT model. For a quality check, however, it is necessary to validate the climate data sets with each other before running the SWAT model. This evaluation is performed in Section 3.2.3. In addition to the completeness of data, the MPI dataset does not contain missing values. The GSOD Mekness station, however, does contain missing values. These missing values were filled using data from the Rabat station.

Table 3: Characteristics of different meteorological data sources.

Name	*Type*	*Format*	*Temporal resolution*	*Nr. stations* / spatial resolution*	*Availability*	*Variables***
ABHS	Observed	Station	Monthly	16	1973-2002	P, Tmean
GSOD	Observed	Station	Daily	4	1980-present	P, Tmax, Tmin, DEWPT, WNDAV
MPI	State of the Art Climate Model	Grid	6 hourly, stored, daily used	0.22°	1961-2000	P, Tmax, Tmin, T, Rad, DEWPT, WNDAV, VP
TRMM	Satellite rainfall	Grid	Daily	0.25°	1988 – present	P
CRU	Climate grids	Grid	Monthly	0.5°		P, Tmean, Tmax, Tmin, DEWPT
FEWS-NET	Satellite rainfall	Grid	Daily	0.1°	2000-present	P

* The number of available stations present within the study basin.

** P = precipitation, Tmax = maximum temperature, Tmin = minimum temperature, T = temperature, DEWPT = dew point, WNDAV = average wind speed, VP = vapour pressure, Rad = radiation.

3.2.3 Climate data evaluation

3.2.3.1 Other studies

The Sebou basin is generally classified as having a Mediterranean climate; however, it still varies between seasons and regions. While the coastal areas are still influenced by the southwest trade winds, the inland areas are more continental with cold winters and hot summers. The climate in the mountain peak areas of the Atlas and the Rif changes dramatically with snow covers most of the time during the year. The winter period between October and April is known to be the rainfall season, while the remaining months show mainly dry periods. The main agro-climatic zones of the Sebou River basin are shown in Figure 16.

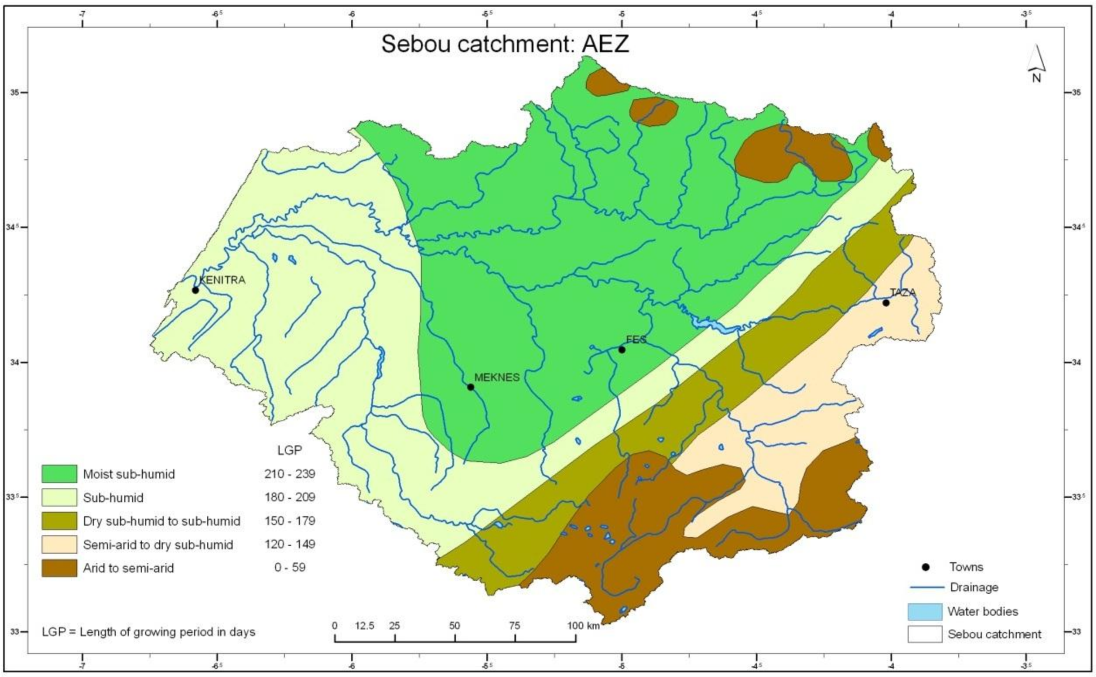

Figure 16: Main agro-climatic zones which are based on the balance between precipitation and evapotranspiration. The Sebou encompasses five main climatic zones ranging from moist sub-humid to arid (source: Fischer et al. 2002).

Droogers and Immerzeel (2008) analyzed precipitation and temperature data of the WMO Meknes meteorological station for the period 1997-2006. They concluded that temperatures range from 10°C during winter up to roughly 25°C during summer. Precipitation from June to September is very low. The average monthly precipitation sum and average monthly temperature of the Meknes meteorological station for 1997-2006 are shown in Figure 17. Another interesting result from the WMO dataset is that the year-to-year variation can be substantial, and ranges from 300 to about 600 mm (Figure 18).

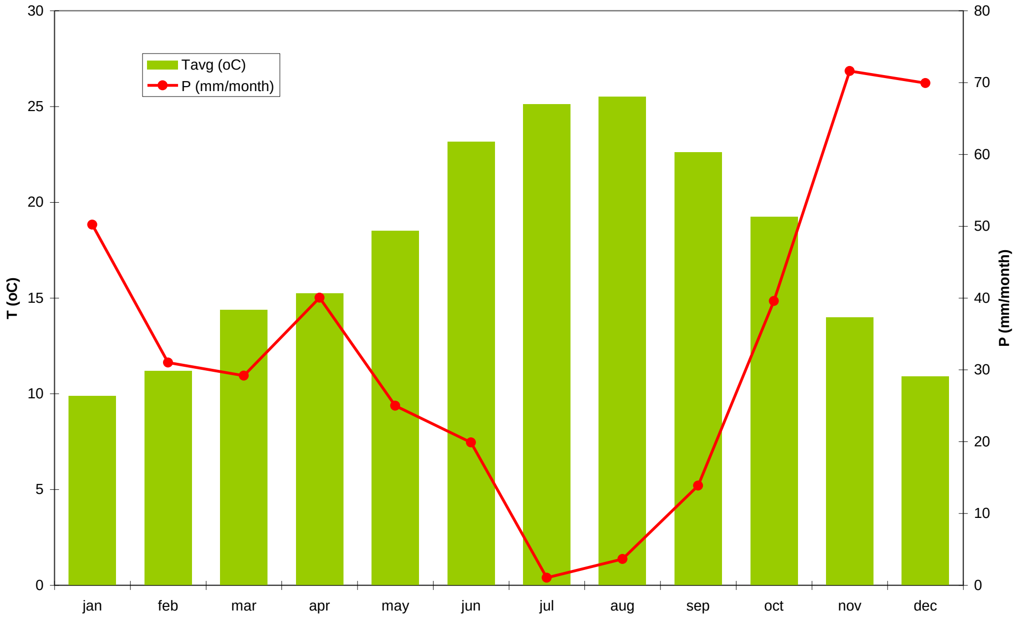

Figure 17: Average monthly temperature and precipitation of Meknes station for 1997-2006.

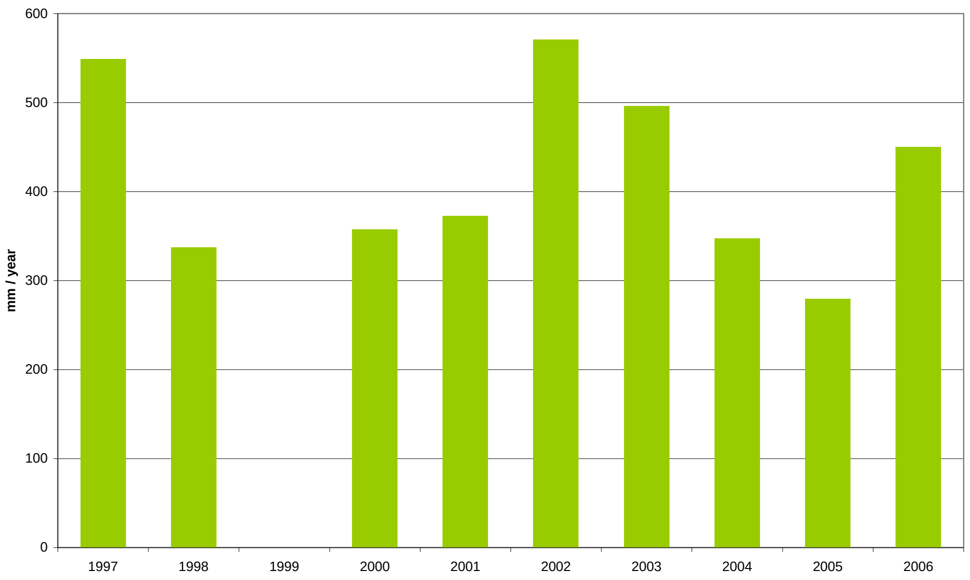

Figure 18: Annual precipitation of Meknes station for 1997-2006.

This distribution of annual precipitation derived from TRMM is shown in Figure 19. Based on TRMM, it is shown that the northern part of the basin is characterized as a wet region, while the southern and eastern parts of the basin are drier.

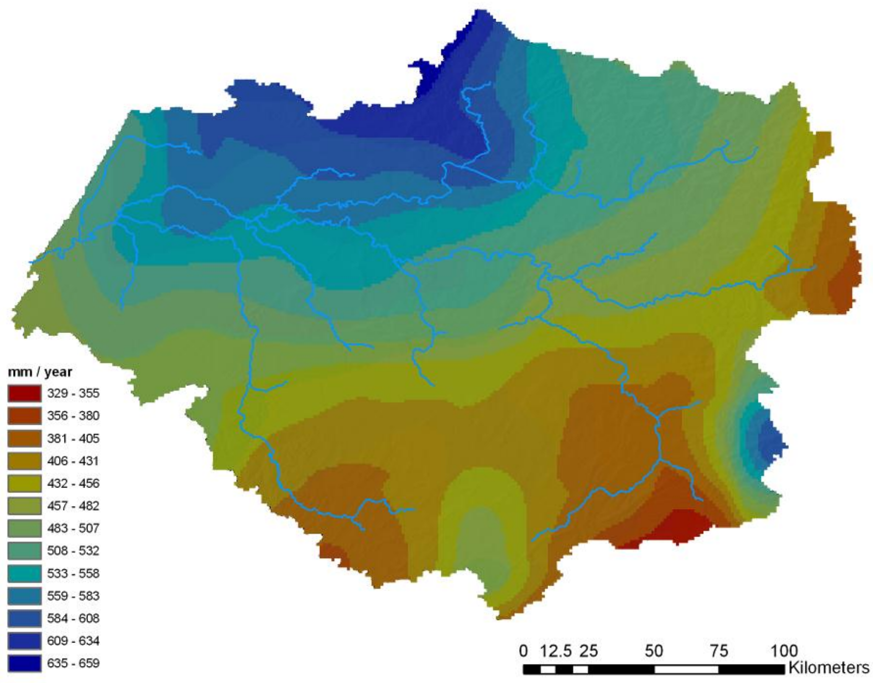

Figure 19: Annual precipitation distribution derived from TRMM (average of 1998-2006)

3.2.3.2 Comparison of GSOD, MPI and AB HS data

GSOD meteorological data were available for 1980-2010, MPI model data were available for 1971-2000, and ABHS data were available for 1973-2002. This means there is an overlapping period of 1980-2000 to compare the datasets with each other. For the analysis, each of the four

GSOD stations is compared with the closest ABHS station, and with the average of the four surrounding MPI grid points, which are assumed to be representative for that specific GSOD station. The Meknes data is also compared with the WMO and TRMM data of Droogers and Immerzeel (2008).

Figure 20 represents the average monthly precipitation sums of the GSOD, MPI and ABHS data for the period 1980-2000. It is clear that MPI is significantly different from the GSOD and ABHS data. The yearly precipitation pattern, with the very dry months July and August, is clearly present in all three datasets. MPI, however, is substantially wetter than the other two, except for Taza where GSOD and ABHS are wetter for most of the year. It is clear that the GSOD and ABHS data are more or less in the same order of magnitude, although there are small differences between these two during winter months. Differences between MPI and the GSOD and ABHS data are largest during winter, and are in the range of 10 up to roughly 50 mm/month. If we compare the WMO precipitation data of Meknes (Figure 17) with the GSOD, MPI and ABHS precipitation, then it is clear that MPI is too wet. According to the TRMM precipitation (Figure 19), Mekness annual precipitation should be in the order of 440 mm. This also proofs that MPI is too wet, and that the GSOD data is a more reliable data source. According to TRMM, the annual precipitation for Rabat is 470 mm, for Fes 440 mm, and for Taza 415 mm. All these values, except for Taza, are closest to the GSOD and ABHS data.

Figure 20 shows the average monthly precipitation sum over the period 1980-2000. This makes it hard to see how all the individual months behave. Therefore scatter-plots of all monthly precipitation sums have been made for each of the four stations. These scatter-plots are shown in Figure 21, with on the x-axis the GSOD monthly precipitation sums, and on the y-axis the MPI monthly precipitation sums. Also these plots show that the MPI precipitation sums for the individual months are too large when compared with the GSOD precipitation. For a minority of months the GSOD precipitation is higher. Differences between GSOD and MPI are largest for Taza, as was already noticed in Figure 20. The correlation between GSOD and MPI is very low for Taza, and for most months the MPI precipitation sum is too small.

The maximum and minimum temperatures from GSOD and MPI have been analyzed as well. This analysis showed that MPI overestimates the GSOD temperatures significantly. This is true for both the maximum and minimum temperatures. The maximum MPI temperature is modeled to high during summer. During winter the maximum temperature of MPI is quite comparable to the GSOD maximum temperature. The minimum temperature seems to be overestimated by MPI during both summer and winter time. Differences are smallest for TAZA, although still too large.

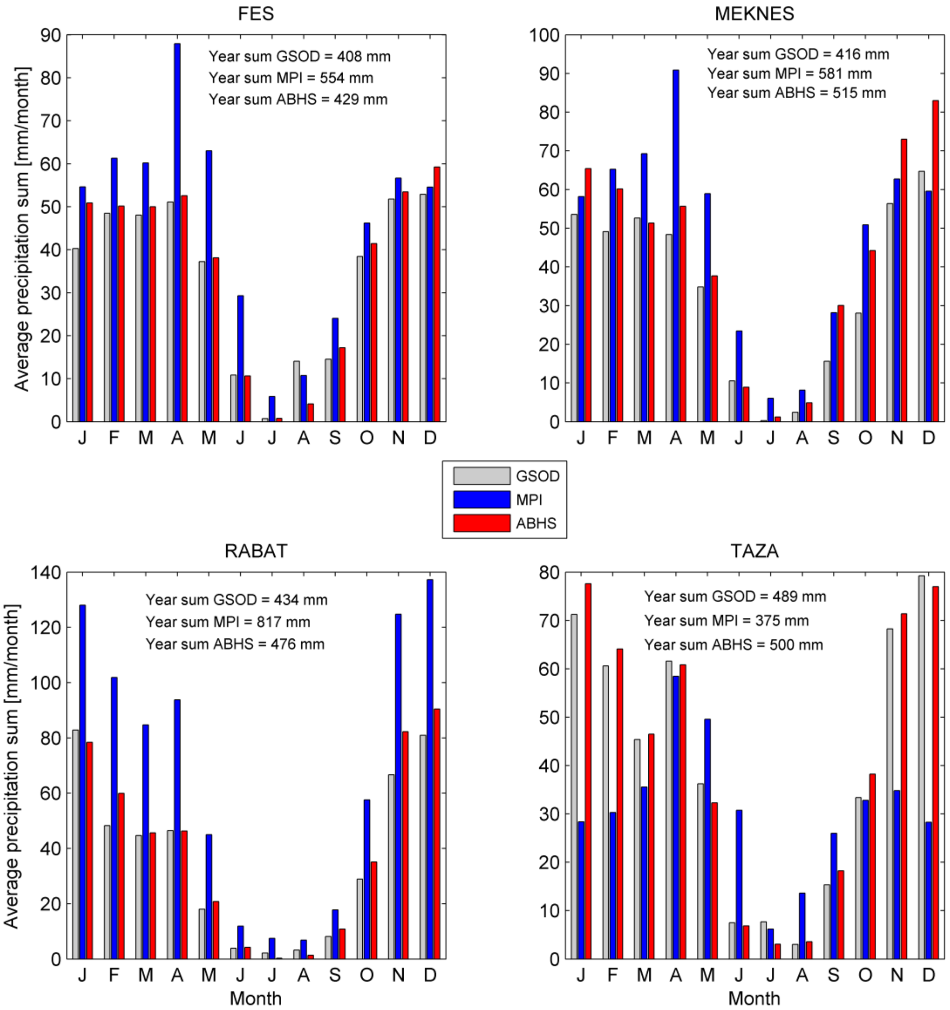

Figure 20: Average monthly precipitation sums of the GSOD, MPI and ABHS data for the period 1980-2000. MPI model data is taken as the average of four grid points, assuming that the average represents the GSOD stations and ABHS stations.

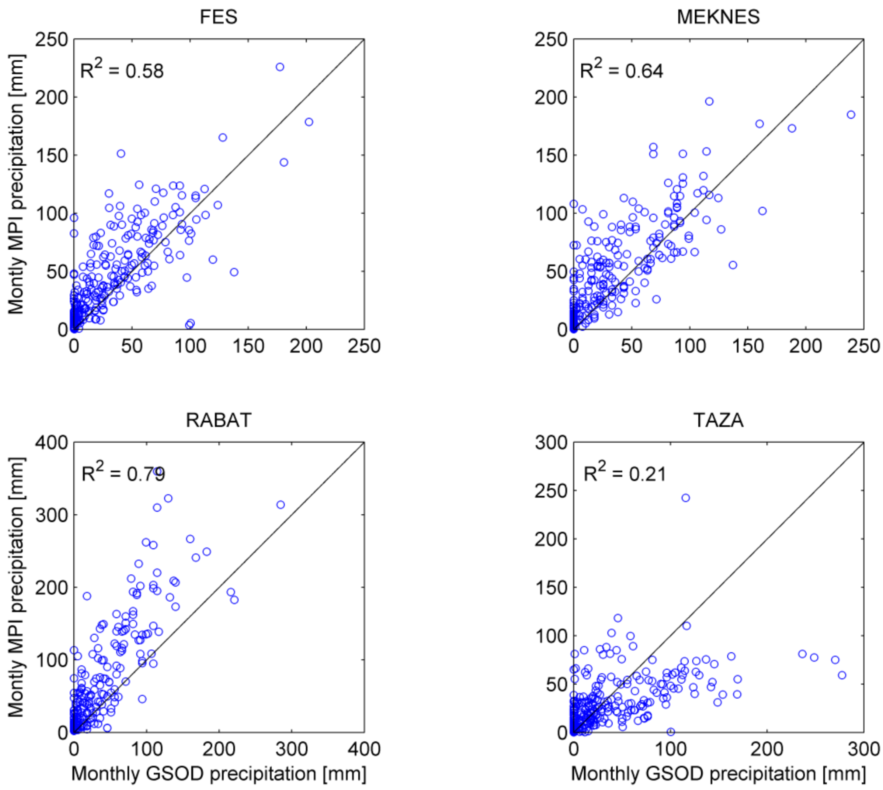

Figure 21: Scatter-plots of monthly GSOD precipitation sums versus the monthly MPI precipitation sums for 1980-2000. R^2 is the correlation coefficient.

