Green Water Credits Morocco: Inception Phase

Green and *Blue Water* Resources for the Sebou Basin, Morocco

Soil and Water Management Scenarios using the Soil and Water Assessment Tool (SWAT)

August 2011

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ISRIC World Soil Information

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Abbreviations and Acronyms

ABHS	Agence Du Bassin Hydraulique Du Sebou
AML	Arc Macro Language
APAR	Absorbed Photosynthetical Radiation
AWC	Available Water holding Capacity
CIAT	International Center for Tropical Agriculture
DEM	Digital Elevation Model
EEA	European Environment Agency
ENVISAT	Environmental Satellite
ESA	European Space Agency
eSOTER	Soil and Terrain database
FAO	Food and Agriculture Organisation
GAEZ	Global Agro-ecological Assessment study
GLC2000	Global Land Cover 2000
GlobCover	Global Land Cover Map
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GSOD	Global Summary of the Day
GWC	Green Water Credits
HRU	Hydrological Response Unit
HWSD	Harmonized World Soil Database
IFAD	International Fund for Agricultural Development
IGBP	International Geosphere-Biosphere Programme
INRA	Institut National De La Recherche Agronomique
ISRIC	International Soil Reference and Information Center
JPL	Jet Propulsion Laboratory
JRC	Joint Research Centre
LCCS	Land Cover Classification System
LUE	Light Use Efficiency
MERIS	Medium Resolution Imaging Spectrometer
NCDC	National Climatic Data Center
PTF	Pedotransfer Functions
RMSE	Root Mean Squared Error
SMC	Steering Management Committee
SPAM	Spatial Production Allocation Model
SRTM	Shuttle Radar Data Topography
SWAT	Soil and Water Assessment Tool
TRMM	Tropical Rainfall Measuring Mission
UNEP	United Nations Environment Programme
USDA – ARS	Agricultural Research Service

USLE	Universal Soil Loss Equation
WISE	World Inventory of Soil Emission Potentials
WMO	World Meteorological Organization
WOCAT	World Overview of Conservation Approaches and Technologies

Key Points

- In Morocco, *blue water* resources are overexploited and nearing the limit of ecologically sustainable withdrawal. Population growth in the Sebou basin is putting increasing pressure on land and water resources. Land use and management changes that are taking place are altering the overall water balance, leading to an increase in runoff, peak flows, soil erosion and sedimentation of downstream reservoirs. The costs of mobilising more *blue water* are becoming more and more expensive.

- 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 the Rharb plain. The upstream part of the basin supports a large population of rainfed farmers offering significant opportunities for improved *green water* management practices.

- The main advantage of using the SWAT model for the exploration of GWC in the Sebou basin is that it uses a physical-based rainfall-runoff scheme. This guarantees more reliable scenario simulations where there are only poorly gauged catchments. Furthermore, the model is primarily focused on the interaction between land management versus water-and erosion processes.

- The crops with the highest potential to respond to the implementation of *green water* management practices are those that are cultivated in the upstream areas. These are the rainfed crops of wheat, barley and broad beans.

- A selection was made of three management practices from the WOCAT database that have shown large potential in previous GWC assessments. These were:
  1. Stone lines (*cordons de pierres*)
  2. Bench terraces (*banquettes*)
  3. Contour tillage

- It was concluded that all three *green water* management scenarios, in addition to their direct benefits to upstream farmers for the selected crops, result in a decrease in sediment inflow into the three reservoirs. Sediment inflow decreases by 22% for Allal El Fassi, by 14% for Al Wahda, and by 18% for Idriss 1 Er.

- The following data gaps were identified during this phase and are being addressed:
  - A more detailed land use dataset is in preparation with the Moroccan counterparts and should be included in a consequent follow-up analysis.
  - Currently only the northern and western parts of the basin are covered by a detailed soil map: similar maps should be obtained for the remainder of the basin.
  - More detailed information on overall agricultural practice is needed to enhance the reliability of the assessment of the *green water* management measures.

1 Introduction

1.1 Context

In Morocco, *blue water* (see Figure 2 for the concept of GWC and definitions) resources are overexploited and nearing the limit of ecologically sustainable withdrawal of ground and surface water. Population growth in the Sebou basin, Morocco, is putting increasing pressure on land and water resources. Land use and management changes that are taking place are altering the overall water balance, leading to an increase in runoff, peak flows, soil erosion and sedimentation of downstream reservoirs, and thus reducing water availability throughout the watershed. Flooding and pollution have been identified as the major issues in the Sebou river basin. The costs of mobilising more *blue water* are becoming more and more expensive and are nearing the limit of economic viability.

A mind-shift is necessary regarding the way we think about water and agriculture. Instead of a narrow focus on utilisation of river and groundwater, it is important to be aware that precipitation is the ultimate source of water that can be managed. There is high potential to improve the use and management of rainwater in upstream rainfed agriculture: this is termed *green water* management. Current land management practices by farmers show loss of rainwater by (i) large quantities of surface runoff, enhancing both flash floods and erosion (Figure 1), and (ii) high losses of water by evaporation, directly from the bare soil.

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

The knowledge and the tools to improve upstream management and land use in arable, range and forest areas are available, but these need to be more widely implemented. Upstream land users can effectively provide rainwater management services to water users downstream, to improve the available *blue water* resources in terms of quantity and quality.

The implementation of *green water* management options can enhance water availability, but farmers need incentives to put them in place. At the same time, downstream users may be unaware of the benefits they can gain through farmer implementation of these measures in upstream areas.

This report builds on the Proof-of-Concept assessment that evaluated the possibilities for Green Water Credits in the Sebou river basin in Morocco. In the first mission to Morocco in April 2009, interest in the Proof-of-Concept phase was explored on the basis of basin identification (Green

Water Credits, Work Plan, 2010). This indicated that the Sebou river basin offered scope to implement a Green Water Credits programme. The choice of the Sebou river basin was acknowledged in the Steering Management Committee (SMC) meeting in Rome in July 2009. This project will be supported under IFAD's Large Grant Green Water Credits Pilot Operations.

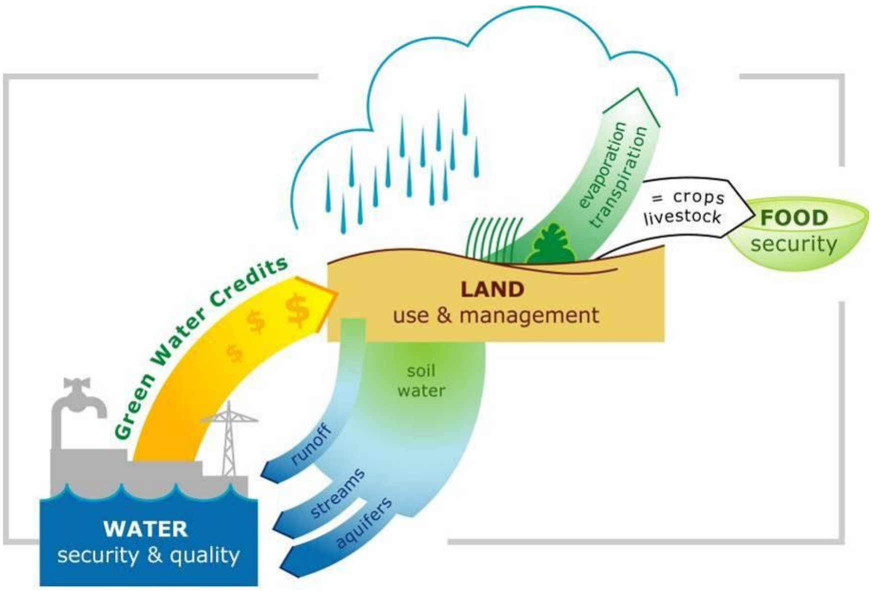

Figure 2: Green Water Credits: the concept.

The overall goals of GWC are to enable rural people to better manage land and water resources leading to benefits including:

- Enhanced water flows;
- Reduced erosion and siltation of reservoirs
- Mitigation of floods;
- Mitigation of droughts;
- Mitigation of climate change impacts.
- Improved food and water security and public health;
- Improved local resilience to economic, social and environmental change by asset building (stable soils, improved water resources, reduced rate of poverty, and diversification of rural incomes);

A study was undertaken for the implementation of GWC within the Tana basin in Kenya (Hunink *et al.* 2009). The analysis of this basin showed that the implementation of GWC could significantly reduce problems related to the growing demands for hydropower generation, and of both municipal water utilities, and irrigators. Different *green water* management options were analysed, which showed that considerable improvements could be obtained in terms of water security for both upstream as well as downstream stakeholders.

1.2 Basin characterisation

1.2.1 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 rainfed agriculture, the latter being the target of GWC. The plan aims at boosting market-oriented agriculture that should improve the livelihoods of smallholders and subsistence farmers, which is also a target of the GWC.

1.2.2 Basin overview

The Sebou river basin (Figure 6), with a total area of 39,021 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 30% of the national potential of surface water resources and 20% of the groundwater 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 with the *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 raises above 2800 m in the Middle Atlas mountains and is underlain mainly by calcareous rocks. Mean annual precipitation is above 1000 mm, and at high elevations winters are snowy. The mid-Sebou basin is located in the Rif and pre-Rif mountains, which are characterised by an average altitude of 2000 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 the 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 rainfed farmers (Figure 3), offering significant opportunities for improved land and water management in agricultural and forest land.

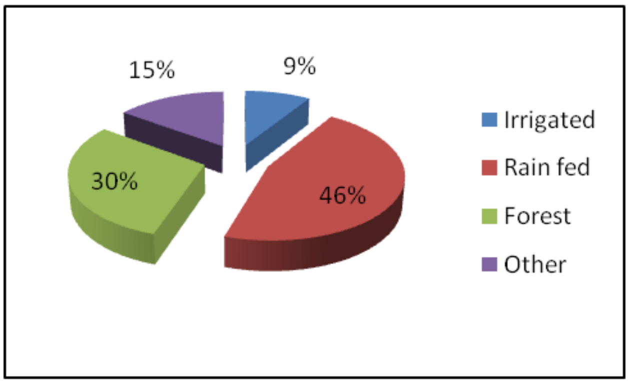

Figure 3: Percentage of land use (Green Water Credits, Work Plan (2010)).