The maximum and minimum temperatures of the GSOD stations and MPI model points have been averaged over 1980-2000. These results are shown Figure 22. Again it is clear that the MPI temperature is too high. Differences are largest for the minimum temperature, which can be 4°C for Fes. For both maximum and minimum temperature, differences between GSOD and MPI are largest during summer. Based on this assessment, we have chosen to use the temperature data from the GSOD stations in the SWAT model. This is acceptable, because temperature is spatially much more uniform distributed than precipitation, which can be spatially very different. In SWAT a T-lapse rate is used to lower the temperature every 1000 m in altitude.

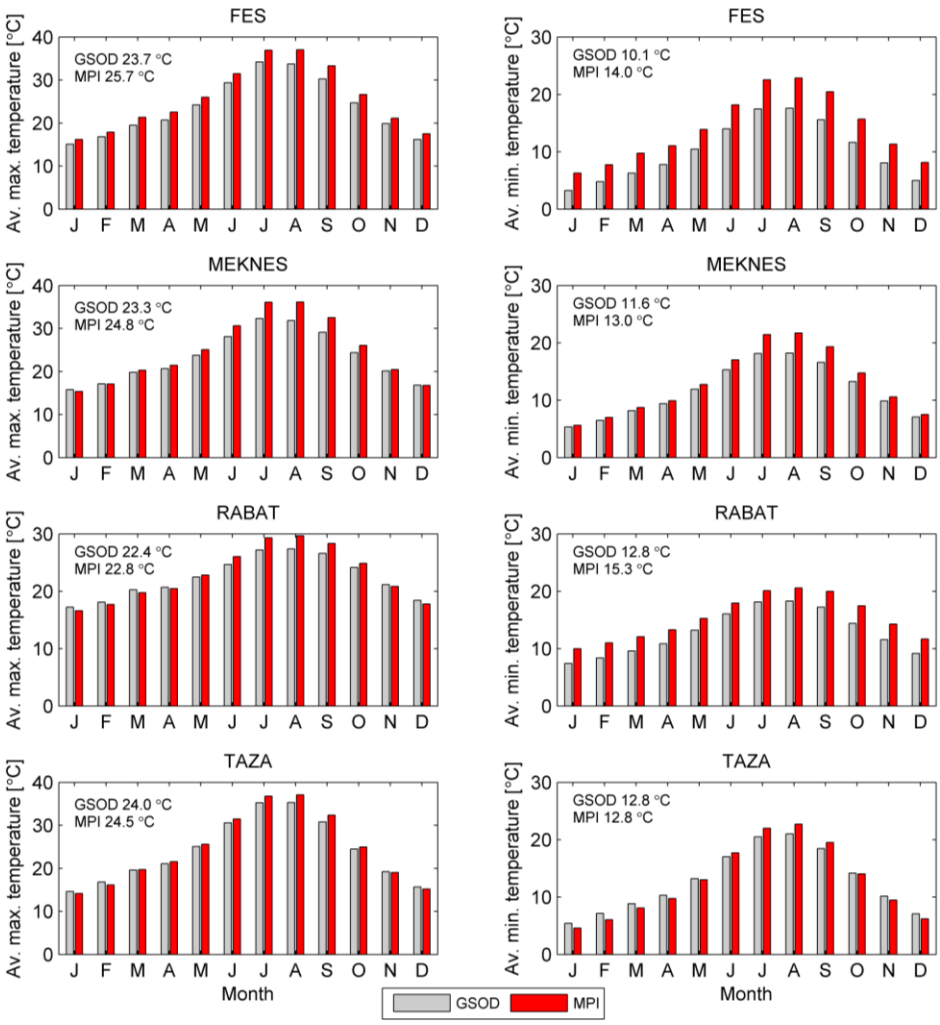

Figure 22: Maximum (left) and minimum temperature (right) monthly temperature of the GSOD stations and MPI model points, averaged over 1980-2000. MPI model data is taken as the average of four grid points, assuming that the average represents the GSOD stations. Yearly average is shown in top left corner.

The conclusion is that the difference in precipitation of up to 100 mm/ month between the measured time series from the GSOD database and the MPI dataset is too large to make it a useful set for the purposes of GWC. Also temperature data is significantly different between the GSOD database and the MPI model data. It has been decided to use for temperature the data of the four GSOD stations. Because temperature is spatially less variable than precipitation this can be justified. To account for the decreasing temperatures at higher altitudes, a T-lapse rate of -6 is used in the SWAT model. This results in a 6 degrees temperature decrease for every 1000 m increase in elevation. For precipitation, however, the four GSOD stations do not capture the spatial variability that exists in the basin. Therefore, of all the available datasets, the optimal choice of rainfall model input for the current assessment is the monthly ABHS station dataset. These stations cover a major part of the basin and are scattered throughout the area, except for the north-eastern part. To convert the monthly precipitation data to a daily time series, the following assumptions were used:

- Half of the monthly precipitation amount falls on 1 day;
- One quarter of the monthly precipitation amount falls on another day;
- The remaining part of the precipitation falls homogeneously over the remaining days in that month;

At this state, this assumption is acceptable because we analyze the results on a monthly timescale. For a daily analysis, this approach would not be accepted.

For the consecutive steps in the proof-of-concepts phase, the use of more precise rainfall products may be considered. Accurate satellite precipitation products together with additional data from weather stations to be received from the Moroccan counterparts would be a good quality improvement.

3.3 Land use

3.3.1 GlobCover dataset

GlobCover[11] is an ESA initiative in partnership with JRC, EEA, FAO, UNEP, GOFC-GOLD and IGBP. The GlobCover project has developed a service capable of delivering global composite and land cover maps, using as input observations from the 300 m MERIS sensor on board of the ENVISAT satellite mission. The GlobCover service has been demonstrated over a period of 19 months (December 2004 - June 2006), for which a set of MERIS Full Resolution (FR) composites (bi-monthly and annual), and a Global Land Cover map have been produced.

The GlobCover composites are derived from a set of processed MERIS FR images, such as cloud detection, atmospheric correction, geo-localization, and re-mapping. The GlobCover Land Cover map is compatible with the UN Land Cover Classification System (LCCS).

The use of medium resolution data brings a considerable improvement in comparison with other global land cover products, which have a lower spatial resolution, like e.g. the GLC2000 dataset. The quality of the GlobCover product, however, is highly dependent on the reference land cover database, which is used for the labeling process, and on the number of valid observations available as input. When the reference dataset is of higher spatial resolution with a high thematic detail, the GlobCover product also shows a high accuracy. On the other hand, the number of valid observations is a restrictive factor. The spatial coverage of the MERIS data clearly determines the quality of the temporal mosaics and therefore, of the land cover map. The GlobCover land use classification map for the Sebou River basin is shown in Figure 23. The GIS section of the ABHS provided irrigation extends of all known large scale irrigation areas in the Sebou River basin. Unfortunately, there is currently no record available for areas where landowners provide irrigation based on non-registered or private irrigation wells.

[11] http://www.esa.int/esaEO/SEMGSY2IU7E_index_0.html

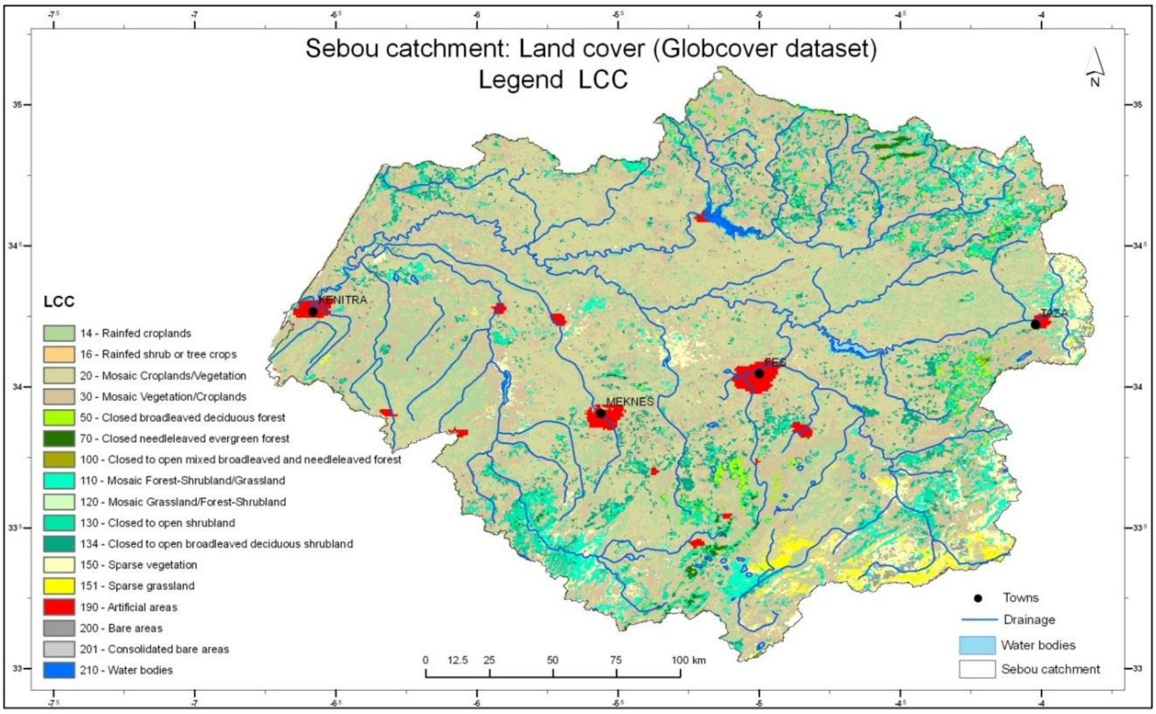

Figure 23: The GlobCover land use classification for the Sebou River basin.

3.3.2 *Forest Cover dataset*

The Ministry of Forestry of Morocco provides a map of Forest Types[12] in Morocco, which was extracted for the Sebou River basin. This map is shown in Figure 24.

[12] http://www.eauxetforets.gov.ma/fr/text.aspx?id=993&uid=23

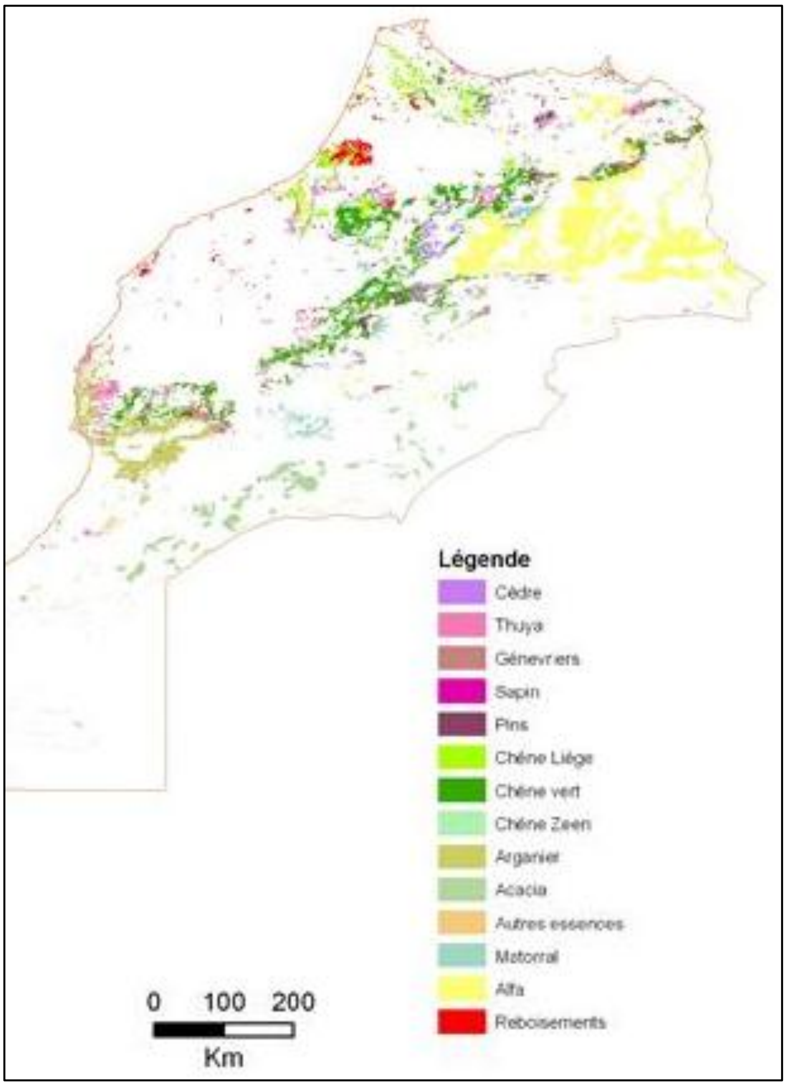

Figure 24: Forest types in Morocco (source: Ministry of Forestry of Morocco).

3.3.3 SPAM

SPAM [You et al., 2009] delivers disaggregated agriculture statistics based on a cross entropy approach utilizing national or sub-national administrative regions statistics together with crop-specific suitability information based on local climate and soil conditions and land use. We reclassified the SPAM dataset to delineate major harvested area for the Sebou basin, as detailed information of the crop distribution at the current time was missing. Based on this map, we adjusted boundaries to large scale topographic differences. A map of the five different cropping regions is given in Figure 25.

3.3.4 Processing of land use data

The development of land use data was done in an automated way using a python script in which the following steps were performed:

- All datasets were reprojected into the Lambert Conformal Conic projection;
- The datasets were converted into 250 m grids, using nearest neighbor resampling;
- The datasets were clipped into the basin border;

- The Forest Cover and GlobCover dataset were reclassified according to the SWAT data model land use descriptions;
- It is assumed that the forest dataset represents the local conditions more accurately. Therefore any no data gap in the forest dataset was filled with information from the GlobCover dataset;
- Finally, information was added from the irrigation extent as well as from the major crop type dataset (Figure 25).

These steps resulted in the SWAT land use map as shown in Figure 26, with the total areas for each land use listed in Table 4. Due to the downscaling methodology, based on the SPAM dataset in which the dominant crop types were extracted, sharp boundaries exists related to administrative regions. An updated version of this map in which the methodology of merging the various sources has been improved, is currently under discussion with the Moroccan counterparts.

For future elaboration on Phase II local land use data should be obtained from different Agencies (OFRE, Ministry of Agriculture) to represent the most accurate and detailed ground truth available. Still, the problem persists, that probably not a complete coverage of the Sebou basin might be reached and therefore a data aggregation combined approach is needed, similar to the one implemented in the current approach. As long as local data are available, they will override any information provided by global datasets.

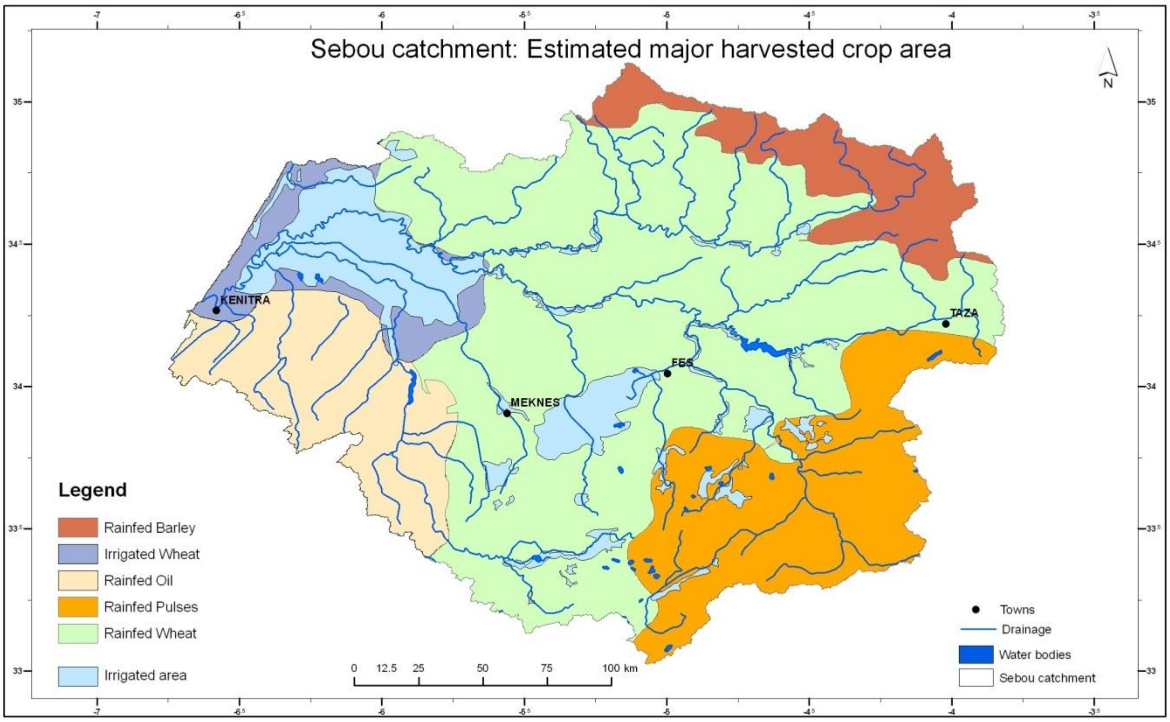

Figure 25: Estimated major crop regions in the Sebou River basin with the boundaries adjusted to topographic differences based on the global SPAM dataset.

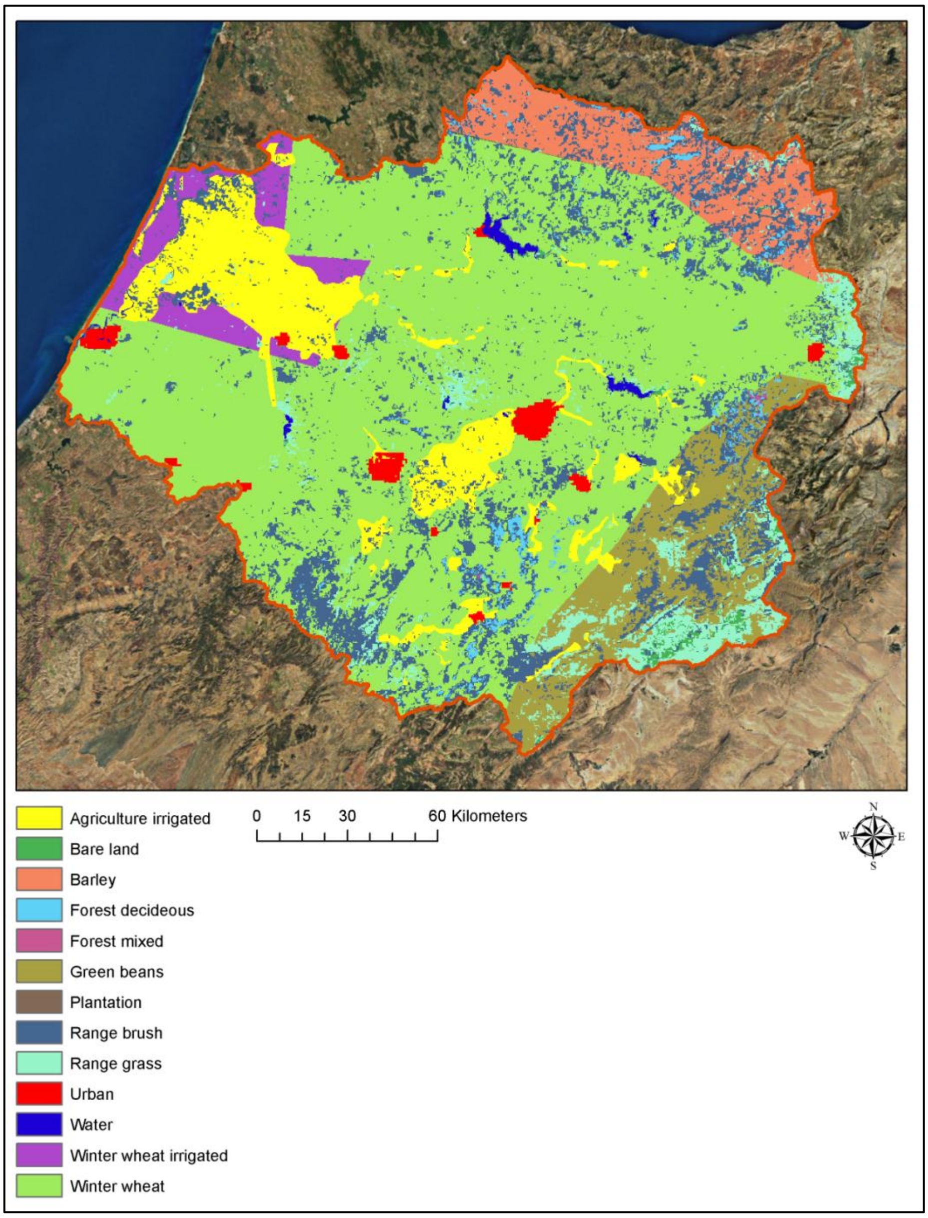

Figure 26: Land use map as used in the SWAT model.

Table 4: Total area of each land use class

Land use class	Area (km2)	% of total area
Bare lands	184	0.5%
Barley	2183	5.7%
Deciduous forest	486	1.3%
Irrigated agriculture	3588	9.3%
Irrigated wheat	1172	3.0%
Mixed forest	13	0.0%
Plantation	2	0.0%
Pulses	2742	7.1%
Rangelands brushes	5148	13.4%
Rangelands grasses	1873	4.9%
Urban	481	1.2%
Water	155	0.4%
Winter wheat	20502	53.2%
Total	38528	100%

3.4 Soils

3.4.1 Data sources

The area of the Sebou River basin is covered with different soil datasets from different scales and more importantly, various attributes. From a global perspective, the Harmonized World Soil Database[13] (HWSD) is available for the whole globe. Its aim is to deliver improved soil information worldwide, particularly in the context of the Climate Change Convention and the Kyoto Protocol for soil carbon measurements and the immediate requirement for the FAO/IIASA Global Agro-ecological Assessment study (GAEZ 2008). While this database is rather quite coarse, it contains mostly all parameters which are required to be used in the SWAT model. For Morocco, we are aware of three different products which would be suitable:

1. A soil map with the scale 1:2 million, covering almost the entire area in digital format and containing soil names;
2. Two map sheets in the scale 1:500.0000. These maps, however, do not cover the Sebou area completely. These maps are only available in analogue format, containing only soil names for the attributes;
3. Pending results from the e-SOTER project[14]. While these map sheets/datasets contain significantly more spatial detail with respect to the HWSD, the only attribute information which would be currently available is the soil name.

The dominant soils in the Sebou River basin are shown in Figure 27.

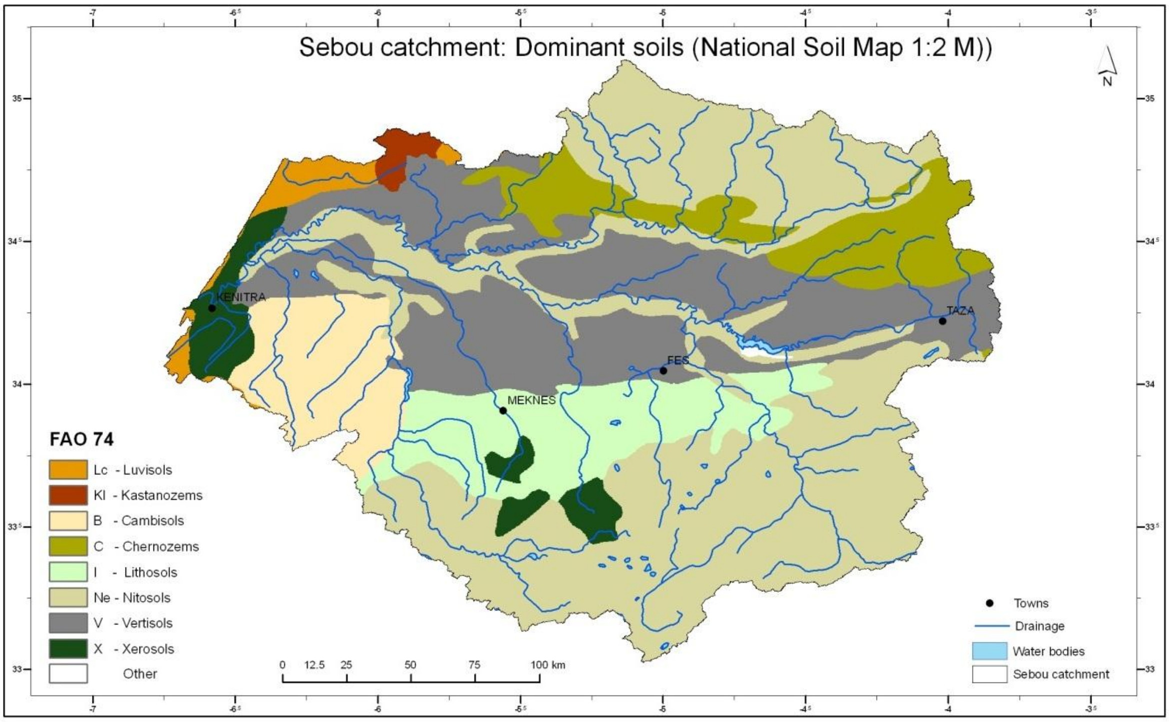

Figure 27: Dominant soils (scale 1:2 million) in the Sebou River basin, Morocco.

[13] http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/

[14] http://www.esoter.net/

3.4.2 *Processing of soil data*

To achieve the best spatial and attribute detail, we used data from the Moroccan 1:2 million soil map, and extended the polygons using data from the HWSD, where soil polygon data were missing. Initially we sought to use a taxo-transfer rule-based procedure, which heavily draws on soil analytical data held in the ISRIC-WISE soil profile database. Currently, however, there were not sufficient profiles to allow such a procedure. Therefore we assigned the attributes based on the soil names in the FAO1974 classification from the HWSD.

An important characteristic, which is not provided in the HWSD database, is the saturated hydraulic conductivity. A well-developed technique to overcome this problem is to use so-called pedo-transfer functions (PTF). A wide range of pedo-transfer functions have been developed and applied successfully over the last decades over various scales (e.g. field scale in Droogers et al., [2001] and basin scale in Droogers and Kite, [2001]]). Sobierja et al. [2001] concluded from a detailed analysis that most PTFs were not very reliable and that the impact on runoff estimates could be considerable. The PTF that generates conductivity values close to measured ones is the Jabro equation [Jabro 1992]:

$$K_{SAT} = exp^{(11.86-0.81*\log(st)-1.09*\log(cl)-4.64*BD)}$$

where:	K_{SAT}	=	Saturated Hydraulic Conductivity (cm/h)
	st	=	% silt
	cl	=	% clay
	BD	=	Bulk Density

The erodibility factor needed by the SWAT model was calculated according to the formulas below:

$$K_{USLE} = f_{csand} * f_{cl-si} * f_{orgc} * f_{hisand}$$

$$f_{csand} = \left(0.2 + 0.3 * exp^{-0.256*ms*\left(\frac{1-msilt}{100}\right)}\right)$$

$$f_{cl-si} = \left(\frac{msilt}{mc + msilt}\right)^{0.3}$$

$$f_{orgc} = (1 - 0.25 * orgc + exp^{3.72-2.95*orgc})$$

$$f_{hisand} = \left(1 - \frac{0.7 * \frac{1-ms}{100}}{\frac{1-ms}{100}} + e^{-5.51+22.9*\left(\frac{1-ms}{100}\right)}\right)$$

where	K_{USLE}	=	Erodibility factor
	ms	=	% sand
	msilt	=	% silt
	mc	=	% clay
	orgc	=	% organic matter

For future elaboration on Phase II, local soil maps (1:500.000) vector and attribute data should be obtained from the responsible Agencies (INRA, OFRE, Ministry of Agriculture), to represent the most accurate and detailed ground truth available. Besides the more classical way, two other techniques could be applied. First, the pending results from the e-SOTER project for Morocco could be investigated to be transferred into the Sebou Basin. The other approach would be to use Digital Soil Mapping techniques, where soil parameters are estimated based on soil profiles and auxiliary information.

3.4.3 Soil data evaluation

As mentioned earlier, the final soil map as was used in SWAT is shown in Figure 27. The related soil characteristics are shown in Table 5. In this table also the saturated hydraulic conductivity and erodibility (K_{USLE}) are represented. It is clear that the Lithosols have the lowest hydraulic conductivity and erodibility values. These soils also have very low available water capacity values, meaning that water for crops is sparse on these soils. Figure 28 represents the map with saturated hydraulic conductivities, based on the dominant soil types. The erodibility is shown in Figure 29, where a higher value is related to a more erodible soil type.

Table 5: Average soil moisture characteristics of dominant soils in the Sebou River basin, Morocco.

Dominant soil	*Soil hydrologic group**	*Available water capacity** [%]*	*Total available water*** [mm]*	*Saturated hydraulic conductivity**** [mm/h]*	K_{USLE}****
Lc - Luvisols	A	15	150	16.3	0.16
Kl – Kastanovems	A	15	150	15.3	0.16
B – Cambisols	A	15	150	14.7	0.17
C – Chernozems	A	15	150	14.9	0.16
I – Lithosols	B	15	15	7.3	0.07
Ne - Nitosols	A	15	150	17.0	0.16
V – Vertisols	C	12.5	125	24.5	0.14
X – Xerosols	A	15	150	15.2	0.17

* Soil hydrologic group (A, B, C, or D):

A = Soils having high infiltration rates even when thoroughly wetted, consisting chiefly of sands or gravel that are deep and well to excessively drained. These soils have a high rate of water transmission (low runoff potential).

B = Soils having moderate infiltration rates when thoroughly wetted, chiefly moderately deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C = Soils having slow infiltration rates when thoroughly wetted, chiefly with a layer that impedes the downward movement of water or of moderately fine texture and a slow infiltration rate. These soils have a slow rate of water transmission (high runoff potential).

D = Soils having very slow infiltration rates when thoroughly wetted, chiefly clay soils with a high swelling potential; soils with a high permanent water table; soils with a clay pan or clay layer near the surface; and shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission.

** Available water or plant extractable water.

*** Total available water = Available water capacity over maximum rooting depth (available for crop).

**** Taken as average of the first and second soil layer (if present).

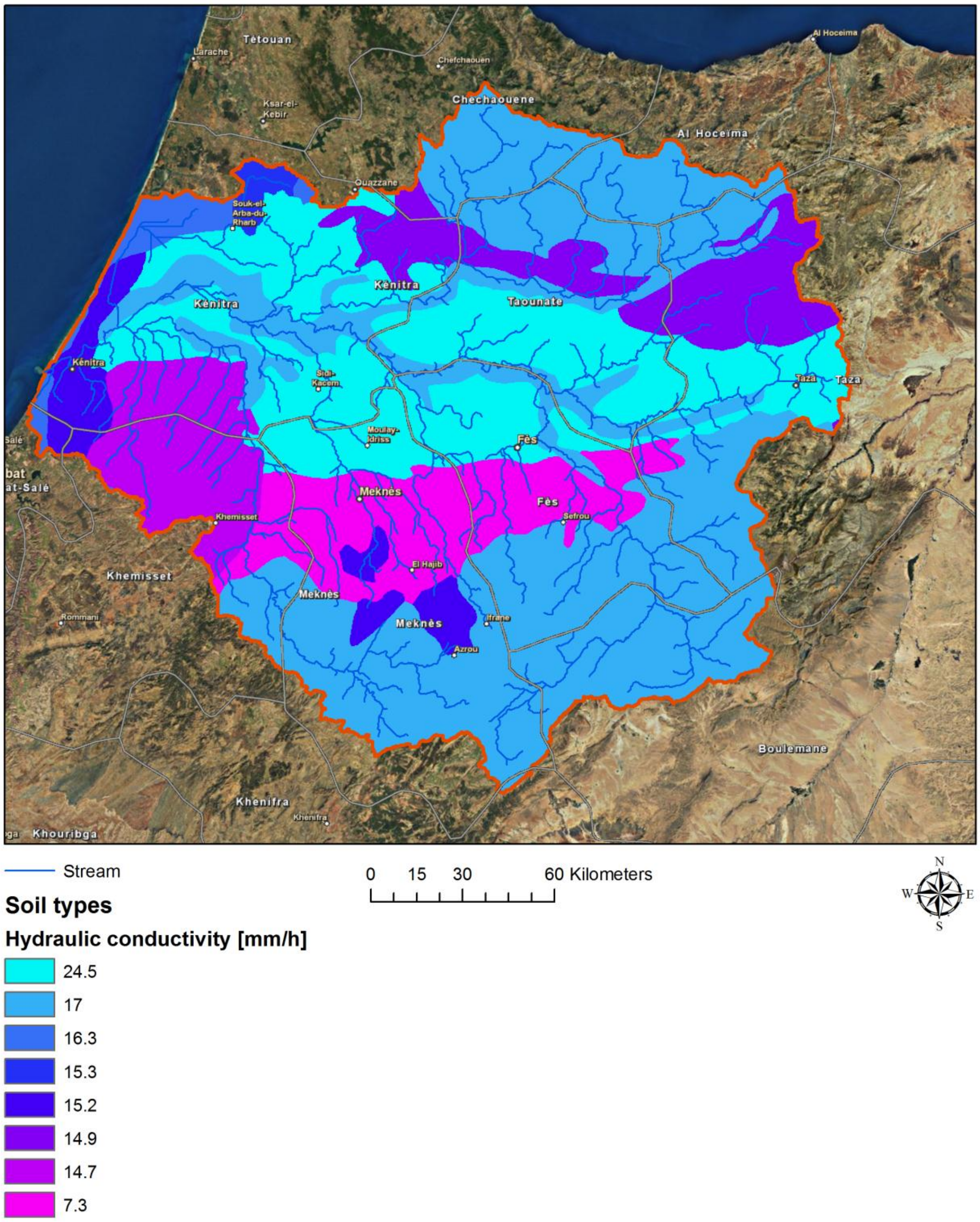

Figure 28: Saturated hydraulic conductivity based on dominant soil types.

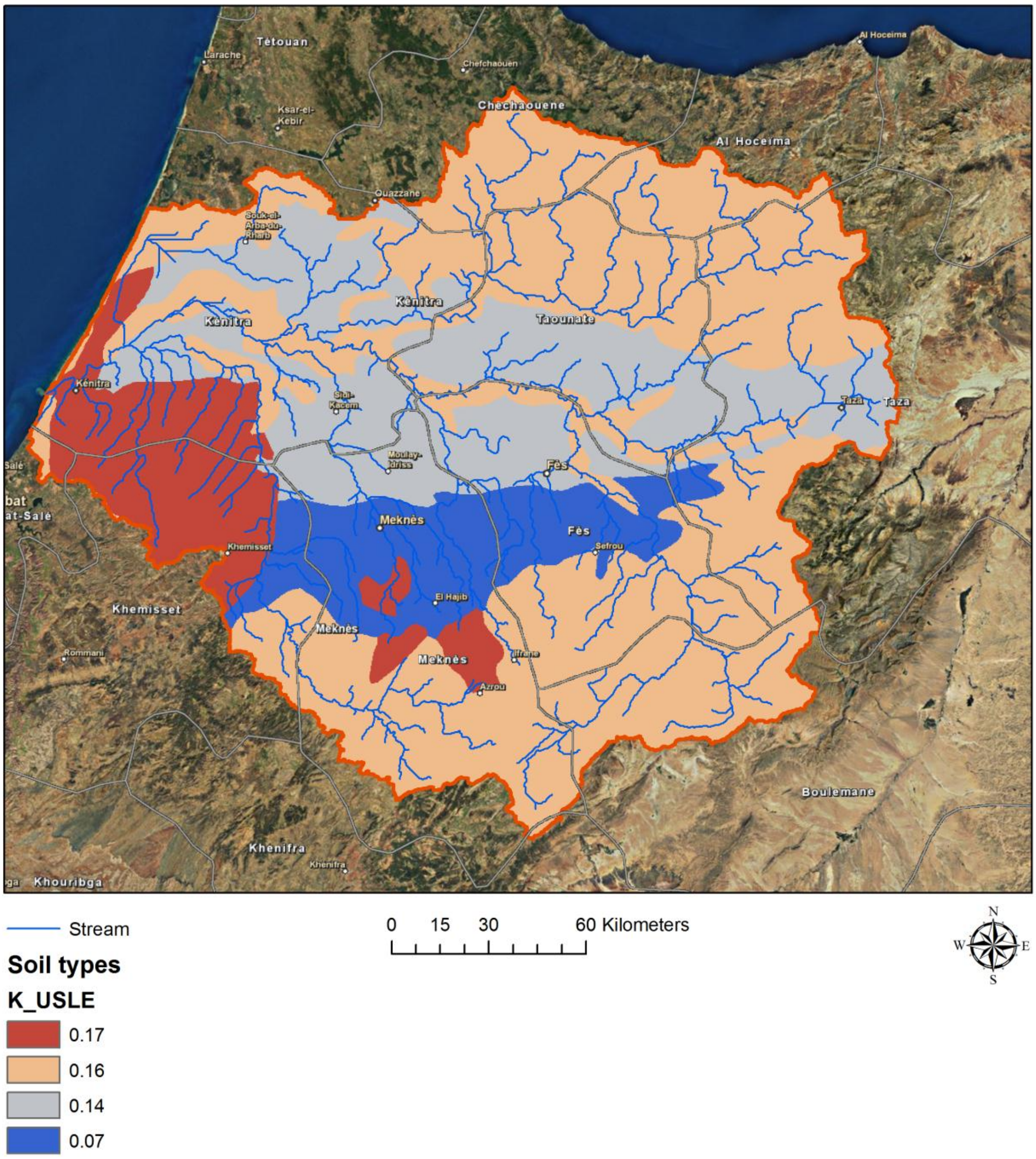

Figure 29: Soil erodibility map (K_USLE), based on the dominant soil types.