A total of 6.7 million people live in the basin (23% of Morocco's population), of which 57% live in rural areas. Most of the population is concentrated in the urban centres 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 pre-Rif.

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

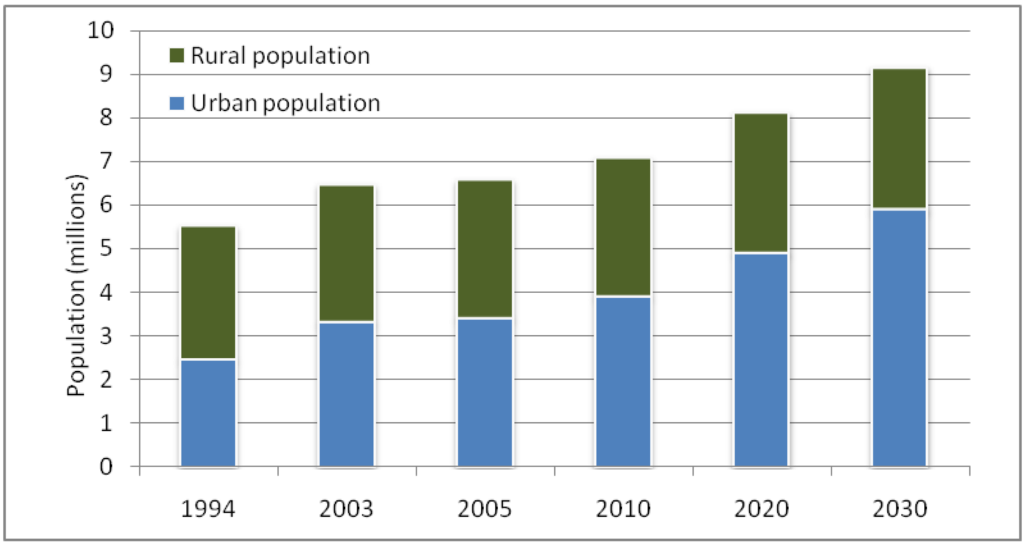

Figure 4: Past and future population growth (data source: PDAIRE, 2005).

Another major problem recognised in the basin is the massive deforestation and associated land degradation which has several negative impacts: these include siltation of dams, loss of arable land, and flooding. These problems are especially relevant in the high mountain areas of the Middle Atlas and the Piedmont area. Localised, intense precipitation, especially in summer or fall, cause damage to fields, erosion of fertile land, and give rise to hazardous flood levels in the rivers. Prolonged floods also occur, affecting downstream areas. These harmful events have most likely become more frequent in recent years due to the continuing land use changes in the mountain areas.

- The Sebou River Basin in northern Morocco runs roughly 500 kilometers, from the Middle Atlas Mountains in the east to the Atlantic Ocean in the west. The area of the basin is 39,021 square kilometers.

- The Sebou water resources potential is about 5.6 billions of cubic meters, representing 28% of the national potential. This basin possesses large agricultural potential: a total agricultural area of 1.8 million hectares, of which 357,000 ha are irrigated. The Sebou basin includes various industrial, touristic and handicraft activities.

- The Sebou Basin Hydrological Agency (ABHS) faces many challenges:
    - Droughts which are becoming increasingly regular
    - Flooding
    - Groundwater depletion through overexploitation
    - Pollution
    - Watershed erosion and dams silting up
    - Poor efficiency of the water distribution systems
    - Under-developed irrigation potential with respect to the command area of dams

Figure 5: The Sebou river basin in a nutshell.

1.2.3 *Water balance*

A rough estimate of the water balance of the Sebou river basin is shown in Table 1, derived from previous studies (Green Water Credits, Work Plan 2010), which shows that runoff to rivers and reservoirs is 18% of the annual rainwater, and groundwater recharge is 5%. So far, efforts in improved water management have mainly directed at harnessing *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 a “target for improvement” under the GWC programme.

Table 1: The Sebou estimated water balance (Green Water Credits, Work Plan 2010)[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

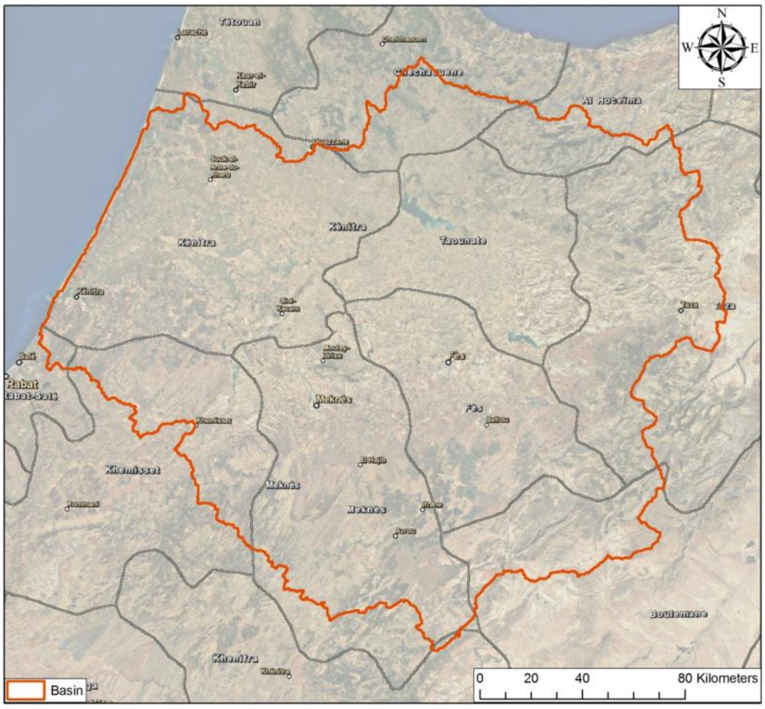

Figure 6: The Sebou river basin (red line) in Morocco.

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

2 Methodology

2.1 Model selection

The circulation of water within the earth and atmosphere is a complex mechanism of energy exchange and different ways of transportation. A schematisation of the different processes involved in the water cycle is shown in Figure 7. Hydrological models are a tool to simulate these paths of water movement under different conditions. They are used 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 water availability and sediment yield.

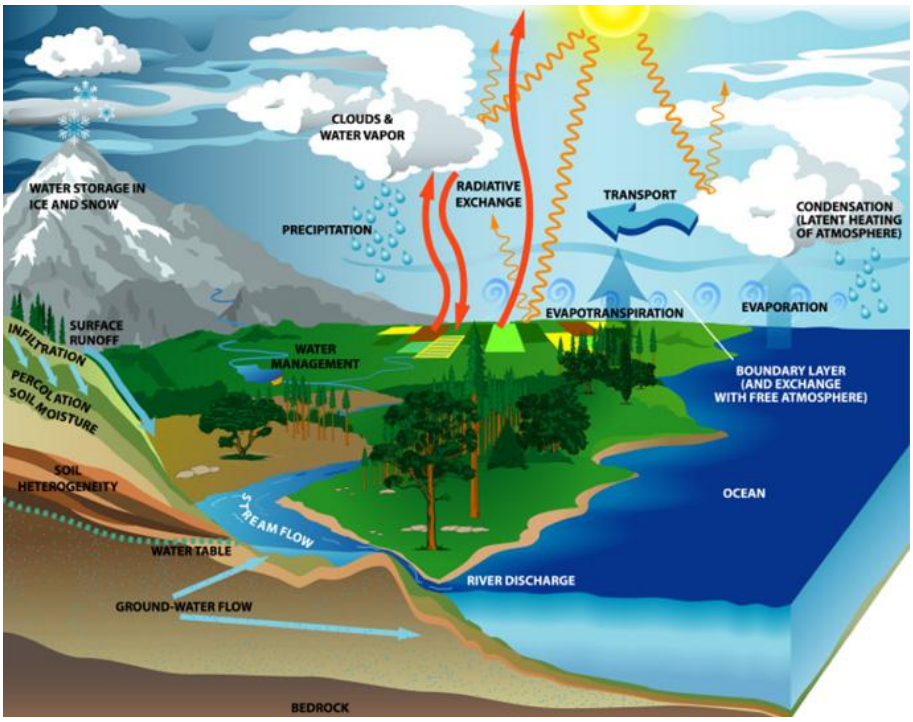

Figure 7: Schematisation of the global water cycle.

Currently, a huge number of hydrological models are available to analyse soil-water relationships at the field and catchment/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 of SWAT 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 at this scale. Besides, the model is primarily focused on the interaction between land management versus water-and erosion processes. This makes the tool appropriate for this study, as it is able to represent and simulate the impact of land management practices on basin-scale water and sediment yields.

In brief, strong aspects of the SWAT model that make it suitable for the current project can be summarised 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's extensive experiences in application as well as training.
- Modelling 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-catchments. The soil map and land cover map within sub-catchment boundaries are used to generate unique combinations, and each combination will be considered as a homogeneous physical entity, namely a Hydrological Response Unit (HRU). The water balance for HRUs is computed on a daily time basis. Hence, SWAT disaggregates the river basin into units that have similar characteristics in terms of soil, land cover, and that are located in the same sub-catchment.

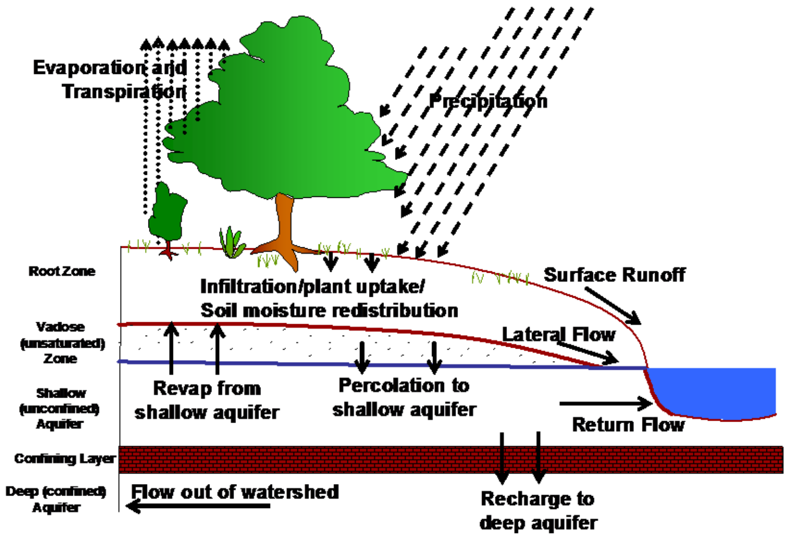

Figure 8: Main processes as implemented in the SWAT model.

Irrigation under 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, a reservoir, a shallow aquifer, a deep aquifer, or a source outside the basin.

SWAT can deal with standard groundwater processes (Figure 8). 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 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 has infiltrated into the soil, it can 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 9). 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.

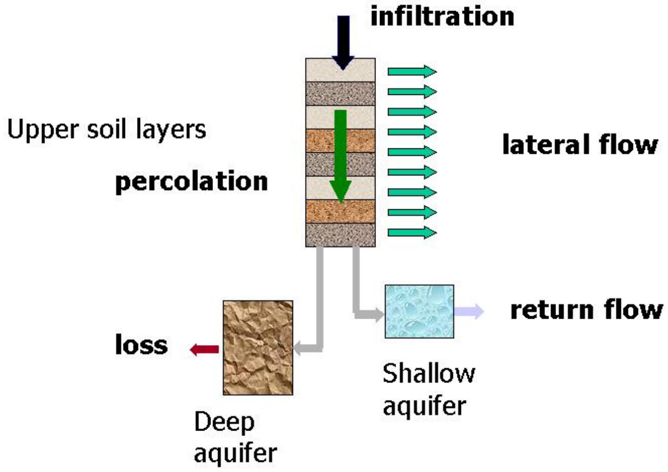

Figure 9: Schematisation of the SWAT sub-surface water fluxes.

For each simulation day, potential plant growth, i.e. plant growth under ideal growing conditions is calculated. Ideal growing conditions require 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, under SWAT, is 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 10).

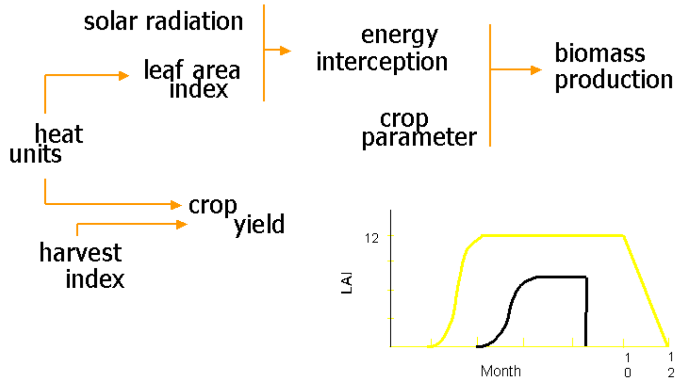

Figure 10: Parameterisation of crop production in SWAT

2.3 Data needs

An overview of the data required to perform the biophysical assessment is provided in Figure 11. The datasets were requested and obtained from the Moroccan counterparts and evaluated, as described in the following sections. In addition, the remainder of the data necessary for the schematisation of the model was obtained from global public domain datasets.

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

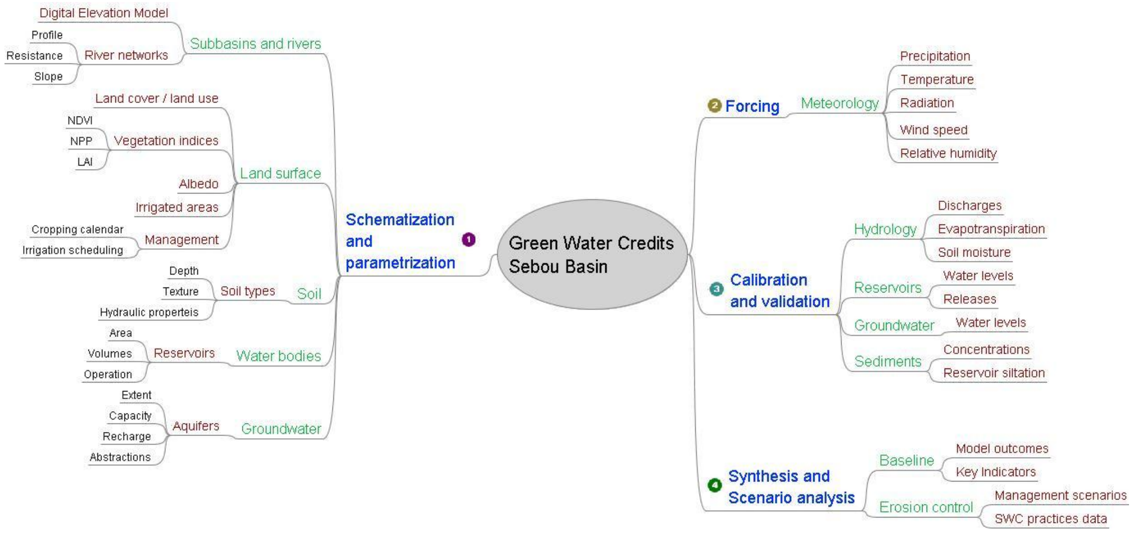

Figure 11: Diagram of required data and modelling components for the GWC Bio-physical Assessment for the Sebou basin.

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 must be analysed with the appropriate tool. As was mentioned before, the SWAT model is used in this study to analyse 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 were used to build-up the distributed hydrological model 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 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 latitude 60 degrees North and 56 degrees South. 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 (Lemoine *et al.* 1998). The SRTM-DEM data were 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 Arc Macro Language 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 12 for the Sebou river basin in Morocco. Based on this DEM, we note that the elevations in the basin range between 0 and 2921 m.a.s.l. Large elevation differences are found in the south-eastern and north-eastern part of the basin, which belong to the Atlas mountain range.

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

[3] http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Lambert_Conformal_Conic

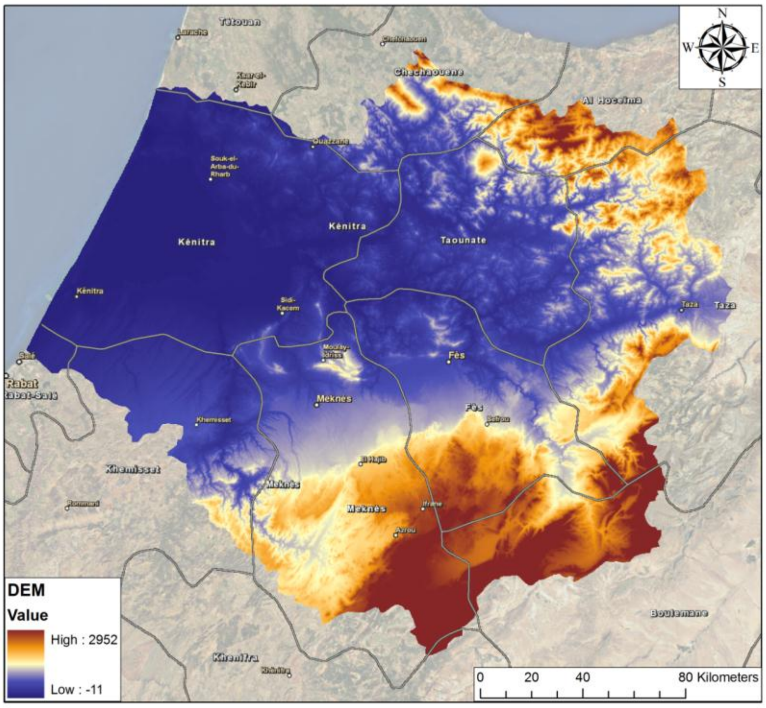

Figure 12: Digital Elevation Model (DEM) of the Sebou river basin at a spatial resolution of 250 m.

3.2 Climate

3.2.1 Data needs

SWAT requires daily rainfall data, as well as other meteorological input data that depend on the evapotranspiration method used. Several methods are available to calculate the potential evapotranspiration. The most advanced method available, the Penman-Monteith method (Monteith *et al.* 1965), 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, because the variables solar radiation, wind speed, and relative humidity were not available at a high spatial resolution.

Various sources for precipitation and temperature 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-Concept phase of Green Water Credits, local data were obtained from 32 meteorological stations in the basin (Figure 13). These data were provided by the Agence Du Bassin Hydraulique Du Sebou ABHS. More stations were available, but these did not cover a sufficient period of time. In addition to this, these stations also contained many missing records. The 32 stations selected provide a continuous time-series of daily precipitation for the period 1998-2007. As can be noticed from Figure 13, the network of stations is quite dense and also providing daily precipitation data in the mountainous regions. These stations cannot be used for temperature data because they only provide a daily average temperature. For SWAT a daily maximum and minimum temperature is necessary to calculate evapotranspiration.