3.5 Discharge

Several discharge gauging stations are present in the Sebou River basin. The discharge gauging station data was provided by ABHS. These stations provide discharge data on a monthly basis. The following table and map (Figure 30) show the characteristics and the locations of the discharge gauging stations that have been obtained. It is noticed that for the southern part of the basin there are hardly any stations present. For consecutive Green Water Credits phases, it would be highly desirable to have discharge stations in this region as well. In addition, it is also desired to have more recent discharge data. This would allow a more accurate assessment using high-quality satellite-precipitation products such as TRMM or FEWS.

Table 6: Characteristics of all obtained discharge gauging stations in the Sebou River basin, Morocco.

Station name	Station nr.	Data availability	Upstream area [km^2]	Elevation [MASL]
AitKhabbach	585	1971-1980	1264	1011
ElMers	541	1982-2002	963	848
DarElArsa	2263	1971-2002	7318	1918
Ain Louali	2210	1988-2002	332	1396
Lalla Mimouna	1815	1978-2002	123	117
My Ali Chrif	1545	1968-2002	482	377
AinTimedrine	581	1933-2002	4379	1811
Azzaba (pont)	583	1958-2002	4666	2008
Dar Hamra	1000	1985-2002	681	910
Pont du Mdez	582	1933-2002	3426	1736
Azib Soltane	1540	1960-2002	16143	2071
Belksiri	633	1968-2002	-	-
Had Kourt	1436	1968-2002	670	370
Kharrouba	454	1988-2002	89	279
Khenichet	1359	1971-2001	7321	1484
Souk El Had	3261	1968-2002	1873	1058
A´n A´cha	1217	1982-2002	2504	1580
Bab Ouender	260	1952-2002	1783	861
Galez	1216	1984-2002	517	1030
Pont Sra	81	1952-2001	524	1468
M'JaÔra	609	1960-2002	6260	1419
Tabouda	1215	1979-2002	866	827
Bab Echoub	702	1989-2002	612	1056
Bab Marzouka	551	1971-2002	1502	961
Beni Hitem	672	1988-2002	252	750
El Kouchat	653	1977-2001	2623	1250
Sidi Allal Tazi	1355	1967-1990	25779	2142
Tissa	1542	1933-2002	1194	836
El Hajra	2244	1969-2002	1384	1456
Rhafsai	607	1952-2001	768	1320
Tafrant	608	1952-1995	1040	879
Ourtzagh	79	1956-1996	3579	1351

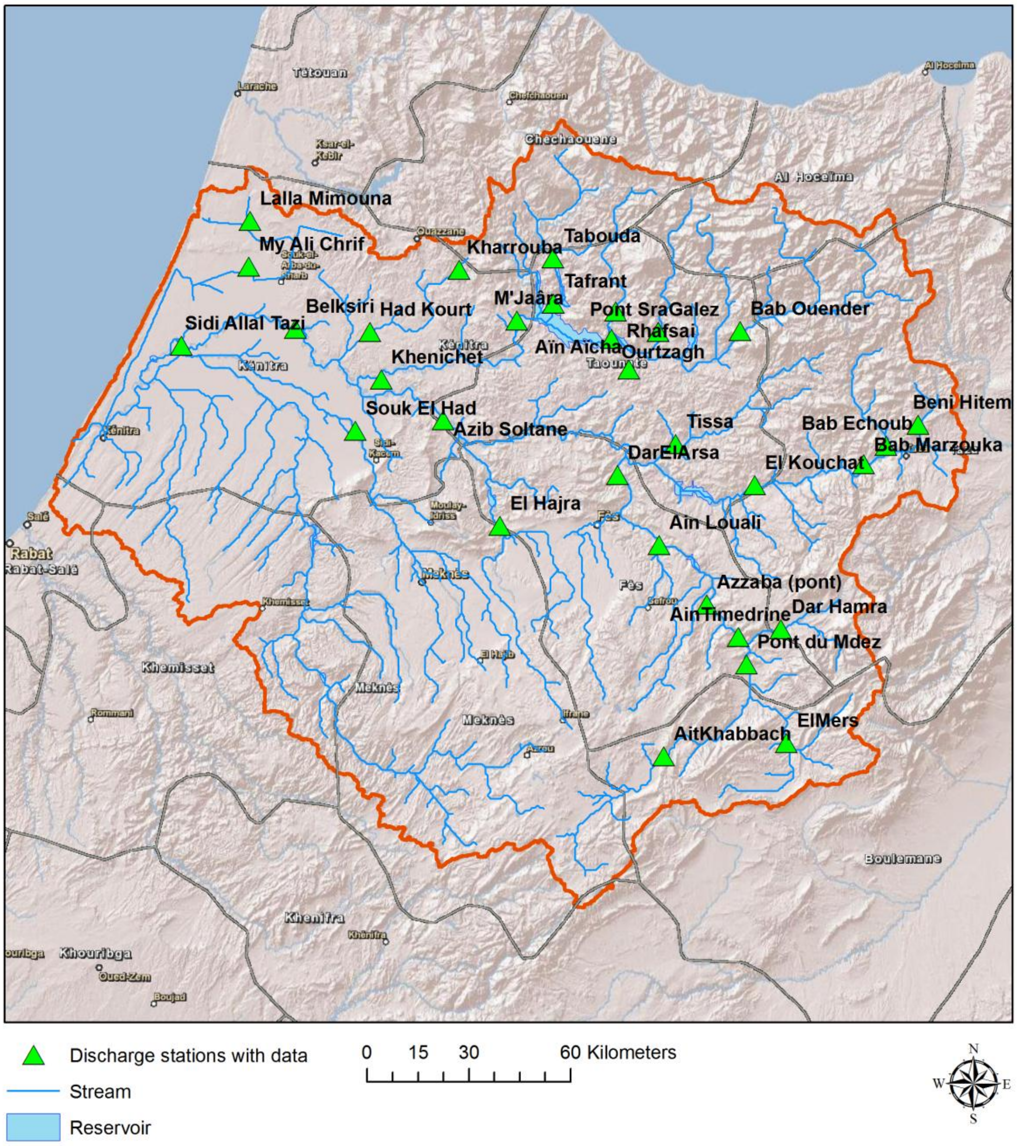

Figure 30: Streamflow gauge locations of which data have been obtained.

3.6 Reservoirs

The Sebou River basin encompasses several large reservoirs as well as small ones built over a period of 70 years. The El Kansera reservoir was constructed on the Beht River in 1935. It was initially used to retain floods but now also stores water. By 1973, there were at least 15 dams with 5 large reservoirs and 10 small dams. These reservoirs are now a major source of irrigation and drinking water and strongly regulate the flow in the upper, mid, and lower catchments. The Al Wahda dam (Figure 31), constructed on the Ouerrha River between 1991 and 1996, is the second most important dam in Africa after the High Aswan dam. It has a storage capacity of $3.8{\cdot}10^3$ MCM and a height of 88 m. This reservoir provides long-term storage, irrigates 100,000 ha, generates a hydroelectricity potential capacity of 400 GW h year^{-1}, transfers a water capacity of $600{\cdot}10^6$ m^3 towards the southern regions, and protects the Rharb Plain from high floods.


Figure 31: Al Wahda dam, Sebou River basin, Morocco.

A typical example of the impact of dams is given by Snoussi et al., [2007] who mentioned:

"The Al Wahda dam can reduce the flood volumes at the Rharb plain by more than 95%, avoiding an economic loss estimated at close to USD 27 million/yr."

The impact of the reservoirs on runoff is also indicated with Figure 32. It is shown that annual discharge rates have significantly decreased after the construction of the dam. The well-known "Sebou Project" supported by various donors, including the World Bank, UNDP and FAO, started in the 1960's and can be considered as the actual start of the development of the basin. Since then, the infrastructural works were intensified, in order to supply drinking water, extend the agricultural space and productions, control floods and provide power generation. The accomplished infrastructures now include 10 large dams, 44 smaller dams (for a total storage capacity of 5,872 MCM, for regularization of a total volume of 2970 MCM), and four hydropower stations. Moreover, thousands of wells have been drilled to complement the water needs by groundwater sources [Minoia and Brusarosco, 2006]

The characteristics of the 8 principial reservoirs in the Sebou basin are shown in Table 7. Besides hydropower generation these reservoirs serve for irrigation purposes, transfer, and as source for drinking and industrial water. The locations of these 8 main reservoirs in the Sebou River basin are shown in Figure 33.

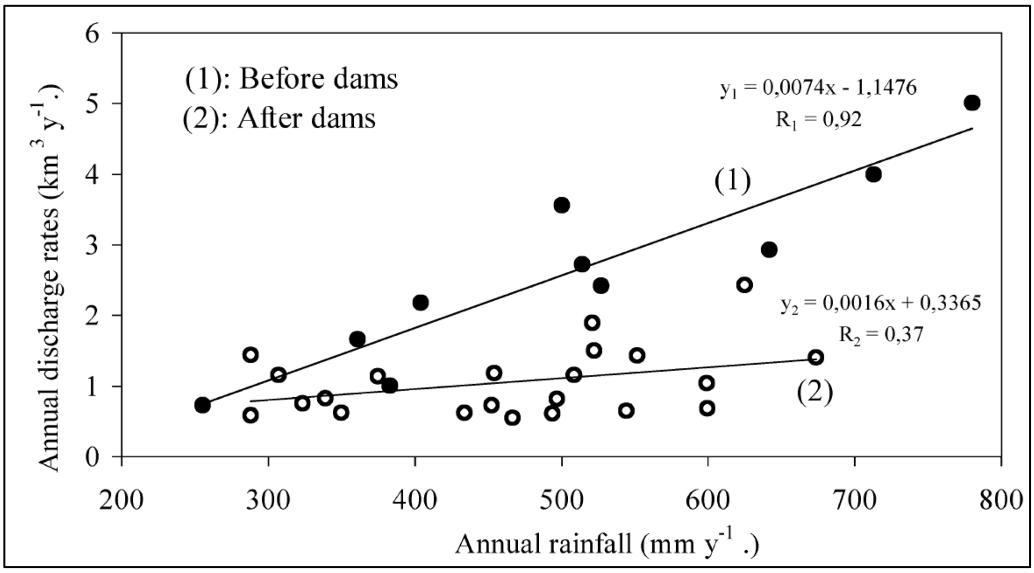

Figure 32: Relationship between the annual water discharge and annual rainfall before (solid circles) and after (open circles) the construction of dams for station Azib Es Soltane (source: Snoussi et al., 2002).

Table 7: Principal reservoirs in the Sebou basin

Reservoir/dam	*Year of construction*	*Use**	*Surface area [km^2]*	*Height [m]*	*Capacity [MCM]*	*Irrigable surface [ha]*	*Hydropower [GWh/year]*
El Kansera	1935	DI,I,P	18	68	266	29050	30
Idriss 1 Er	1973	P,I	68	72	1186	72000	66
Allal Al Fassi	1990	P,DI,T	5	61	82	26000	270
Al Wahda	1996	P,I	123	88	3800	115000	400
Garde de Sebou	1991		0.7	18	40		
Sahla	1994		4.3	55	62		
Sidi Echahed	1996		10.8	51	170		
Ouljet Essoltane							

* I = Irrigation, P = hydropower, T = transfer, DI = drinking and industrial water.

Figure 33: Location of the 8 main reservoirs and discharge measurement stations.

4 Baseline modeling assessment

4.1 Introduction

This chapter describes the setup of the SWAT model, to serve as the quantitative tool for exploring Green Water Credits. Also the most relevant land use classes regarding GWC have been explored in a crop-based assessment. These are the crops with a potential for the implementation of Green Water Management practices. Furthermore, the spatial distribution of the SWAT model output has been analyzed on the level of Hydrological Response Units (HRUs).

The SWAT model has been setup for a period of 21 years (1980-2000). Justification of data used to build the model was provided in the previous section. To summarize:

- DEM: NASA SRTM dataset
- Climate: for precipitation monthly MPI data is used. For temperature the GSOD dataset is used.
- Land use: a preliminary aggregated land use classification based on various sources, elaborated by ISRIC
- Soil: Harmonized World Soil Database and pedo-transfer functions
- Discharge measurements and reservoir characteristics: obtained from local counterparts.

4.2 Model setup

4.2.1 Basin delineation

In SWAT, the basin outlet is defined as the most downstream point of the Sebou River, which is located west of the city Kenitra. Consequently, all tributaries upstream of this point belonging to the Sebou River basin are included in the analysis.

The DEM forms the base to delineate the catchment boundary, stream network and sub-basins. This is performed by the pre-processing module of SWAT and requires a so-called threshold area. This refers to a critical source area defining the minimum drainage area required to form the origin of a stream. The determination of an appropriate threshold area has to be in accordance with the desired level of detail.

In the current study we have found an appropriate threshold of 5000 ha, which provides a good balance between the level of detail and the computational constraints. This resulted in a total of 421 sub-basins. A first trial was performed with a threshold area of 10,000 ha, but this led to a total of 207 sub-basins, which consequently lacks the desired detail for this study. A threshold of 10,000 ha also results in stretched sub-basins with large elevation differences (>2000 m) within the sub-basin. This has negative effects on the simulation of the orographic precipitation regimes. The delineation of the 421 sub-basins, along with the streams, is shown in Figure 34. It can be seen that the sub-basins are more or less equally sized, and that they are not too stretched. The average sub-basin area with the defined threshold of 5000 ha is 9152 ha. A distribution of the elevation differences within each sub-basin is shown in Figure 35. It is clear that the elevation difference within a sub-basin is below 1000 m for the majority of sub-basins.

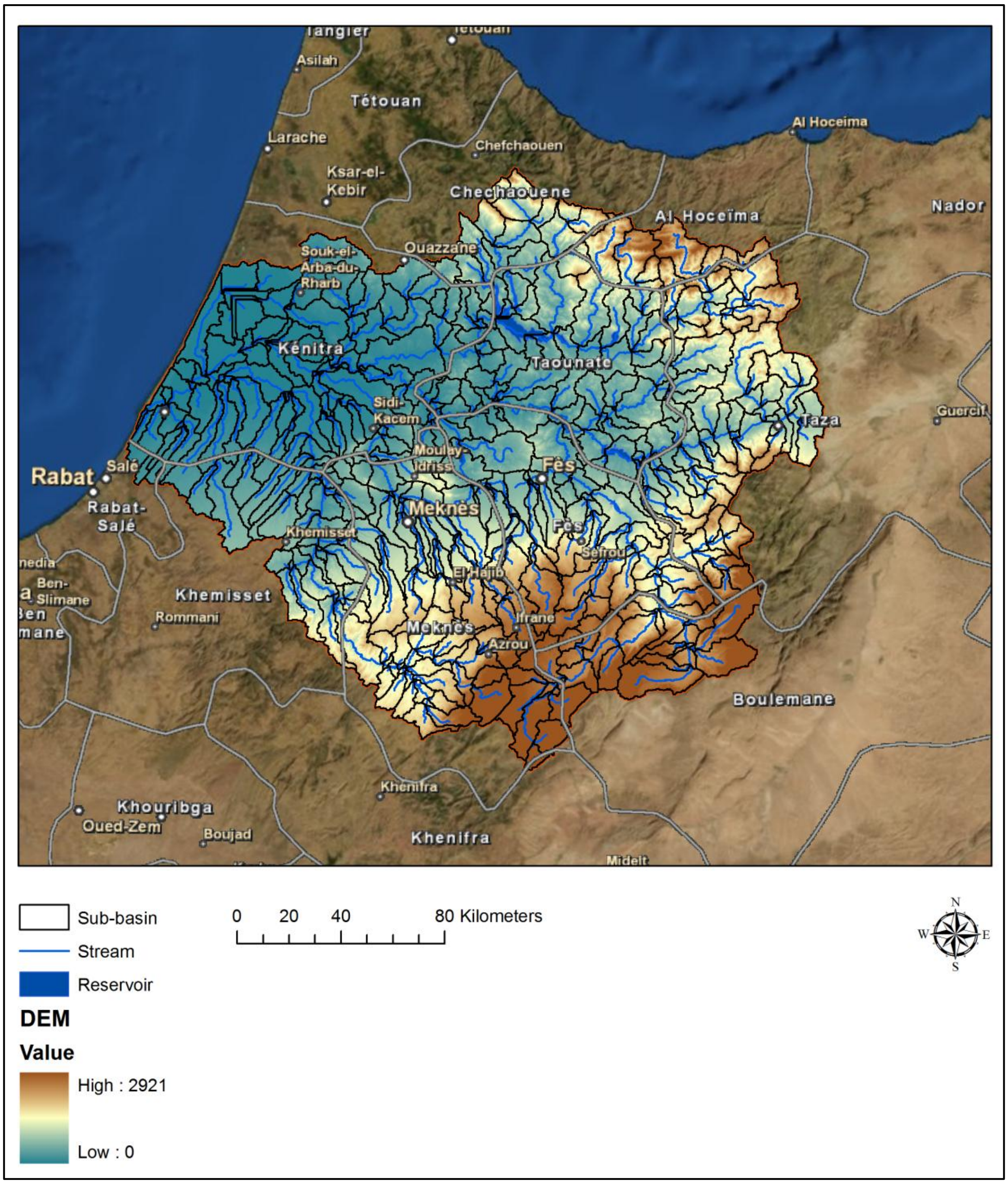

Figure 34: Locations of the 421 delineated sub-basins along with the derived streams. The threshold for delineation was set at 5000 ha.

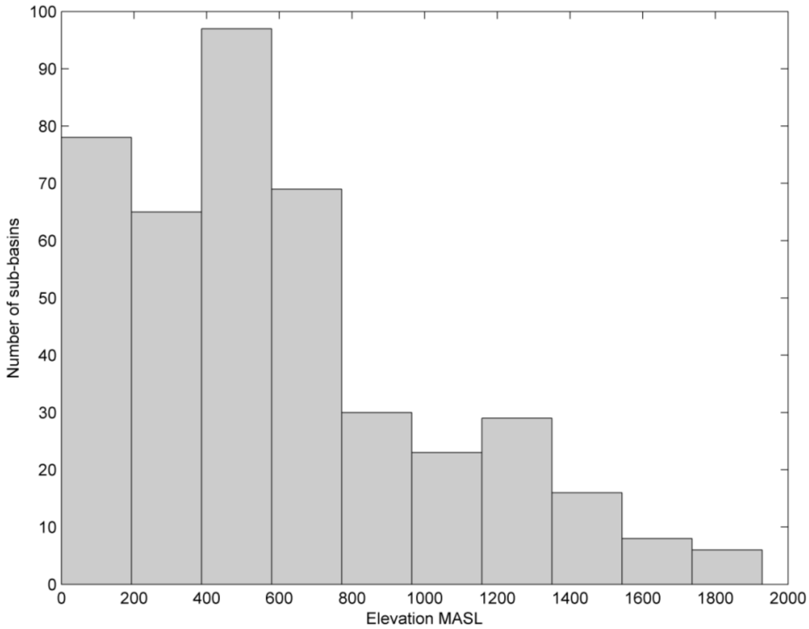

Figure 35: Frequency distribution of the differences in elevation within each sub-basin, using a threshold of 5000 ha.

4.2.2 Hydrological Response Units

For the spatial discretization of the sub-basins, SWAT uses the concept of Hydrological Response Units (HRUs) [Neitsch et al., 2000]: portions of a sub-basin that possess unique land use, management, and soil attributes. In other words, an HRU is the total area in a sub-basin with a specific land use, management, and soil combination. HRUs are used in SWAT since they simplify a run by lumping all similar soil and land use areas into a single response unit. The size of a HRU depends on the size of the total area under consideration.