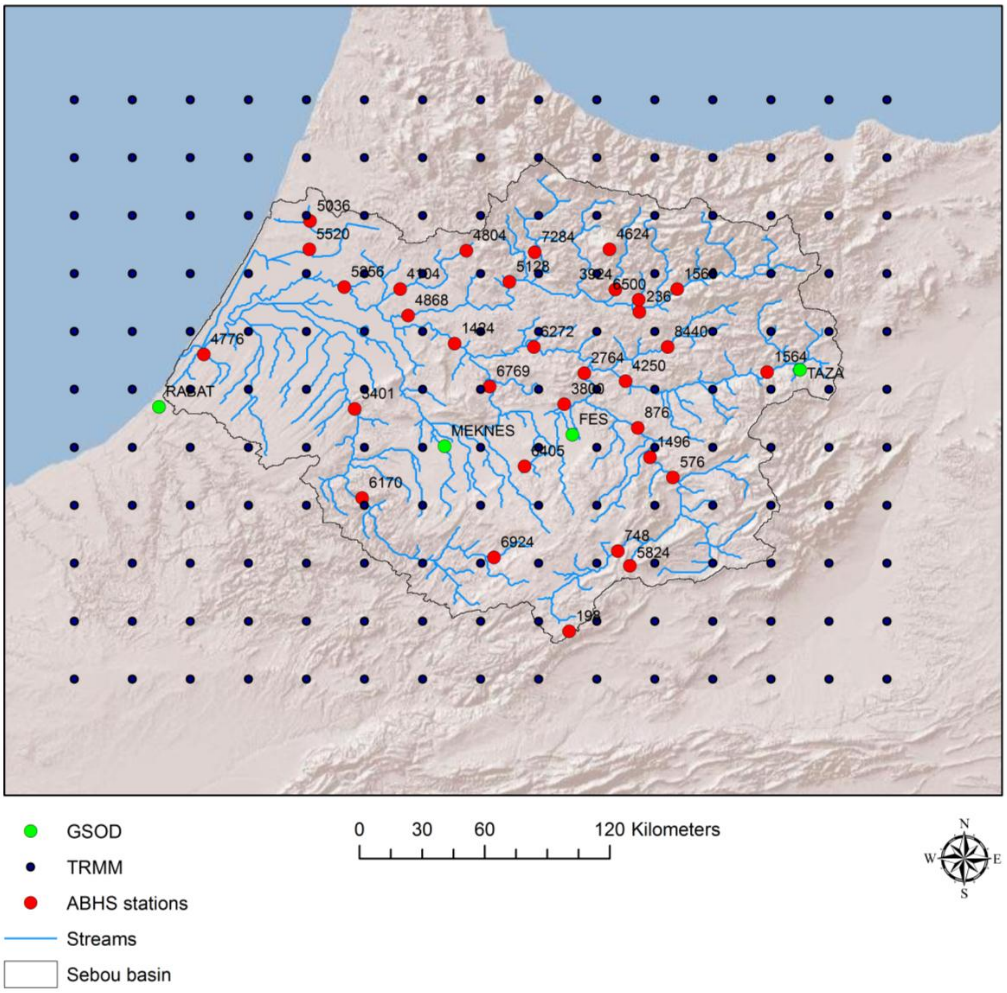

Figure 13: Locations of the GSOD stations, TRMM grid-cells, and ABHS stations.

3.2.2.2 TRMM

A world-wide used source of precipitation data is the Tropical Rainfall Measuring Mission[4] (TRMM). TRMM is a satellite with active precipitation radar on-board and has the following characteristics:

- Data is available at a high spatial resolution of 0.25 degrees (approx. 25 km)
- Data is available from 1998 onwards

It is known that in the first years after launching TRMM, the precipitation data was less accurate. For this reason we have selected the period from 2001 onwards. For the current study, daily TRMM precipitation data has been downloaded for the period 2001-2010. The locations of the TRMM grid points are shown in Figure 13.

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

3.2.2.3 GSOD

Meteorological data from weather stations all over the world can be found at the public domain Global Summary of the Day (GSOD[5]) database archived by the National Climatic Data Center (NCDC[6]). 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 in which errors have been eliminated. For the current study, four active stations located within the Sebou river basin were extracted from the GSOD database for the period 2001-2010. The characteristics of these four stations are described in Table 2. The locations of these meteorological stations are presented in Figure 13. A shortcoming of these four stations is that their location is more or less in the same climatic zone, while no weather stations could be found in the higher mountain areas.

Table 2: Characteristics of the GSOD meteorological stations.

Station name	Elevation(m.a.s.l)	Data
Fes	579	01/01/2001 to 31/12/2010
Taza	510	01/01/2001 to 31/12/2010*
Rabat	79	01/01/2001 to 31/12/2010
Meknes	560	01/01/2001 to 31/12/2010

* Empty records of Taza are filled with records from Fes.

3.2.2.4 Data availability

As described in the foregoing paragraphs, three sources of data are available for this study. The characteristics of these data sources are described in Table 3. As can be seen from this table, only the GSOD data provides maximum and minimum temperature on a daily basis. All three data sources as described in Table 3 provide precipitation data on a daily basis. The TRMM satellite precipitation data provides the highest spatial resolution, and this is desirable for hydrological modelling. Because the GSOD dataset is quality-checked precipitation data, it is likely that this is the most accurate source. However, it is only based on four stations, and therefore it cannot be used for hydrological modelling. It can, however, be used for quality evaluation of the TRMM precipitation data. The ABHS precipitation data can also be considered as coming from a reliable source, because it is locally obtained within a relatively dense network. For hydrological modelling high resolution precipitation data is preferred. Therefore we have corrected the TRMM precipitation data, using the daily ABHS station data. The method of correcting the TRMM precipitation data is described in Section 3.2.3.

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

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

Table 3: Characteristics of the different meteorological data sources.

Name	Type	Format	Temporal resolution	Nr. stations* /spatial resolution	Availability	Variables
ABHS	Observed	Station	Daily	32	1998-2007	P, T*
GSOD	Observed	Station	Daily	4	1980-present	P, T_{max},T_{min}
TRMM	Satellite precipitation	Grid	Daily	0.25°	1998-present	P

* Only the monthly maximum and minimum temperature was available. For a couple of stations daily average temperature was available.

3.2.3 Correction of TRMM satellite data

The 32 ABHS stations provide a continuous time-series of daily precipitation for 1998-2007. TRMM satellite data was selected for the period 2001-2007, because the first years of TRMM (1998-2000) are less accurate. This results in the overlapping period 2001-2007 which can be used to adjust TRMM. For the TRMM grid-cells and the ABHS stations, the average monthly precipitation sums were first calculated based on the period 2001-2007. This results in 12 files, both for the TRMM grid cells (point B, Figure 14) and for each of the stations. Secondly, for each month the 32 stations were interpolated to the same spatial resolution as TRMM, using Ordinary Kriging (Burrough 1986). This results in 12 interpolated grids (one for each month) (point A, Figure 14), having the same resolution as TRMM. Thirdly, a correction factor (C) was calculated for each month by dividing the interpolated station precipitation (A) by the TRMM precipitation grid (B). Finally, the daily TRMM precipitation data for the period 2001-2010 was multiplied by the correction factor grid (C) for that specific month to calculate the corrected precipitation grid for that day. All these steps are shown in Figure 14. The calculation of the monthly correction factor C, for August, is illustrated in Figure 15.

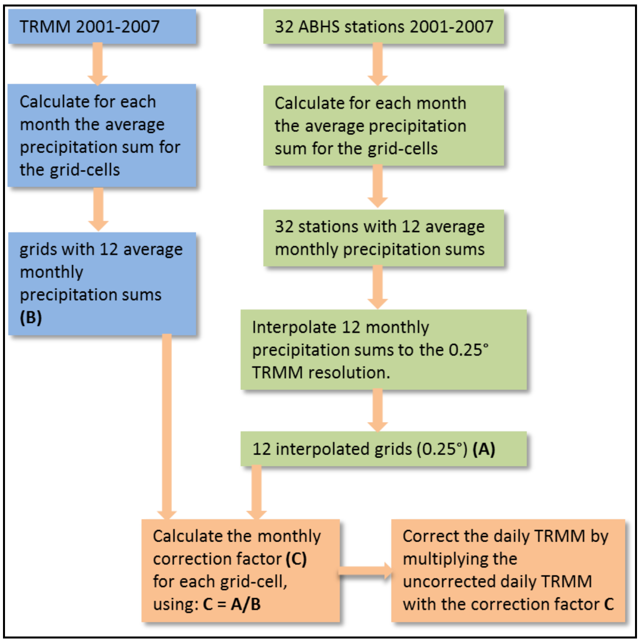

Figure 14: Steps for correcting TRMM precipitation data.