Implicit in the concept of the HRU is the assumption that there is no interaction between HRUs within one sub-basin. Loadings (runoff with sediment, nutrients, etc. transported by the runoff) from each HRU are calculated separately and then summed together to determine the total loadings from the sub-basin. If the interaction of one land use area with another is important, rather than defining those land use areas as HRUs they should be defined as sub-basins. It is only at the sub-basin level that spatial relationships can be defined. The benefit of HRUs is the increase in accuracy it adds to the prediction of loadings from the sub-basin. The growth and development of plants can differ greatly substantially among species. If the diversity in plant cover within a sub-basin is accounted for, then the net amount of runoff entering the main channel from the sub-basin will be much more accurate.

In practice the HRUs are defined by overlaying three data layers:

- Sub-basins;
- Land use;
- Soils;

Based on these three data layers 2279 HRUs (Figure 36) were determined for the Sebou River basin.

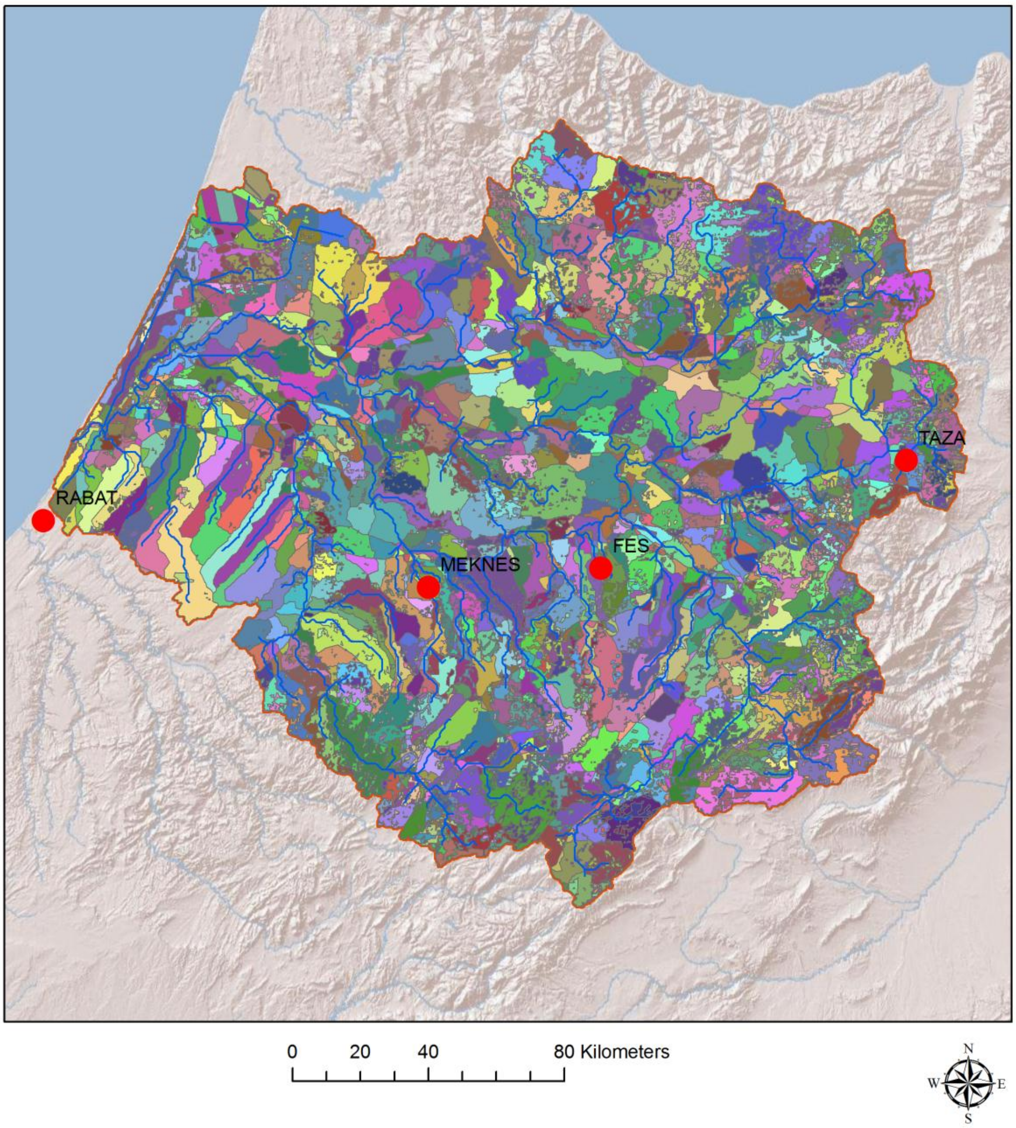

Figure 36: The defined hydrological response units (HRUs).

4.3 Calibration and model performance

Seven discharge gauging stations have been selected for the analysis of the model performance. For the model performance we have selected four performance coefficients, as shown in Table 8. These stations have been selected because their locations are representative for the entire Sebou River basin. The locations of these stations are shown in Figure 37. Their corresponding names can be found in Table 6. Unfortunately, no discharge stations with sufficient data are found in the southern part of the basin. For an improved model evaluation, it is required that more discharge data is available.

The Pearson coefficients show a reasonably correlation for the seven selected stations. The Normalized Root-Mean-Square-Error (Normalized RMSE) indicates how the individual simulated monthly discharges behave with respect to the individual observed monthly discharges. The closer to zero, the closer are the simulated monthly discharges to the observed monthly discharges. Two stations, 1436 and 581, have a Normalized RMSE larger than 0.1. These two stations also have a large negative Nash-Sutcliffe coefficient. This indicates that the observed mean discharge is a better predictor than the simulated discharge. The Nash-Sutcliffe coefficient can range between minus infinity and 1. The closer the value is to 1, the better the model performs. This coefficient is sensitive for peakflows. Thus if the observed peakflows are largely over- or underestimated by the model, then the Nash-Sutcliffe coefficient will be small or even negative. Considering the bias, which is the average simulated discharge divided by the average observed discharge, it is likely that the model overestimates the discharge for station 1436, and underestimates the discharge for station 581.

To get a better view of how the model behaves, time-series of observed and simulated monthly discharges have been plotted for two stations, Khenichet (ID 1359) and Ain Timedrine (ID 581). These time-series are shown in Figure 38 for Khenichet and in Figure 39 for Ain Timedrine. Overall, the timing of the peaks is simulated reasonably well, although the magnitude of the simulated peaks differs from the observed peaks. This is what we expected, considering the small Nash-Sutcliffe coefficients of Table 8. The low flows are simulated quite satisfying for Khenichet. For Ain Timedrine, however, it seems that baseflow is underestimated by the model. Considering the coefficients of Table 8, and the simulated time-series of Figure 38 and Figure 39, it can be concluded that model improvement is necessary for the consecutive steps in the proof-of-concepts phase. Therefore it is recommended to use more precise satellite precipitation products, providing precipitation data on a daily basis. A second point of improvement would be to incorporate managed reservoirs when data is available on the reservoir outflows. Currently, only two reservoirs (Al Wahda and El Kansera) out of eight reservoirs are implemented in the model as managed. Finally, when more recent data becomes available on reservoir flows and discharges throughout the basin, a detailed calibration procedure is recommended for the phase that follows the proof-of-concept, in order to achieve better model performance.

Table 8: Performance coefficients for seven representative discharge stations, based on monthly data.

Performance coefficient	1436	1359	581	1217	260	633	702
Pearson coefficient	0.60	0.53	0.36	0.61	0.57	0.53	0.58
Normalized RMSE	0.10	0.09	0.24	0.12	0.13	0.19	0.22
Nash-Sutcliffe coefficient	0.28	0.23	-1.48	0.30	0.28	-0.72	-0.28
BIAS	1.21	0.58	0.96	0.59	0.65	1.39	1.85

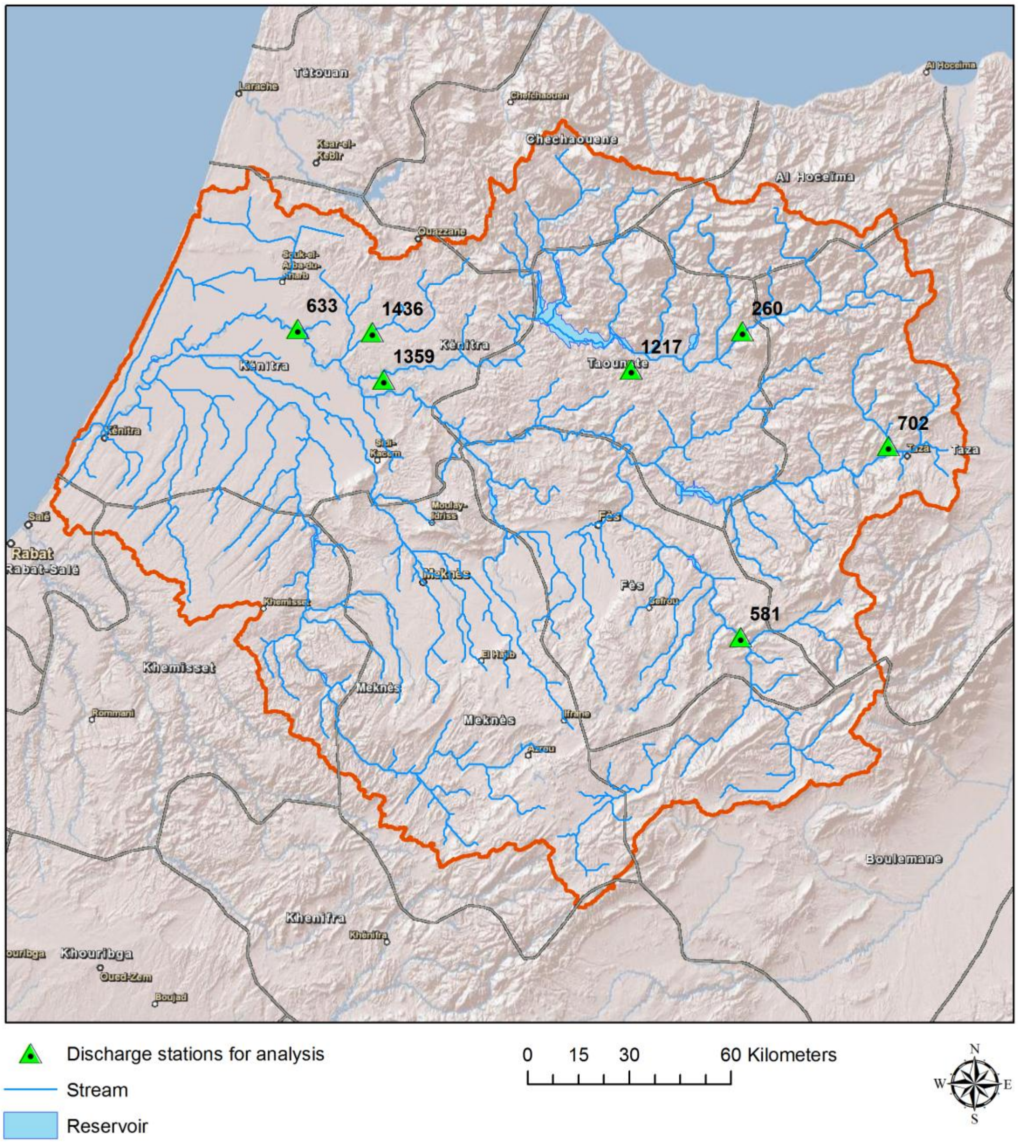

Figure 37: Selected discharge stations for model performance analysis.

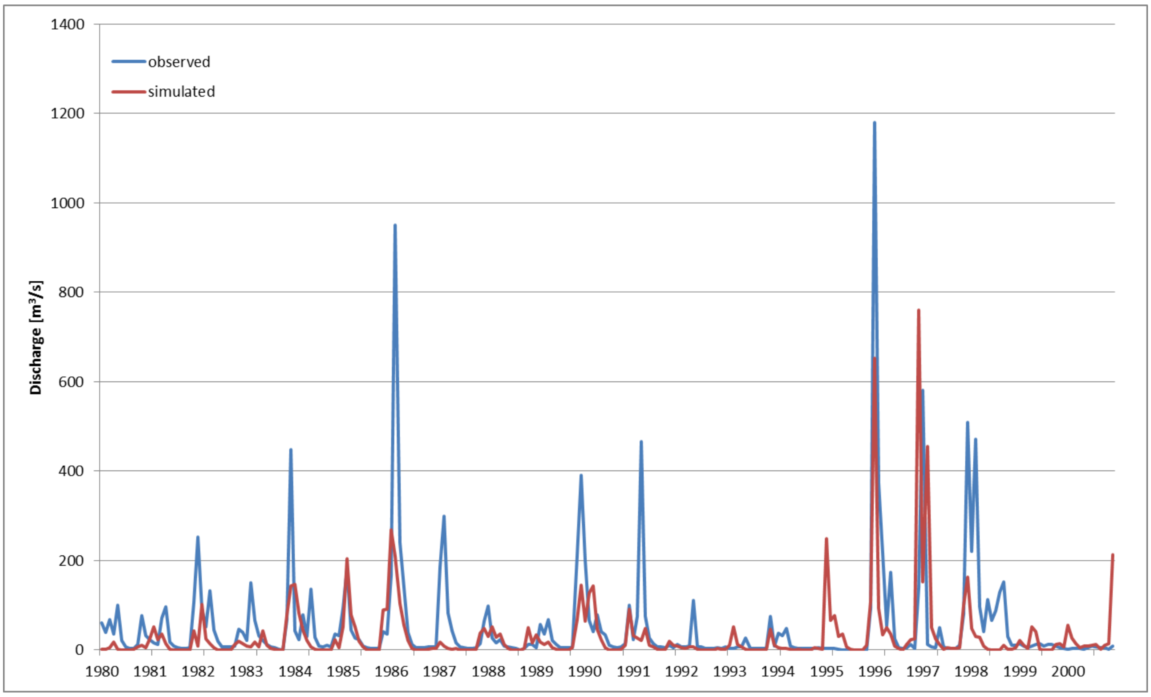

Figure 38: Simulated and observed inflow for gauge station Khenichet, ID 1359.

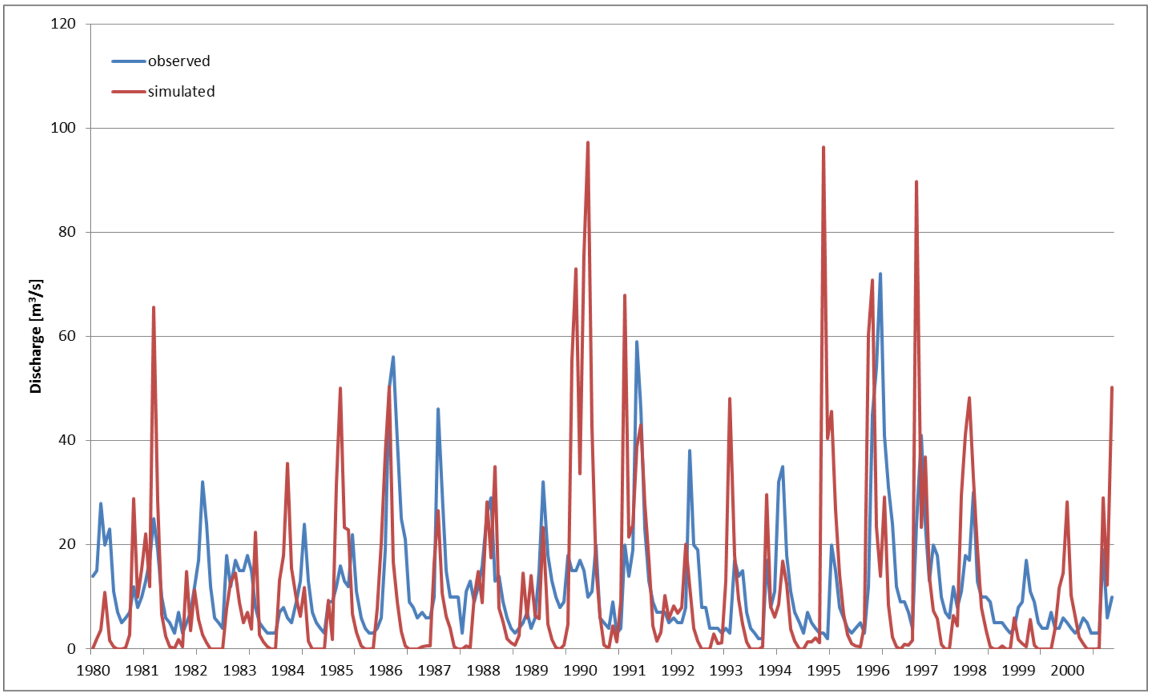

Figure 39: Simulated and observed inflow for gauge station AinTimedrine, ID 581.

4.4 Crop-based assessment

To explore the most relevant land use classes regarding Green Water Credits, results were aggregated for each land use class. The following results are plotted:

- The total amount of water consumed by vegetation (crop transpiration) and water lost by soil evaporation (Figure 40).

- T-fraction: percentage of total evapotranspiration used for crop transpiration (Green Water). This factor indicates the effectiveness of the vegetation to use the Green Water source (Figure 41).
- Blue Water: water entering the streams by surface runoff, drainage and returnflow (i.e. groundwater discharge) (Figure 42).
- Erosion: gross erosion rates (Figure 43).

Evapotranspiration is the sum of water consumed by the plants to grow (crop transpiration) and the water lost through evaporation, mainly from the soil surface (evaporation also occurs by rainfall interception but this process was not included in the analysis). Soil evaporation can be considered an actual unbeneficial loss of water from the system. The water gained by reducing soil evaporation can be either used for crop transpiration or can be infiltrated and serve for groundwater recharge.

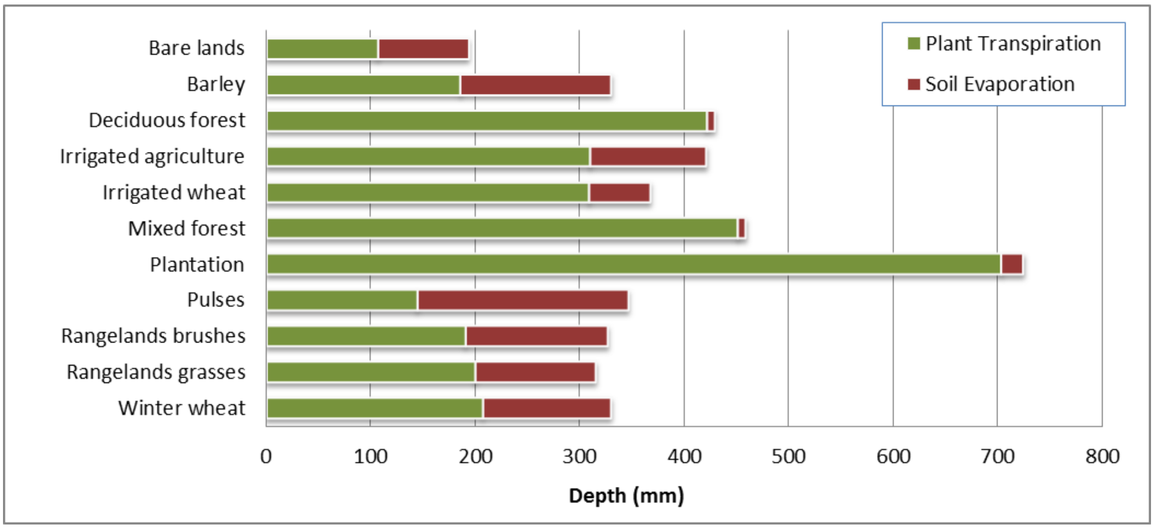

Figure 40: Evapotranspiration split in crop transpiration and soil evaporation for each land cover class, averages over 1980-2000.