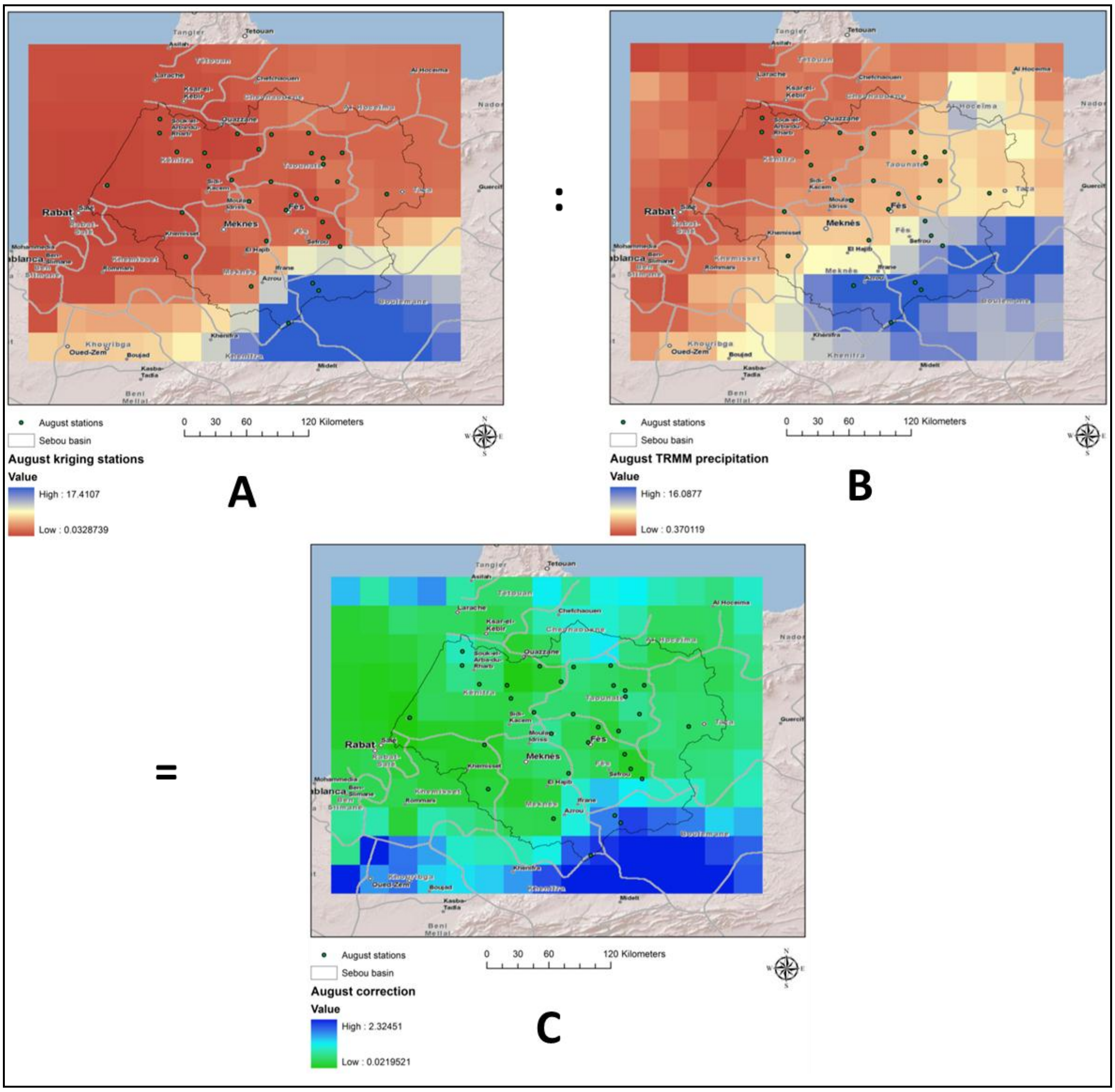

Figure 15: Illustration of calculating the correction factor C for August. A represents the interpolated station grid for August. B represents the TRMM precipitation grid for August, and C represents the correction grid for August.

3.2.4 Climate data evaluation

3.2.4.1 Other studies

The Sebou basin is generally classified as having a Mediterranean climate; however, it naturally varies between seasons and regions. While the coastal areas are still influenced by the south-west 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 Riff changes dramatically with snow cover most of the year. The winter period, between October and April, is known to be the rainfall season, while the remaining months are mainly dry. The main agro-climatic zones of the Sebou river basin are shown in Figure 16.

Droogers and Immerzeel (2008) analysed precipitation and temperature data of the WMO[7] 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. An interesting result from the WMO dataset is that the year-to-year variation in precipitation can be substantial, and ranges from 300 to about 600 mm (Figure 17).

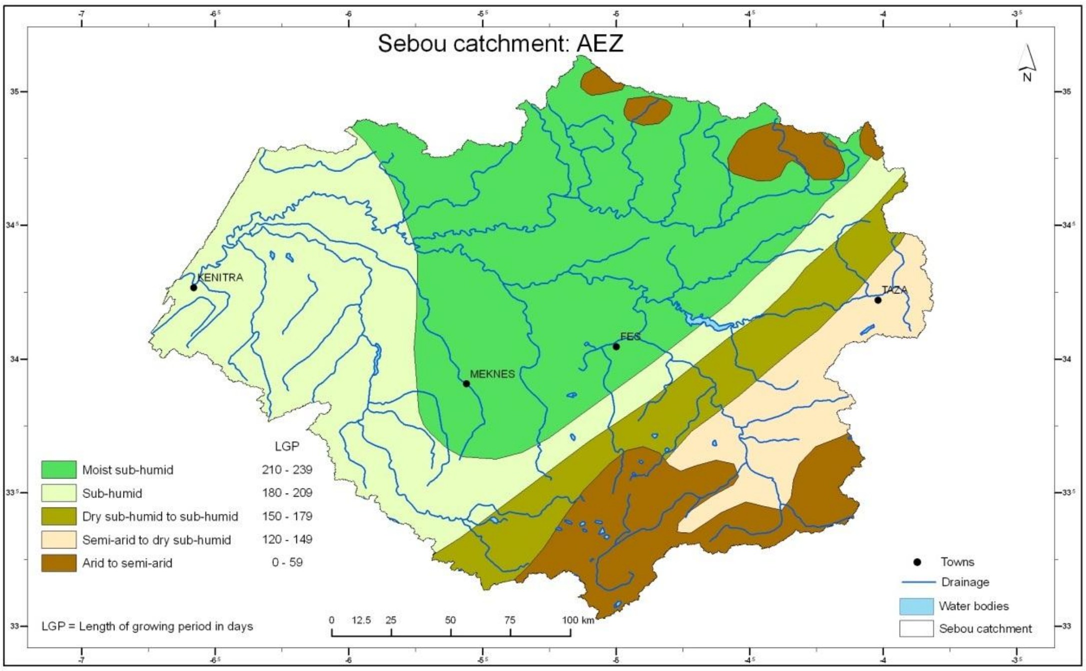

Figure 16: Main agro-climatic zones based on the balance between precipitation and evapotranspiration. The Sebou encompasses five main climatic zones ranging from moist sub-humid to arid (Fischer *et al.* 2002).

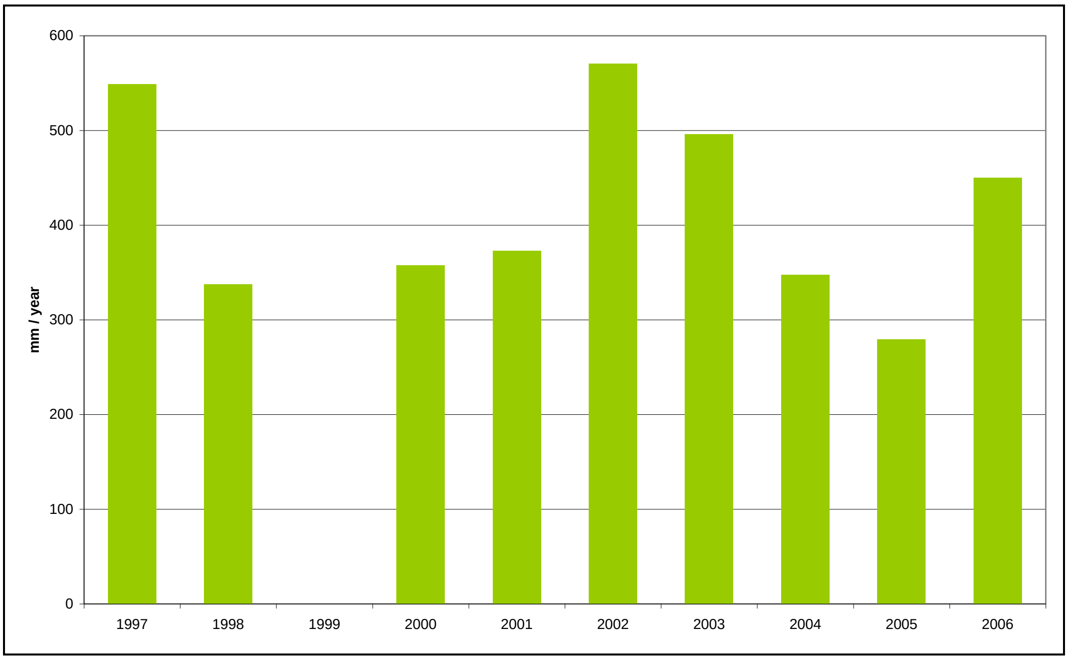

Figure 17: Annual precipitation (WMO), Meknes station for 1997-2006.

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

3.2.4.2 Evaluation of corrected TRMM precipitation

Daily TRMM precipitation was corrected as described in Section 3.2.3. To evaluate the performance of the correction method, monthly precipitation sums of GSOD, uncorrected TRMM, and corrected TRMM were compared for four locations: Fes, Meknes, Rabat, and Taza. Each of these four locations has a GSOD station, as well as a corresponding TRMM grid-cell which was used for the evaluation. The monthly precipitation sums of these locations are shown in Figure 18 for the period 2001-2007. As can be seen from this figure, corrections are largest during winter months. The overall conclusion is that TRMM was too dry, and therefore it was corrected to become wetter for most months. Corrections were especially large for Taza, where the uncorrected TRMM was far too dry during winter months.

The corrected annual precipitation sums for these four locations are shown in Figure 20. It is clear that the year-to-year variation can be large. 2005 is known to have been a very dry year. The years 2009-2010 were extremely wet. This period had many floods and all the dams in the reservoir experienced spill during these years (ABHS 2010). According to the ABHS (2010), rainfall in this extremely wet period reached 2739 mm in the Rif and between 700 and 900 mm in the other areas and sub-catchments.