The crops with potential for the implementation of Green Water Credits management practices are those that are cultivated in the upstream areas. Secondly, the crops of interest should also show the potential to reduce the amount of soil evaporation and reduce erosion. Figure 40 and Figure 41 give insight in which part of total evapotranpiration is used beneficially for the crops and which part is lost through soil evaporation. From these figures can be concluded that the main agricultural crops that show potential for the implementation of GWC practices are:

- Wheat
- Barley
- Pulses

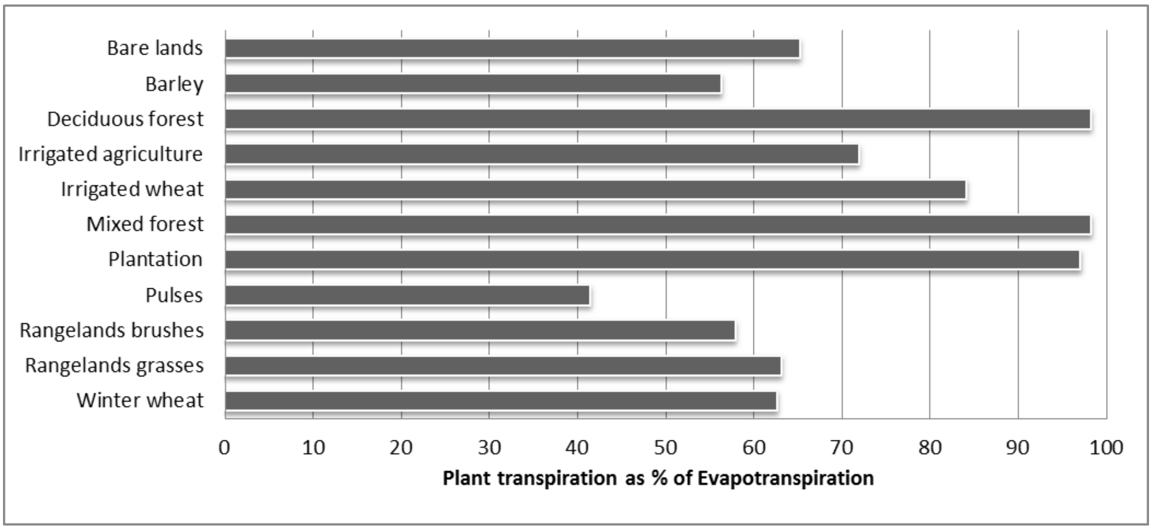

Figure 41: Percentage of total evapotranspiration used for crop transpiration, averages over 1980-2000.

Figure 42 shows the large differences between different land covers in terms of runoff, drainage and groundwater recharge (all Blue Water sources). Part of the water that reaches the ground surface is routed superficially as fast runoff. A second part is routed through sub-surface flow to the streams, generally showing a slower response than runoff. The third component is the water that percolates through the soil reservoir and recharges the groundwater aquifers. The aquifers show a much slower response due to the large travel times and secure a more continuous and reliable water source. Enhancement of groundwater recharge is therefore of interest, especially for downstream water users. The variation between the land covers is caused by the different vegetation, soil and topographical characteristics and conditions at each site.

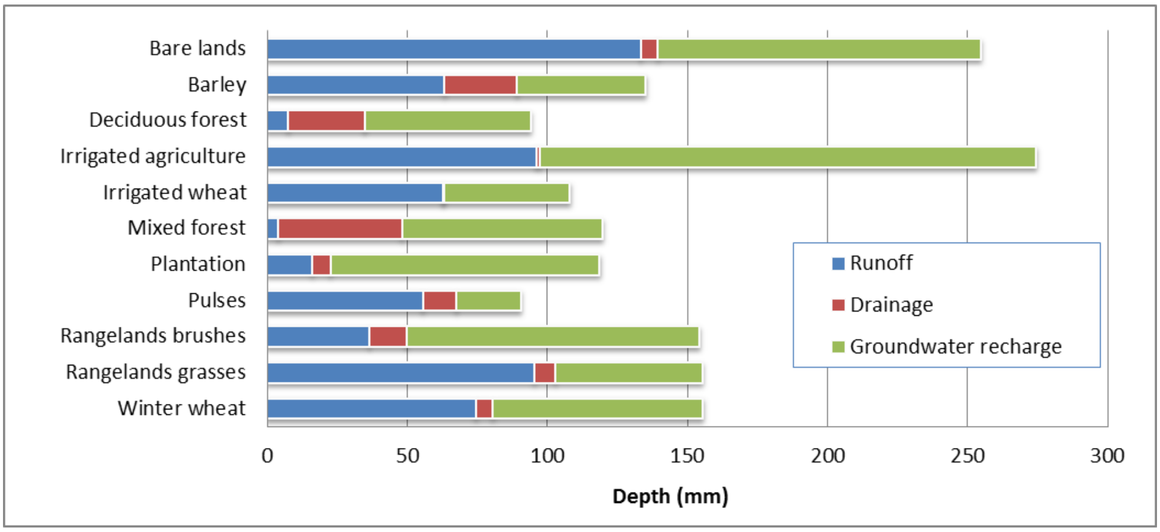

Figure 42: Water entering the streams by surface runoff, drainage and groundwater recharge.

Figure 43 shows the sediment yield for the different land covers, in which can be seen that the forest covers and the irrigated covers show the lowest erosion rates. The cultivated land cover classifications, barley, wheat and pulses, do significantly contribute to total basin sediment yield, with average rates of 8 ton/ha/yr. These numbers confirm that there is a great potential for GWC to reduce the erosion rates so as to limit the loss of fertile lands and mitigate the sedimentation of downstream reservoirs. The preliminary scenario analysis done so far within this study confirms that sediment yields can be reduced significantly.

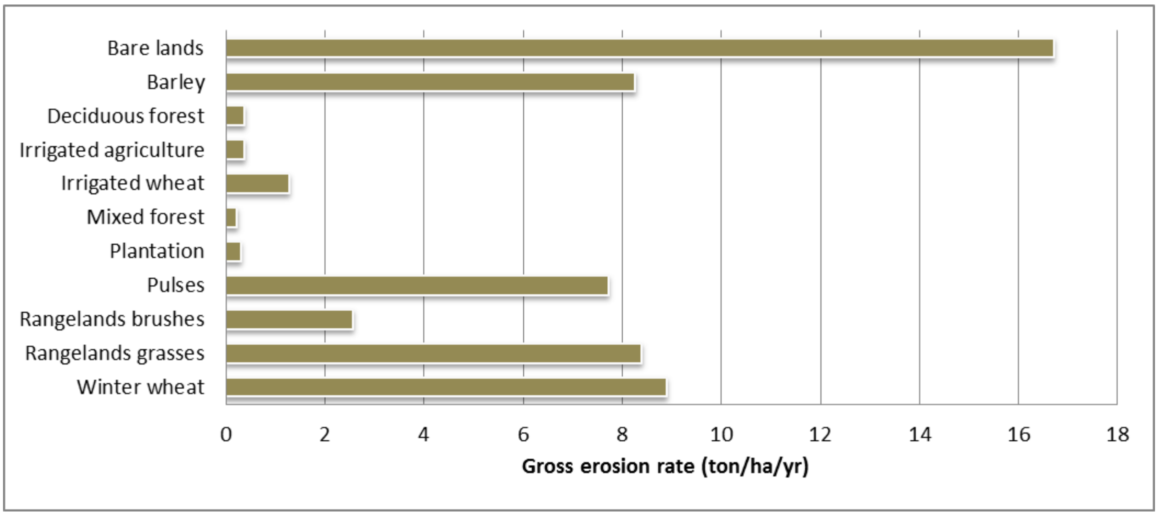

Figure 43: Total actual sediment loss per crop, averages over 1980-2000.

4.5 Spatial analysis

The distributed modeling approach that was chosen for the biophysical assessment of Green Water Credits in the Sebou basin gives the ability to assess the water and sediment flows at a high spatial detail. For the proof-of-concept phase, this will allow obtaining insight in the areas where Green Water Credits implementation is most interesting in terms of benefits. To give insight in the output that will form the basis for the GWC biophysical analysis, the following maps are plotted, based on averages from 1980-2000:

- Annual precipitation: spatial distribution of the annual precipitation sum.
- Actual evapotranspiration: total amount of water consumed by vegetation and water lost by soil evaporation.
- Actual transpiration: total amount of water that is used by vegetation (agricultural as well as natural vegetation) to produce biomass.
- Actual soil evaporation: total amount of water that is lost by soils. This includes bare soils, but also areas partly covered by vegetation. This soil evaporation can be considered as a non-beneficial loss as it does not serve any function.
- T-fraction: percentage of total evapotranspiration used for crop transpiration. This factor quantifies the effectiveness of the vegetation to use the Green Water source.
- Water yield: water entering the streams by surface runoff and sub-surface drainage.
- Groundwater recharge: water that contributes to the groundwater aquifer.
- Erosion: total actual sediment loss.

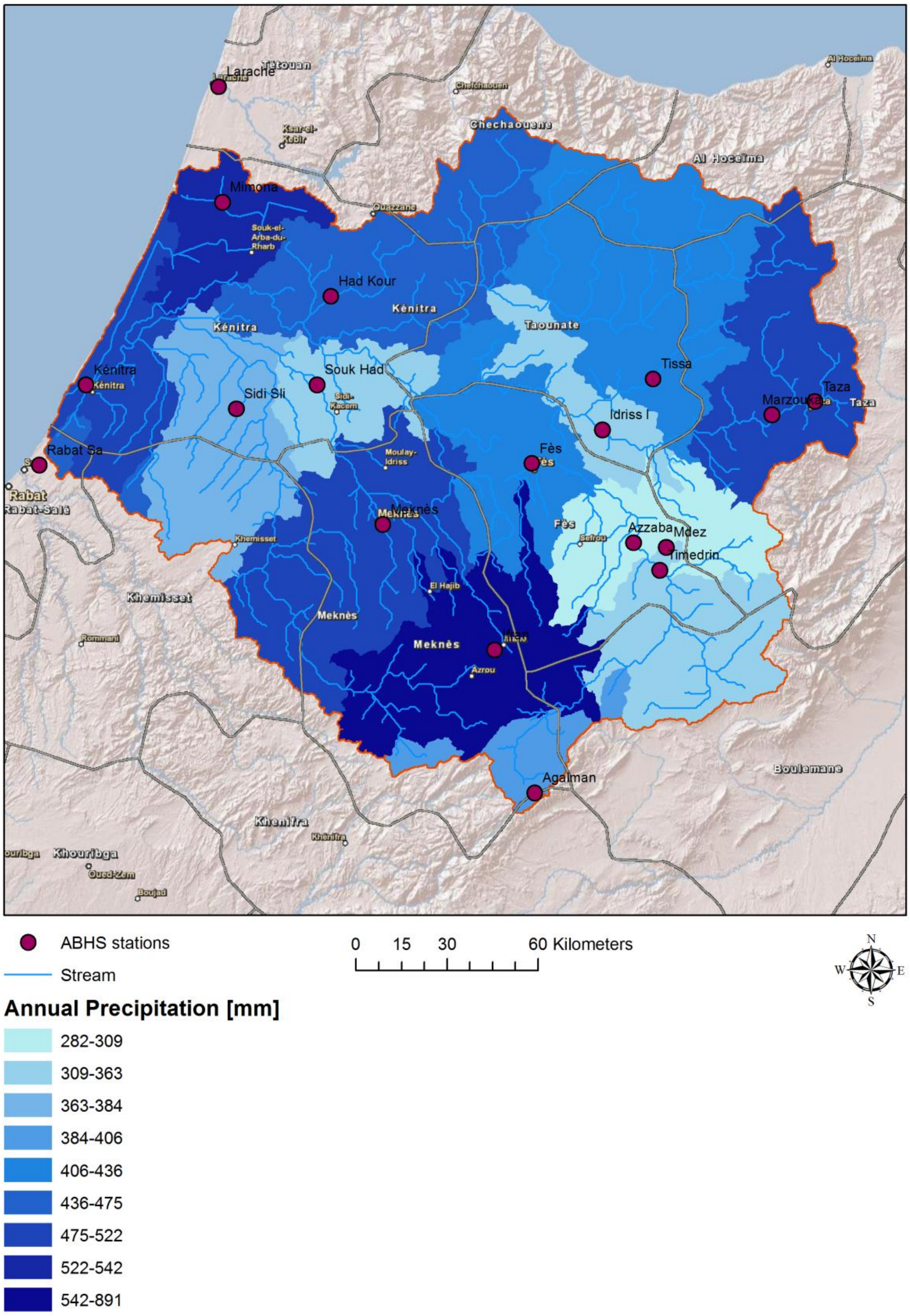

Figure 44: Annual precipitation based on the monthly ABHS station data.

The spatial pattern of annual precipitation is shown in Figure 44. The distribution of annual precipitation is based on the monthly ABHS station (18 stations) data. As can be noticed from Figure 44, the high elevation area in the northern part of the basin is lacking precipitation stations. That results in a quite homogeneous precipitation pattern in this region. It is clear that the central part of the basin is the region with the smallest precipitation sum. The areas around Meknes, the western coastal area, and the north-eastern area around Taza, belong to the wettest parts of the Sebou river basin.

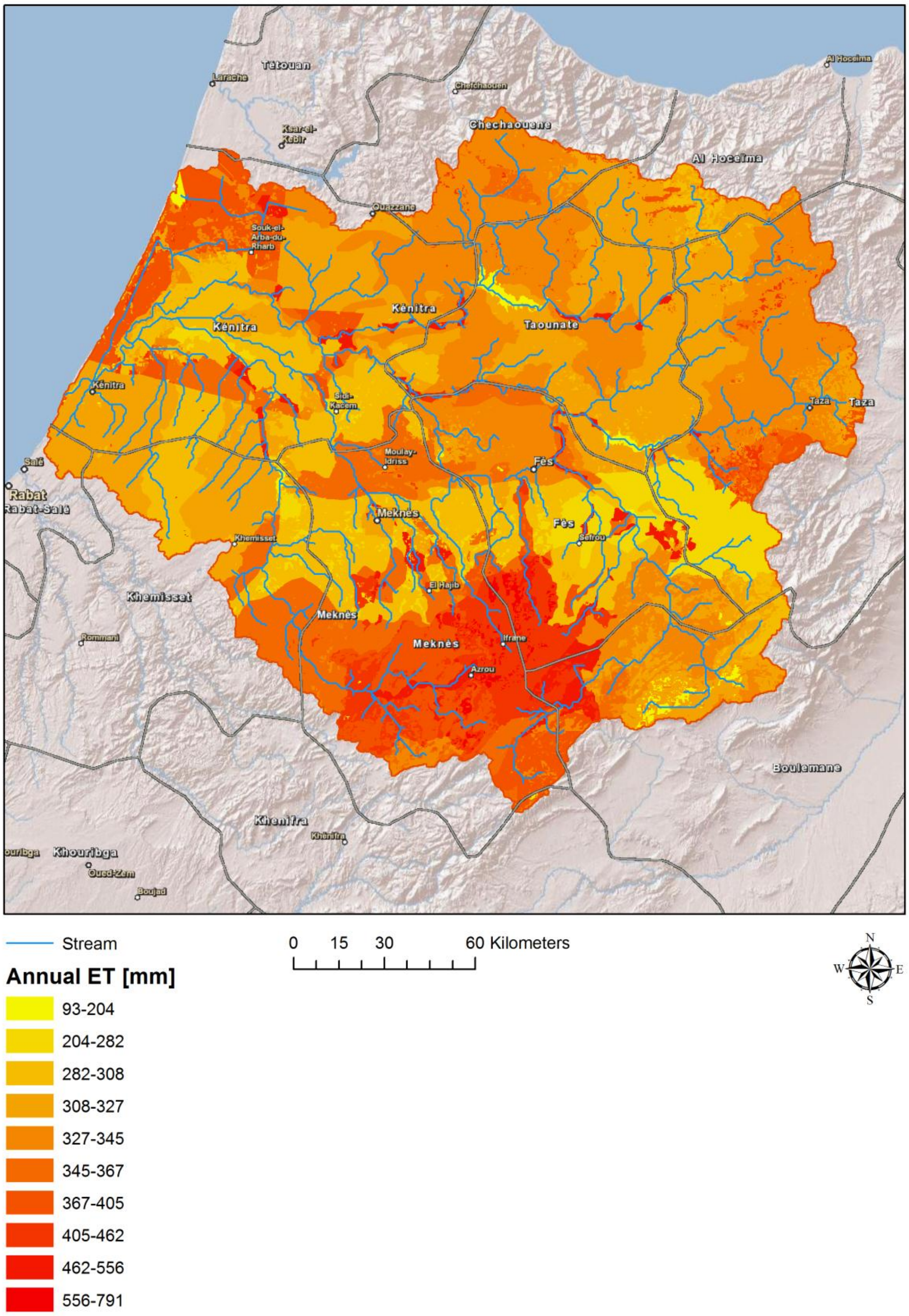

Figure 45: Annual evapotranspiration rate in mm/year (averaged over 1980-2000).

The distribution of annual evapotranspiration rates, averaged over the period 1980-2000, is shown in Figure 45. This is the sum of water consumed by vegetation (transpiration) and water lost by evaporation. The largest evapotranspiration rates are found in the southern region of the Sebou River basin. Wheat and pulses are the dominant crop types in this region. Large evapotranspiration rates are also found in the western region, where irrigated wheat is the main crop type. The irrigated agricultural region within this area shows smaller evapotranspiration rates. For the above analysis it is interesting to know which part is transpiration and which part is evaporation. Therefore, the average annual transpiration and evaporation are shown in Figure 46 and Figure 47, respectively. The potential areas for GWC management practices are the areas with high evaporation rates, which are considered as losses. From Figure 47, it clear that areas with high evaporation rates are located in the northeastern and southeastern part of the basin. This is where Barley and Pulses are the main crop types. These areas were already marked in Section 4.4 as potential areas for GWC management practices. The cities Rabat, Meknes, Fes and Taza are also clearly visible in Figure 47. This is because there is almost no transpiration from these cities because it is mainly paved area.