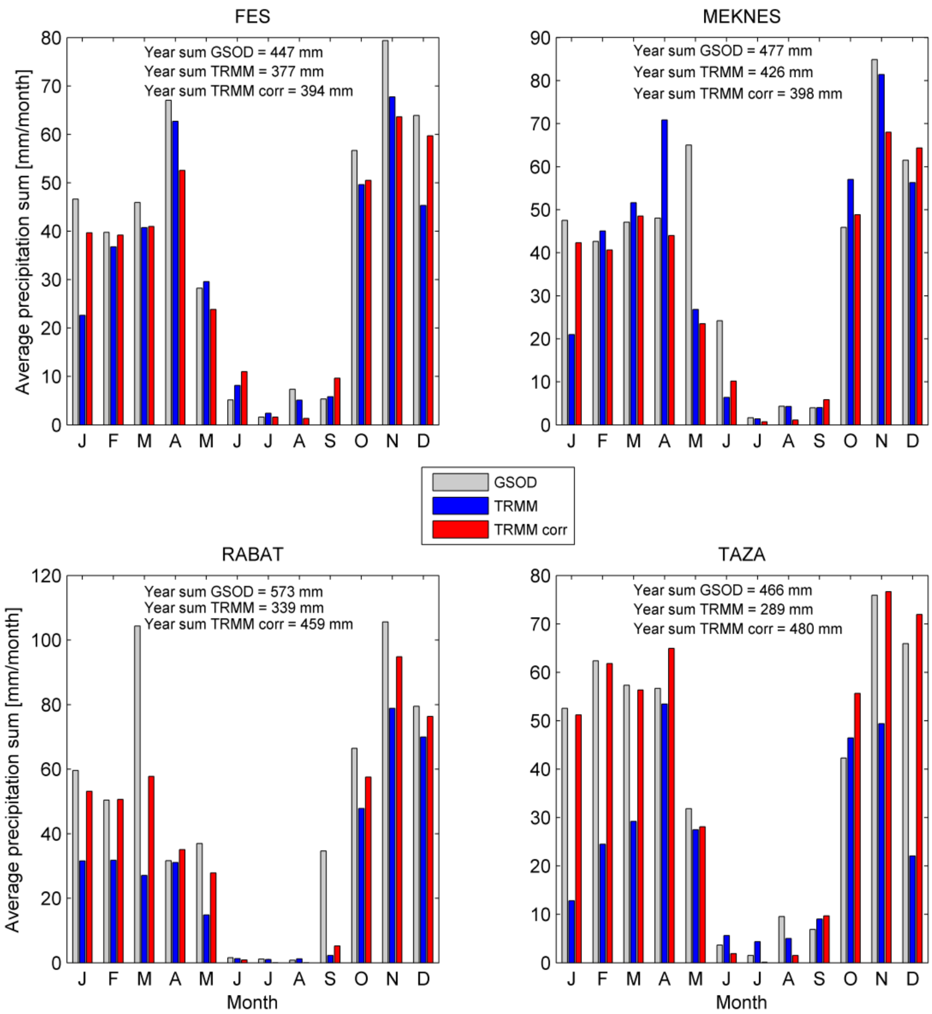

Figure 18: Average monthly precipitation sums of GSOD, TRMM, and corrected TRMM for the period 2001-2007.

Figure 19: Flood in the Sebou basin during 2009-2010 (ABHS, 2010).

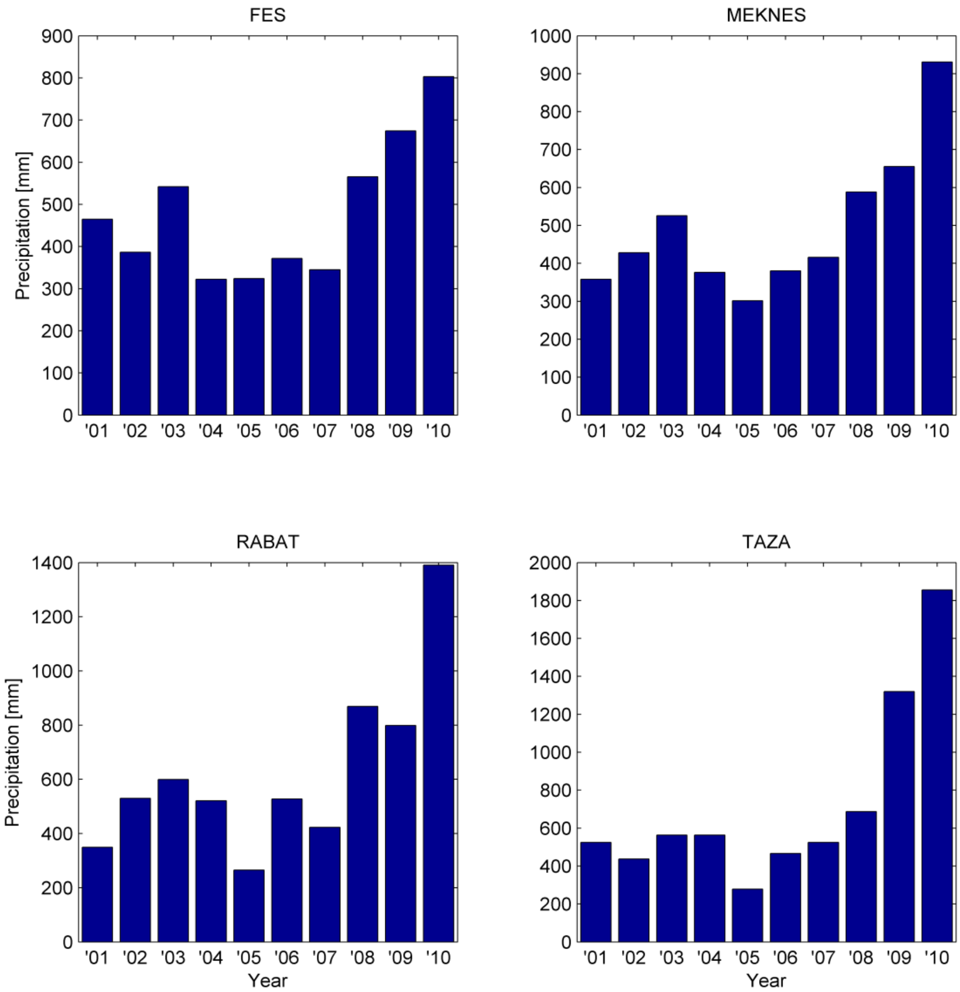

Figure 20: Annual precipitation for Fes, Meknes, Rabat, and Taza for 2001-2010.

3.3 Land use

3.3.1 GlobCover dataset

GlobCover[8] 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 observations from the 300 m MERIS sensor on board of the ENVISAT satellite mission as input. The GlobCover service was 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 were produced.

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

The use of medium resolution data provides a considerable improvement in comparison with other global land cover products, which have a lower spatial resolution, e.g. the GLC2000 dataset. The quality of the GlobCover product, however, is closely dependent on the reference land cover database, which is used for the labelling process, and on the number of valid observations available as input. When the reference dataset is of high 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 21. The GIS section of the ABHS provided irrigation extents 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.

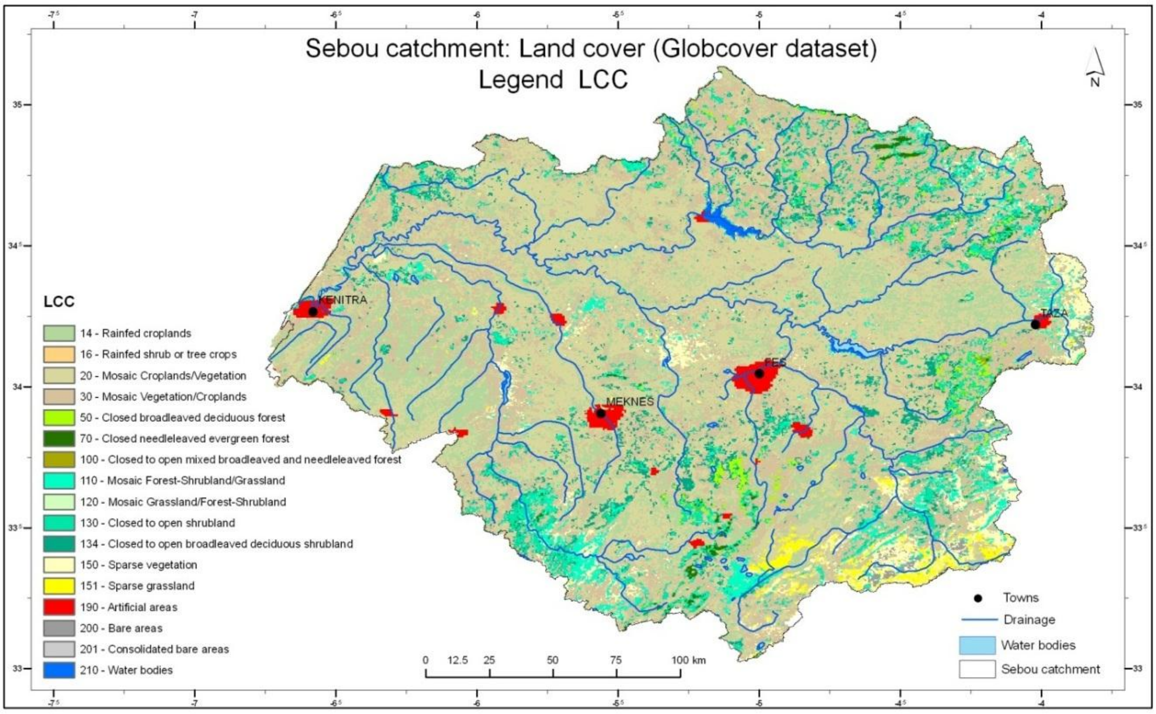

Figure 21: The GlobCover land use classification for the Sebou river basin.

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

3.3.2 *Forest Cover dataset*

The Ministry of Forestry of Morocco possesses a map of Forest Types[9] in Morocco, which was extracted for the Sebou river basin. This map is shown in Figure 22.