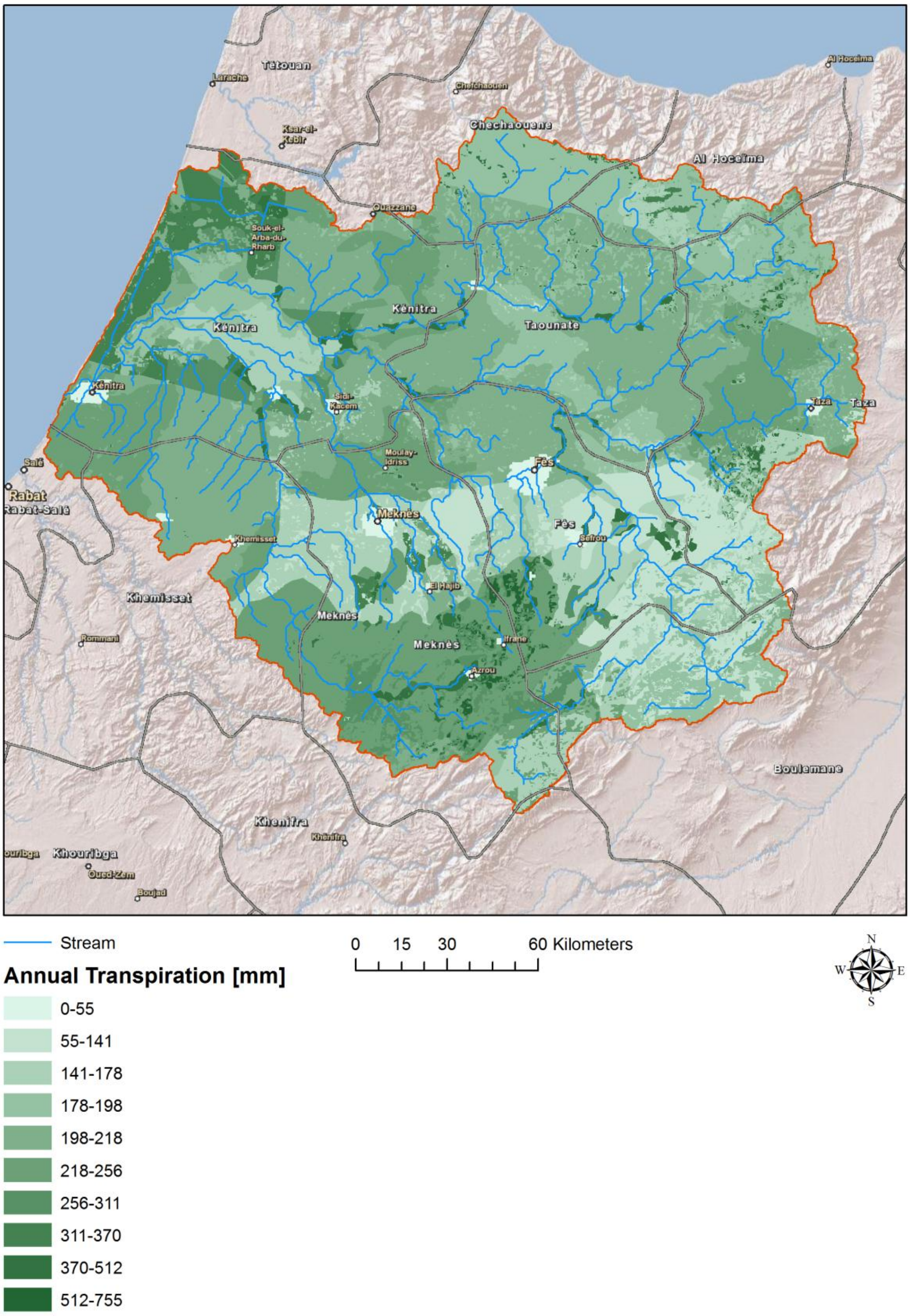

Figure 46: Annual plant transpiration rate in mm/year (averaged over 1980-2000).

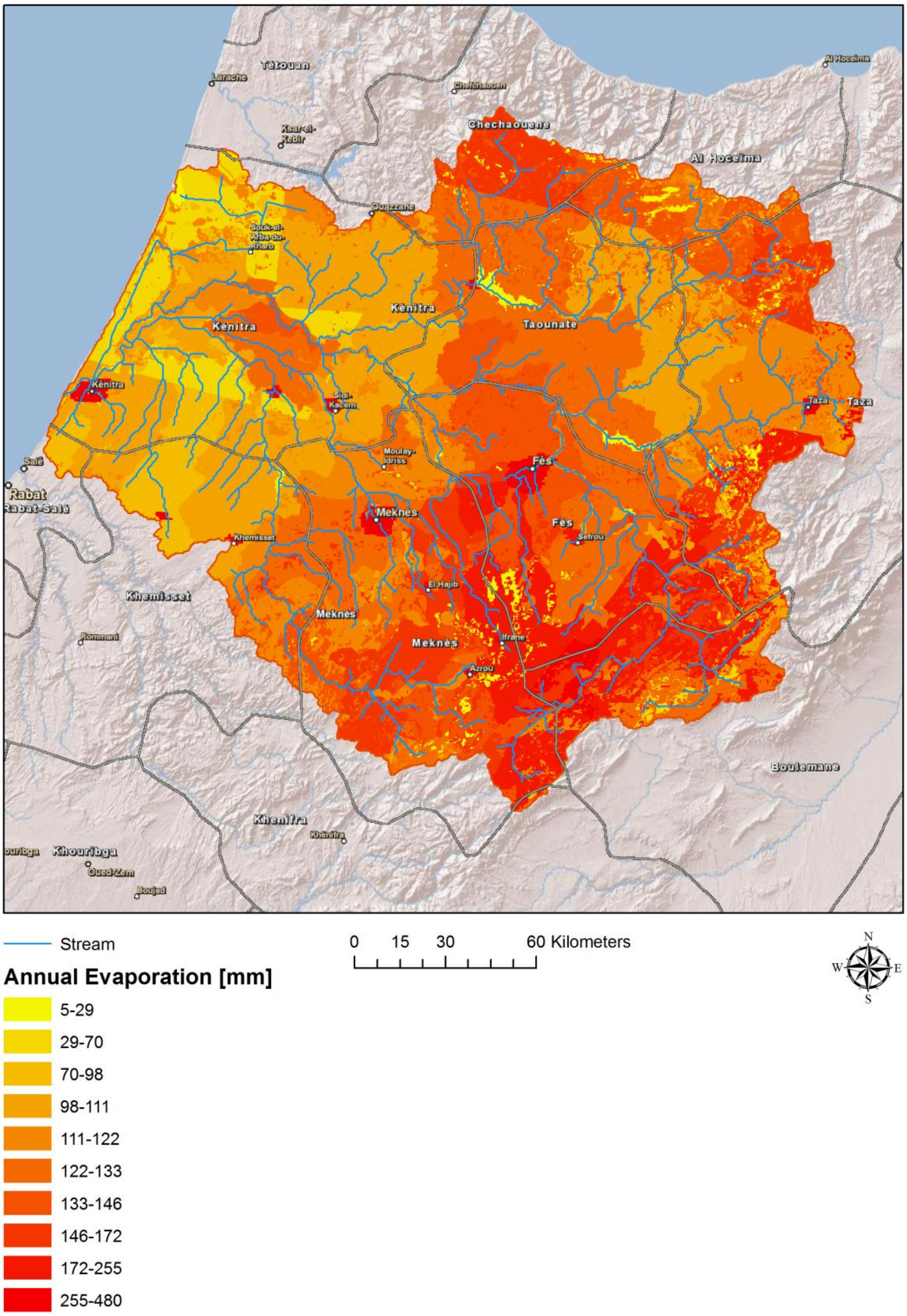

Figure 47: Annual soil evaporation rate in mm/year (averaged over 1980-2000).

The percentage transpiration from the total evapotranspiration is defined here as the Tfraction. The lower this percentage, the more water is lost by evaporation. The average annual Tfraction is shown in Figure 48. Again the northeastern region with mainly Barley, and the southeastern region with mainly Pulses, is clearly visible. Besides this, it seems that the region south of Fes and Meknes has reasonably low Tfraction rates as well. The Tfraction in this area is low because the available water capacity of the soils in this area is very small. This means that the crops hardly can extract water for transpiration. The main crop in this area is Winter Wheat, which was already selected as a potential GWC management crop.

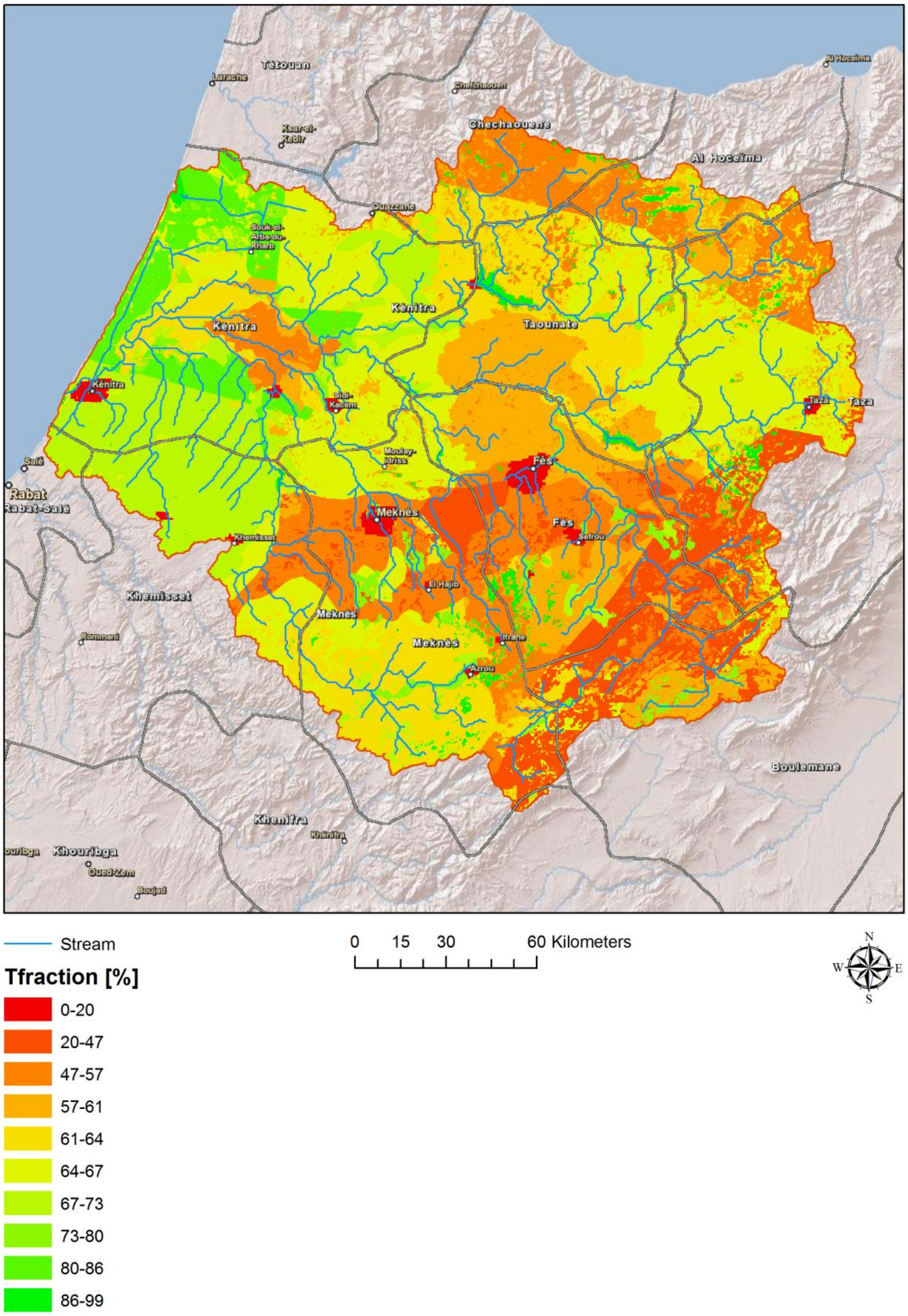

Figure 48: Transpiration as % of total evapotranspiration (averaged over 1980-2000).

The average annual water yield (sum of runoff, sub-surface flow and baseflow) is shown in Figure 49. The largest water yields are found in the southern and western coastal area. The water yields are highly correlated with the rainfall amounts. Average annual rainfall is also largest in these regions. That explains the large water yields in these areas.

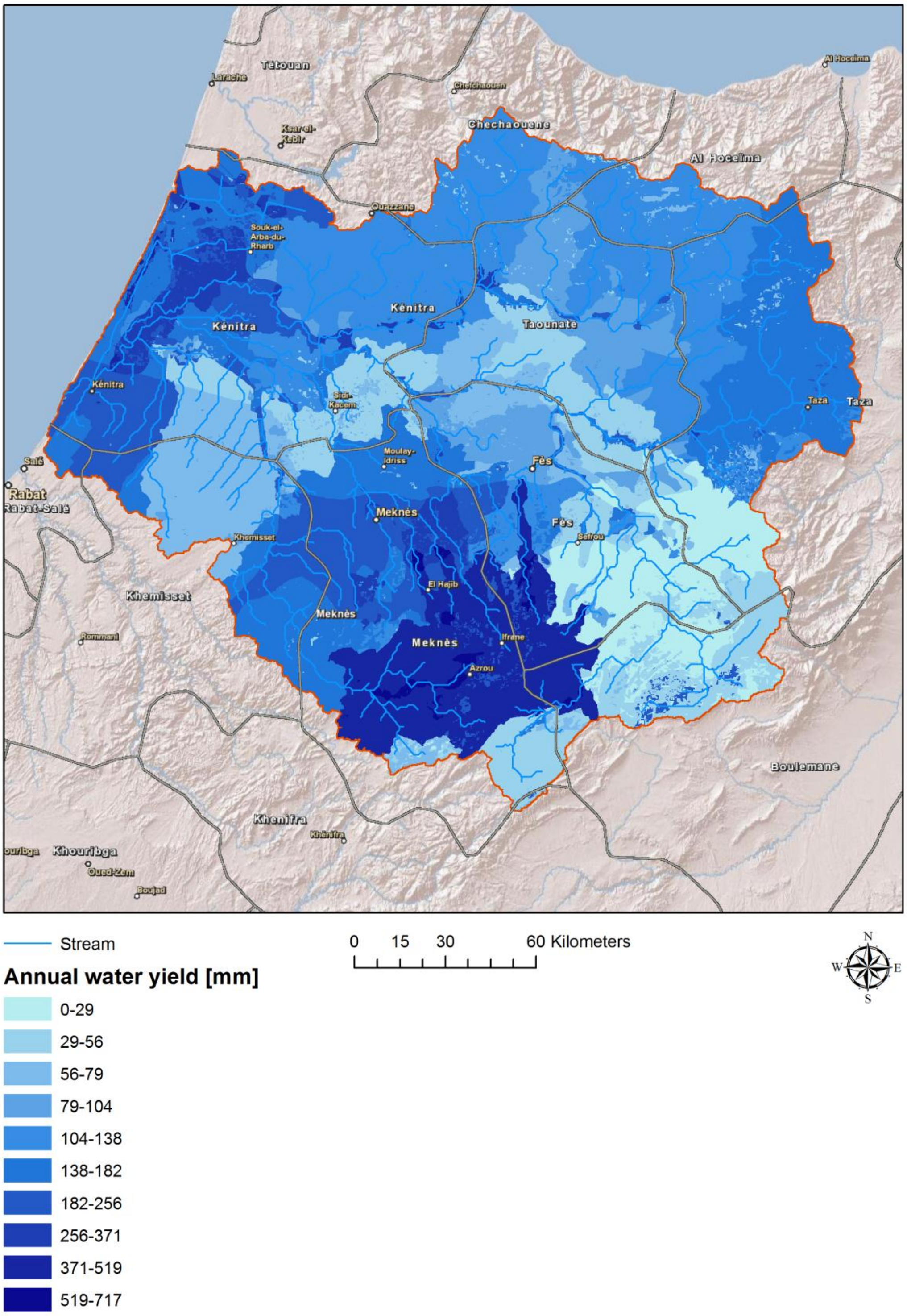

Figure 49: Total water yield (runoff, sub-surface flow and baseflow) in mm/yr (averaged over 1980-2000).

The average annual groundwater recharge (percolation) is shown in Figure 50. Again, these are highly correlated with the rainfall amounts. Therefore large groundwater recharge volumes are found in the regions with large rainfall amounts. The groundwater recharge also depends on the land use and soil type. Soil types with small permeability hardly allow the water to percolate to the saturated zone. A large part of the groundwater recharge will eventually become baseflow and finally enters the streams.

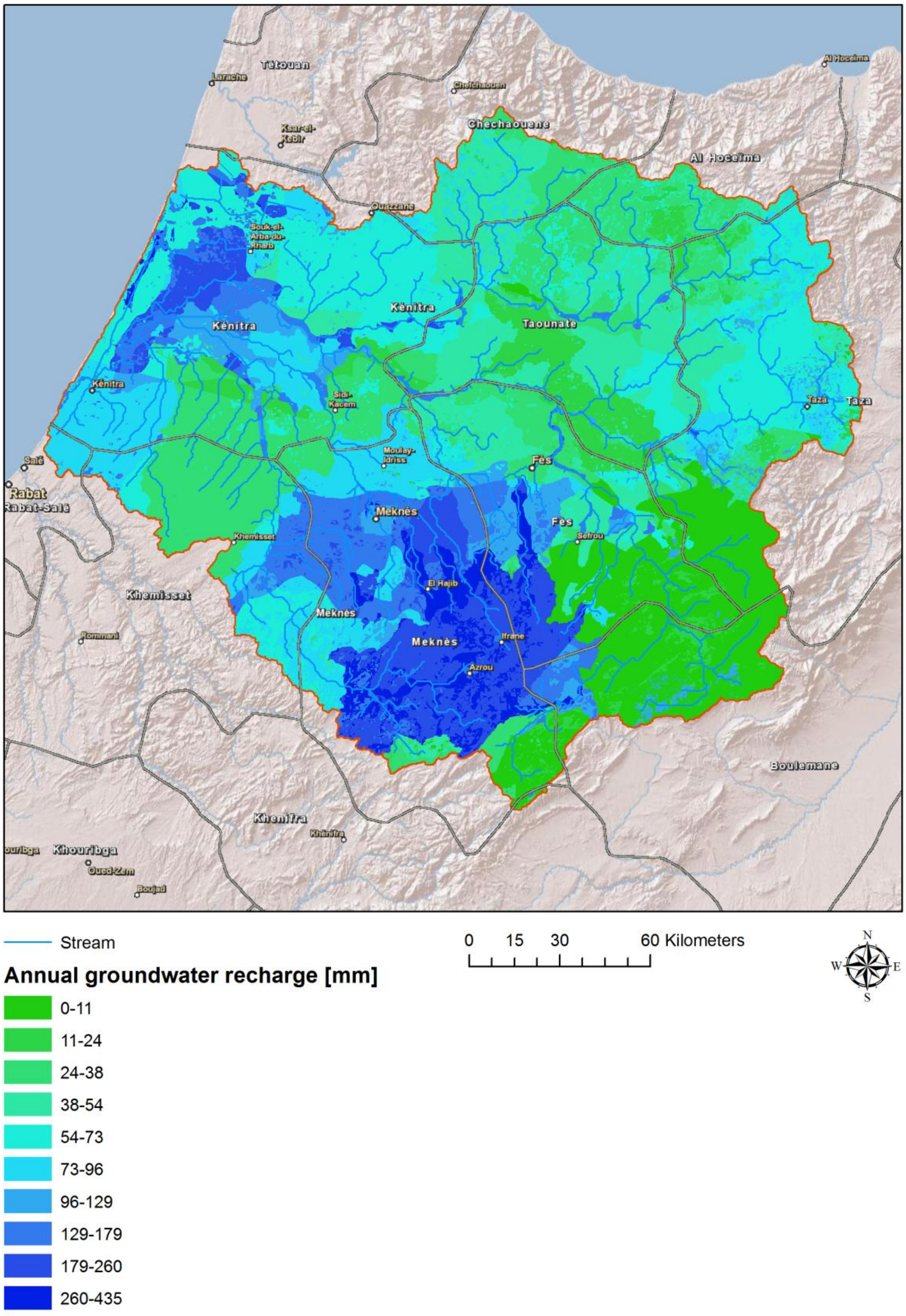

Figure 50: Gross groundwater recharge (=percolation) in mm/yr (averaged over 1980-2000).