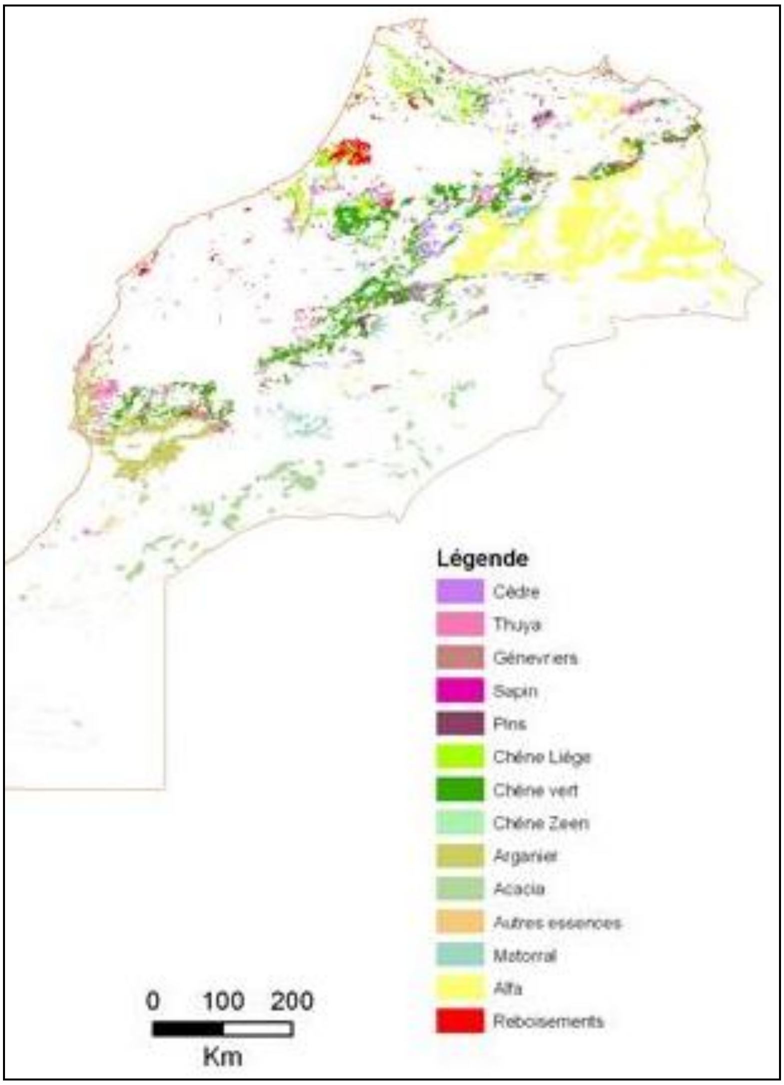

Figure 22: Forest types in Morocco (source: Ministry of Forestry of Morocco).

3.3.3 *SPAM*

SPAM (You *et al.* 2009) delivers disaggregated agriculture statistics based on a cross entropy approach utilising 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 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 23.

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

3.3.4 Processing of land use data

The development of land use data was done in an automated way using a script in the “Python programming language”, in which the following steps were performed:

- All datasets were re-projected into the Lambert Conformal Conic projection;
- The datasets were converted into 250 m grids, using nearest neighbour 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 was assumed that the forest dataset represents the local conditions more accurately. Therefore any 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 23).

Due to administrative regions in the downscaling methodology, based on the SPAM dataset in which the dominant crop types were extracted, sharp boundaries exists. To accommodate for a more realistic image of crop distribution in the Sebou basin, the boundaries were adjusted based on topography, which led to (at least visually) a more realistic crop distribution pattern. This additional step resulted in the final SWAT land use map as is shown in Figure 24. The corresponding total areas for each land use class are represented in Table 4. For future elaboration, more research and a more detailed input are needed, which then can delineate crop patterns in a more precise manner for the second and third phase.

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

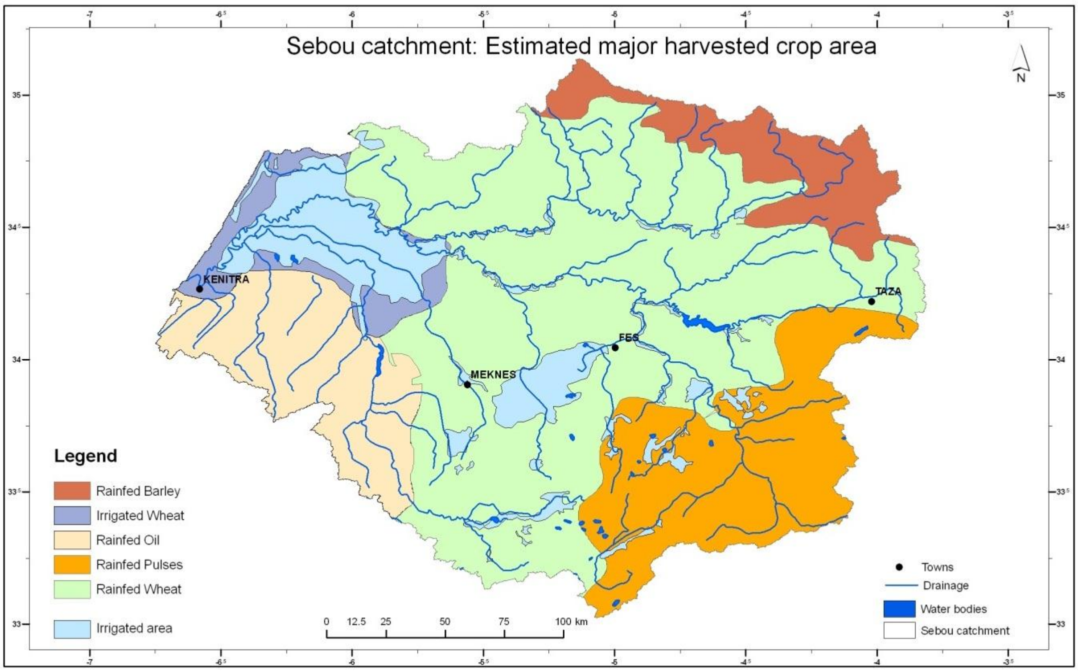

Figure 23: Estimated major crop regions in the Sebou river basin with the boundaries adjusted to topographic differences based on the global SPAM dataset.

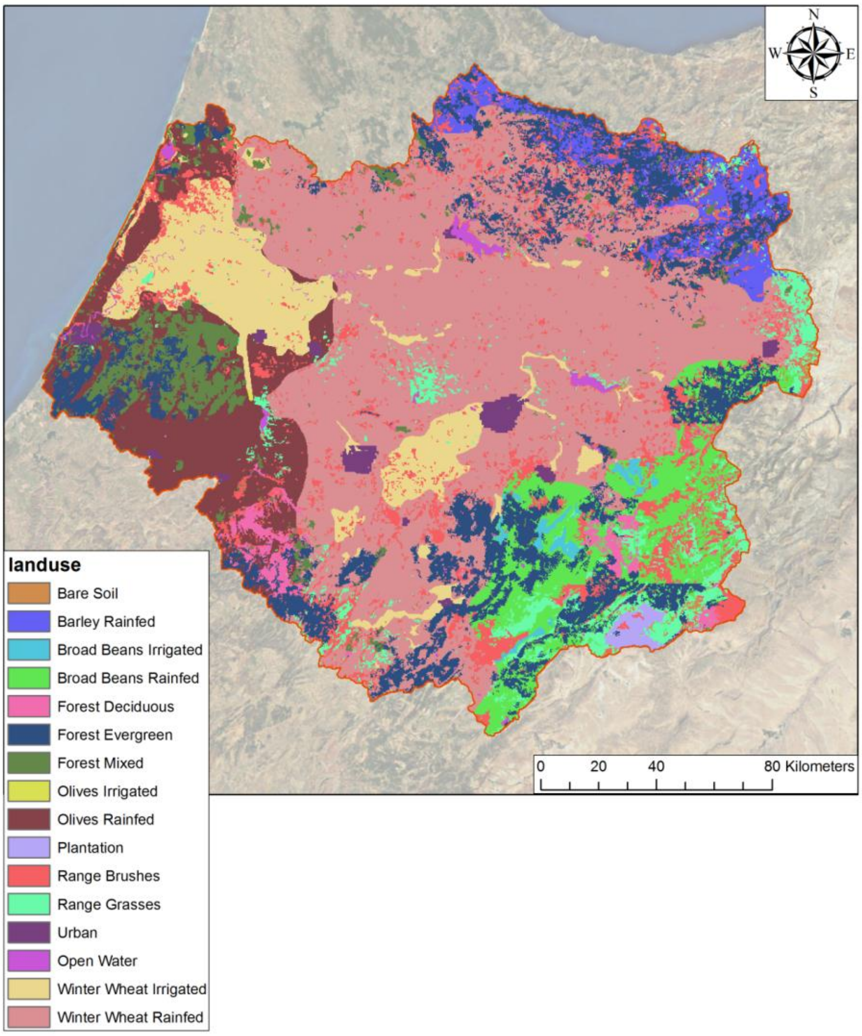

Figure 24: Land use map as used in the SWAT model.

Table 4: Total area of each land use class

Land use class	Area (km^2)	% of total area
Bare soil	117	0.3%
Barley rainfed	1249	3.2%
Broad beans irrigated	234	0.6%
Broad beans rainfed	2497	6.4%
Forest deciduous	624	1.6%
Forest evergreen	5034	12.9%
Forest mixed	1561	4.0%
Olives irrigated	8	0.02%
Olives rainfed	3473	8.9%
Plantation	195	0.5%
Range brushes	3629	9.3%
Range grasses	1522	3.9%
Urban	468	1.2%
Open water	234	0.6%
Winter wheat irrigated	3317	8.5%
Winter wheat rainfed	14,906	38.2%
Total	39,068	100%

3.4 Soils

3.4.1 Data sources

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[10] (HWSD) is available for the whole world. Its aim is to provide improved soil information worldwide, particularly in the context of the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol for soil carbon measurements, and for the FAO/IIASA Global Agro-Ecological Assessment study (Fischer *et al.* 2008). While this database is rather quite coarse, it contains most of the parameters that are required in the SWAT model.