The sediment yield in a certain area is mainly dependent on the rainfall intensity, the land use, the slope, and soil type. The average annual sediment yield is shown in Figure 51. Sediment yields are largest in the southern area of the basin. This is a result of the combination of high rainfall intensities, steep slopes, and erodible soils (Figure 29). It is clear that the flatter areas are less prone to erosion. In these areas, the rainfall is infiltrating more, instead of running over the surface and causing erosion.

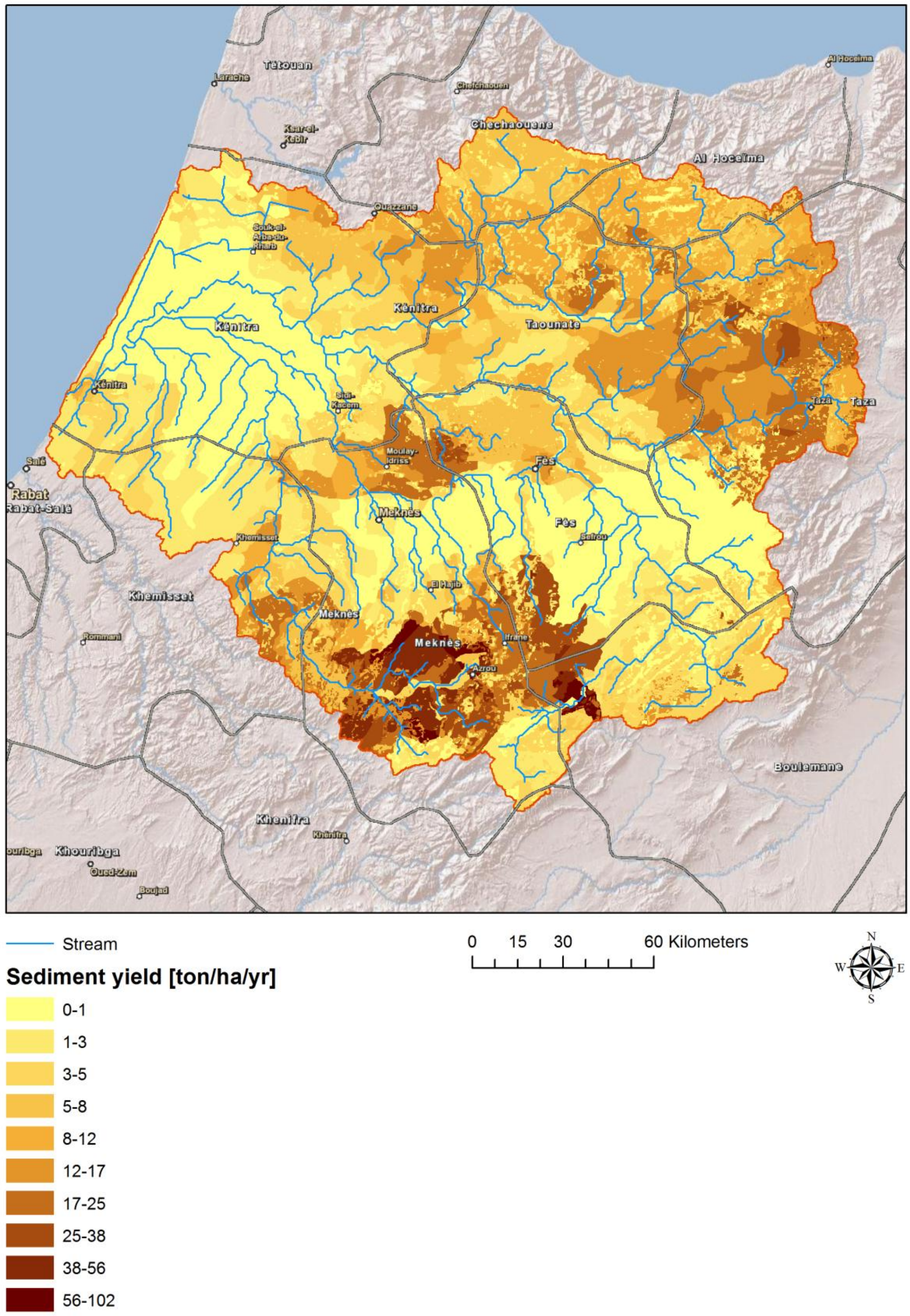

Figure 51: Gross erosion rate in ton/ha/yr (averaged over 1980-2000).

5 Future management options for GWC

5.1 Potential benefits

Green Water Credits is about meeting the interests of upstream land users and downstream water users at the same time. By linking downstream water users and upstream farmers, Green Water Credits enhances the overall water management of the basin and benefits both sides. These potential benefits need to be quantified in order to transform them to an institutional and financial arrangement that sustains the GWC implementation. Different land management options are studied and evaluated in order to opt for the most optimal implementation scheme.

The principal potential benefits that need to be quantified for upstream farmers are:

- Transpiration determining crop production and reduction of non-productive soil evaporation
- Water infiltration and retention in the soil reservoir
- Reduction of gross erosion rates and loss of fertile soils

For downstream water users (irrigators, hydropower, industrial and domestic use) the principal potential benefits that have to be assessed can be summarized as follows:

- Total water flowing from the mountainous areas into the connected reservoirs
- Enhancement of groundwater discharge because of increase soil infiltration and groundwater recharge
- Reduction of sediment input into the reservoirs and preserve storage capacity

These benefits will be quantified by introducing a set of key outcome indicators, as will be explained in the following sections.

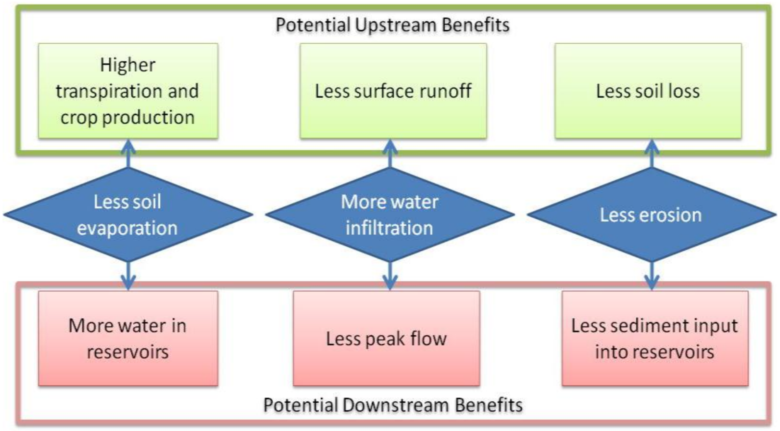

Figure 52: Example of potential upstream and downstream benefits.

A major problem in basin-scale water management is coping with the irregular rainfall and flow regimes that lead to floods in one season and drought in other seasons. Infrastructural solutions as dams, canals and diversions are able to hold certain amounts of water temporarily so as to redistribute the water availability during the seasons and to lessen hazardous peak flows. Also the soil and groundwater storages regulate flows and their capacity is in most basins much bigger than man-made reservoirs. Due to land use change and inappropriate land management, the use of these natural reservoirs is usually not at its full potential. By changing to better land management practices, the use of these free reservoirs can be enhanced.

The main strength of GWC is that both upstream as well as downstream stakeholders have profits. Aiming at only one single stakeholder group would lead to other solutions (fertilizers, sediment traps, artificial groundwater recharge, etc). Green Water Credits aims at a sustainable mechanism to be implemented by enabling the interaction between up- and downstream stakeholders.

Different land and water management options are available as possible candidates for incorporation in the GWC Sebou case. These have to be selected, studied and evaluated. A first selection has been done in the following section. Also a first indicative analysis was carried out in order to show the methodology and outcomes of this part of the assessment.

5.2 Pre-selection of management options

The World Overview of Conservation Approaches and Technologies (WOCAT) is a program that has an objective to use existing knowledge and funds more efficiently to improve decision-making and optimized land management. It is a framework for collecting databases of successful SWC experiences concerning technologies, approaches and map through the use of standardized and simplified questionnaires worldwide. All data are readily analyzed, disseminated and prepared for presentation, evaluation and monitoring. It can be used as a tool in land management for all land users (stakeholders) with benefits that are multiple and mutual, with a chance to reduce problems and pitfalls in achieving better land management through the improved WOCAT decision support system.

A pre-selection was made of three management practices from the WOCAT database of measures that have shown large potential in previous GWC assessments. They are presented here and will be projected with the local stakeholders and representatives in order to initiate the quantitative scenario analysis and determine the upstream and downstream benefits. The following management options were selected:

1. Permanent Vegetative Contour Strips
2. Mulching
3. Tied Ridges

With the agro-hydrological model SWAT, the impacts and possible trade-offs of these practices will be studied and quantified. The following paragraphs give a more detailed explanation on these practices.

5.2.1 Permanent vegetative contour strips

Strip cropping is a practice in which contoured strips of sod are alternated with equal-width strips of row crop or small grain. Strips of grass or other permanent vegetation in a contoured field help trap sediment and nutrients. Because the buffer strips are established on the contour, runoff flows slower and evenly across the grass strip, reducing sheet and rill erosion. The vegetation can also provide habitat for small birds and animals. Permanent vegetative contour strips are in fact an inexpensive substitute for terraces.


Figure 53: Example of permanent vegetative contour strips (source: NRCS).

5.2.2 Mulching

Mulching requires residues produced within the cropping area and/or residues collected from elsewhere and transported to the cropping area. These residues are then applied in the field, spreading them on top of the soil. They protect the soil from erosion, reduce compaction from the impact of heavy rains, conserve soil moisture and maintain a more stable soil temperature. Besides there are several secondary benefits as for example the prevention of weed growth.


Figure 54: Example of tree loppings used as a mulch in the Quesungual system (Honduras) to reduce the loss of rainwater through runoff and evaporation (source: FAO).

5.2.3 Tied ridges

This technique consists of soil ridges of varying width and height, average being 30 cm width and 20 cm height. At regular intervals, crossties are built between the ridges. The ties are about two-thirds the height of the ridges, so that if overflowing occurs, it will be along the furrow and not down the slope.

Farmers find tied ridges hard yet efficient in harvesting water and conserving soil. Crops planted on the ridges grow faster than those in plots without ridges. A disadvantage is the heavy labour input, although levels of maintenance are considerably lower than the initial construction work.

Tied ridges help to minimize problems of drought power and labour shortage in land preparation. There are positive effects on soil erosion in the area.

Figure 55: Example of graded contour ridges with cross ties lower than the main ridges to retain water between the cross ties, but allow excess rainwater to flow between the ridges rather than spill over or break the main ridges (source: FAO).

5.3 Preliminary analysis of one GWC option

A preliminary analysis has been done of one of the pre-selected GWC management options, being the implementation of vegetative contour strips. In order to compare this scenario with the baseline current situation a set of indicators are introduced that gives insight in the impact of the practice.

Stakeholder consultations showed that the key challenges in the basin are maintaining the upstream water source, reduce flooding and the siltation of the reservoirs. Rapid runoff, erosion and sedimentation are a result of upstream forest degradation. Previous studies showed that the life span of the main reservoirs is seriously threatened by these practices. The sedimentation of reservoirs is reported to have increased during recent years. Also water scarcity is an issue as competition between irrigators and urban water supply caused some schemes to be blocked by irrigation interests.

The key indicators show the water and sediment inflow of three principal reservoirs in the basin, being the Allal El Fassi reservoir, the Idriss 1 Er reservoir, and the Al Wahda reservoir. To quantify the effect of the scenarios on the generation of fast surface runoff, an indicator shows the amount of yearly surface runoff generated in the Atlas and Rif mountains.

For this preliminary assessment, it has been assumed that the practices are implemented in all the upstream areas where pulses and barley is cultivated, according to the used classification. The following table summarizes the parameter changes that were incorporated into the model.

Table 9: Parameter changes for a scenario with permanent vegetative contour strips.

Land use	P_{USLE}		CN2	
	Baseline	Scenario	Baseline	Scenario
Pulses	1.0	0.7	77	70
Barley	1.0	0.7	73	60

The following table shows the results for the Key Outcome Indicators for the contour strips scenario. An interesting result between the GWC scenario and the baseline scenario is the reduction of sediment inflow into the three reservoirs (Allal El Fassi, Al Wahda, and Idriss 1 Er). Sediment inflow is reduced with 15% for Allal El Fassi, 5% for Al Wahda, and 4% for Idriss 1 Er. Runoff in the high mountain areas is significantly reduced by about 44%, while basin-wide groundwater recharge is slightly enhanced (1%). Evapotranspiration is similar between both scenarios.

Table 10: Key outcome indicators for contour strips scenario (averages 1980-2000).

	Baseline	Contour Strips		
Key indicators			change	% change
Inflow Allal El Fassi (MCM/y)	519	507	-12.0	-2%
Sediment Inflow Allal El Fassi (Mton/y)	1.27	1.07	-0.2	-15%
Inflow Al Wahda (MCM/y)	812	806	-6.0	-1%
Sediment Inflow Al Wahda (Mton/y)	1.74	1.65	-0.1	-5%
Inflow Idriss 1 Er (MCM/y)	426	423	-2.7	-1%
Sediment Inflow Idriss 1 Er (Mton/y)	1.06	1.02	0.0	-4%
Surface Runoff in mountain areas (mm/y)	60	33	-26.3	-44%
Crop Transpiration (mm/y)	224	224	0.1	0%
Soil Evaporation (mm/y)	119	119	0.0	0%
Groundwater Recharge (mm/y)	87	88	1.0	1%
Sediment loss (ton/ha/y)	5	5	-0.3	-5%
Basin Balance				
Area (km2)	39,053	39,053		
Precipitation (MCM/y)	18,752	18,752	0.0	0%
Transpiration (MCM/y)	8,748	8,754	5.6	0%
Evaporation (MCM/y)	4,634	4,635	0.9	0%
Barley				
Area (km^2)	2,195	2,195		
Crop Transpiration (mm/y)	186	187	0.8	0%
Soil Evaporation (mm/y)	144	145	0.5	0%
Groundwater Recharge (mm/y)	45	73	27.9	62%
Surface Runoff (mm/y)	63	28	-35.3	-56%
Sediment Loss (ton/ha/y)	8	2	-5.9	-71%
Pulses				
Area (km^2)	2,760	2,760		
Crop Transpiration (mm/y)	145	148	3.5	2%
Soil Evaporation (mm/y)	202	202	0.3	0%
Groundwater Recharge (mm/y)	23	34	11.6	51%
Surface Runoff (mm/y)	56	38	-17.2	-31%
Sediment Loss (ton/ha/y)	8	3	-4.2	-55%

The previous table shows also the principal components of the water balance for the crops (barley and pulses) cultivated in the areas where the scenario is applied to. Also these indicators show significant benefits: an increase in groundwater recharge between 51% and 62%, while reducing rapid surface runoff by 31-56%. For the upstream land users the most relevant benefit, however, is the reduction in sediment loss, which is reduced by 55% in the area with Pulses as dominant crop, and 71% in the area with Barley as dominant crop.

It has to be noted that the numbers represented here are the result of the analysis of the output from the preliminary non-calibrated SWAT model. The following section describes the steps that will be taken in the following phase to update the analysis with enhanced and validated input datasets and to calibrate the model with observed streamflow data.

5.4 Further steps

This report summarizes the approach to establish the biophysical analysis of the Proof of Concept for GWC Morocco. Data preparation and verification, model building, preliminary results and initial GWC measures were analyzed and described. Further improvements of the various steps have been identified and will be summarized here.

The following data gaps were identified during this phase and are being addressed currently:

1. The climate dataset used for this analysis needs reconsideration as significant discrepancies were observed with a limited number of time series from local weather stations. It is preferable to use daily data instead of monthly precipitation data as used in the current analysis. A daily dataset of climate data has been requested from the Moroccan counterparts. This dataset, together with a reliable satellite rainfall dataset (e.g. FEWS-NET as was used previously for Kenya-GWC) will greatly enhance the model forcing input.
2. An updated version of the land use dataset is in preparation with the Moroccan counterparts and can be included in the consecutive analysis.
3. More detailed soil information has been requested and will be included in the following analysis steps.
4. More detailed information on the crop cycles, planting, harvest dates and overall agricultural practice is needed to enhance the reliability of the GWC measures.
5. The pre-selected set of management options has to be discussed in detail with stakeholders, in order to obtain a realistic set of management practices to be evaluated for the final assessment.
6. Management data of the 8 main reservoirs in the basin is necessary for model improvement. Currently, only 2 of the 8 reservoirs are implemented in the model as managed.

When these data gaps are addressed, the following analysis steps can be carried out. This will result in the full biophysical assessment of GWC for the Sebou basin, including the determination of potential target areas for GWC implementation in the basin:

1. Calibration and validation of the SWAT model.
2. The final set of GWC options will be evaluated based on the Key Outcome Indicators that enable to compare and benchmark the different scenarios.
3. Detailed maps can be produced to examine the spatial distribution of the upstream and downstream interactions and impacts of the GWC options in the basin.
4. Potential target areas will be derived based on these outputs where the practices are optimally implemented, from a biophysical point of view. This output will be the baseline

for the following economic and institutional analysis carried out within the Green Water Credits framework.

6 Conclusions

Green Water Credits (GWC) is a mechanism for payments to land users in return for specified soil and water management activities that determine the water supply to stakeholders in the basin. Within the Sebou River Basin there are various interrelated issues related to water scarcity, reservoir sedimentation and flooding that offer unique opportunities for implementation of GWC. The implementation of these management options can enhance the water availability and reduce problems related to flooding and erosion. However, farmers need incentives to sustainably implement these GWC measures. At the same time, downstream users may be unaware of the benefits they might gain through farmer implementation of these measures in upstream areas. This Proof-of-Concept phase is meant to demonstrate and quantify the potential benefits to all stakeholders in the Basin.

The GWC methodology was applied to the Sebou River basin. Data was gathered, prepared and verified to set up a biophysical assessment tool (SWAT) to quantify the upstream-downstream interaction in the basin. First estimates of the main GWC output variables, such as soil evaporation, transpiration, gross erosion rates, etc., are presented in this report. Also a preliminary analysis to demonstrate the application of the tool to evaluate a GWC scenario is presented as well. For the scenario analyzed, introducing contour strips, surface runoff and sediment load will reduce substantially and simultaneously groundwater recharge will be enhanced.

The current report is an exploratory study, which will be used to improve the data and modeling over the next couple of months. It is necessary to fine-tune the methodology as presented in this report on various lines:

- First of all, updated databases should be included in the analysis to enhance the reliability of the biophysical analysis.
- Secondly, more emphasis should be put on the validation/calibration of the tool, for which additional data are required as well.
- Thirdly, results have to be discussed more in detail with local experts.
- Finally, but most importantly, the updated biophysical tool will be used to define areas where GWC measures can be implemented best. Combining these results with a water allocation / financial analysis and a socio-economic mapping will result in an improved water and land management in the Sebou Basin.

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