For Morocco, we are aware of three different products which would be suitable:

1. A soil map at the scale 1:2 million, covering almost the entire area in digital format and containing soil names;
2. Two map sheets at the scale 1:500,000 (source: INRA[11]). These maps, however, do not cover the Sebou area completely. These maps are only available in analogue format, with only soil names for the attributes;
3. Pending results from the e-SOTER project[12]. While these map sheets/datasets contain significantly more spatial detail with respect to the HWSD, the only attribute information currently available is the soil name.

The dominant soils in the Sebou river basin are shown in Figure 25.

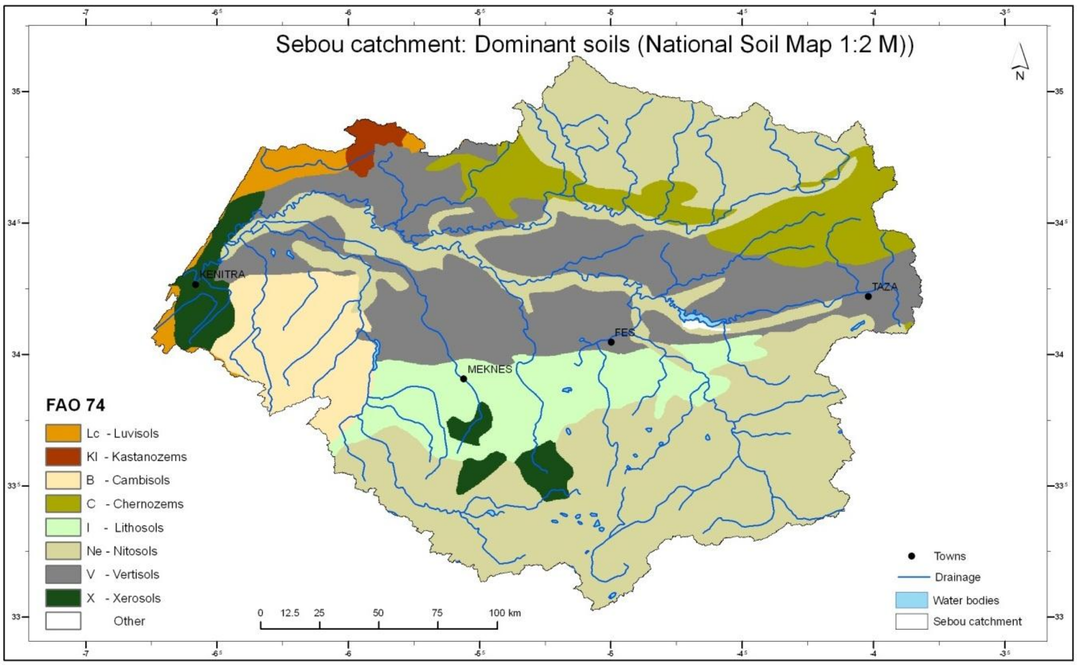

Figure 25: Dominant soils (scale 1:2 million) in the Sebou river basin, Morocco.

Soil resources for the Sebou basin are available at various scales and resolutions, however we had significant problems with INRA in obtaining digital data sources (see Figure 26).

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

[11] http://www.inra.org.ma/accueil1.asp?codelangue=23&po=2

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

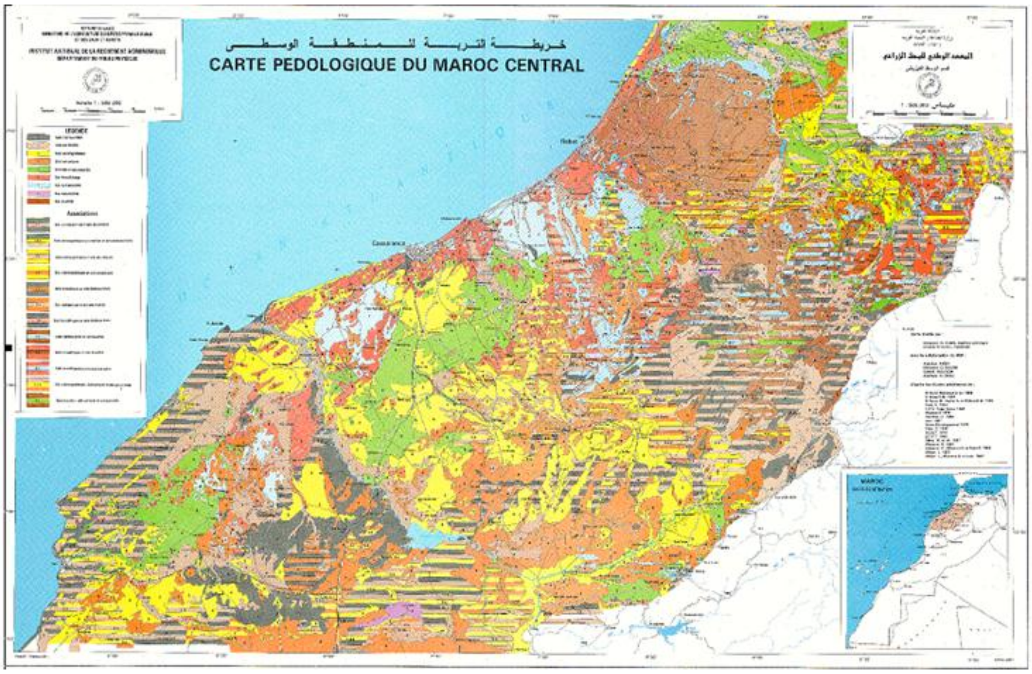


Figure 26: Analogue Soil Map at the scale of 1:500,000 for the southern part of the Sebou basin.

Despite these difficulties we were able to obtain:

- A soil map with soil units classifications for the Gharb region;
- A soil map with soil profiles for the northern area (Figure 27) of the Sebou for the *Basins Versant De Lóued Ouergha* as well as *Amont du barrage al Wahda* on a scale of 1:100,000.

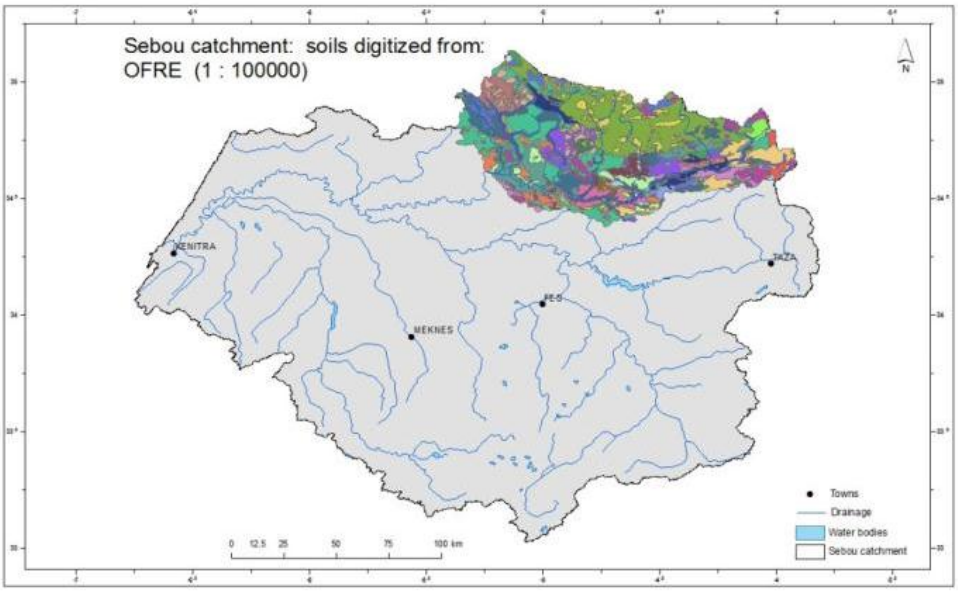


Figure 27: Soil Map for the north-eastern part of the Sebou basin.

3.4.2 *Processing of soil data*

Soil profiles from the 1:100,000 soil map were brought into digital format and were assigned as reference profiles to the soil units found in the 1:100,000 soil map. The properties of the soil units from the Gharb catchment were translated from the French system into the FAO system FAO 1974, based on expert estimates from similar soils as observed in the WISE database. These properties represent a high level of uncertainty, but they are the best guess taking into account missing data from INRA.

To fill the remaining gaps and 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.

All three data sets were converted into raster data, projected into the Lambert conformal conic projection for Morocco with a resolution of 250 m, IDs were adjusted so a running number could be generated for all data sets, mosaicked into one larger raster, and any remaining missing pixels at the border filled with a zonal majority function before an extraction with the basin border was performed.

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 pedo-transfer functions (PTF). A wide range of pedotransfer 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). Sobieraj *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 closest to measured ones is the Jabro equation (Jabro 1992):

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

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:

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

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

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

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

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

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

For future elaboration under 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 approach, two other techniques could be applied. First, the pending results from the e-SOTER project for Morocco could be investigated for suitability to transfer to 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

The final soil map used in SWAT is shown in Figure 28. The highest hydraulic conductivities are found in the central and northern part of the Sebou basin, while the lowest hydraulic conductivities are located in the western part. The most erodible soils are those with the highest USLE_K value. Based on Figure 30, it can be concluded that the soils most sensitive to erosion, are located in the northern, mountainous, part of the basin. The soils in the southern part are also quite erosion sensitive, but less so than in the northern part. Another, but very relevant soil parameter, is Available Water Holding Capacity (AWC) (Figure 31). This parameter defines the percentage of water which can be held in the soil. Considering Figure 31, it is clear that the AWC of the soils in the central and southern part (the largest area of the basin) are very low. An AWC of 0.015% is unlikely – and so low that the soil can hardly hold any water, resulting in severe and rapid water stress and virtually no growth is possible in this situation. This value of AWC is very questionable therefore.

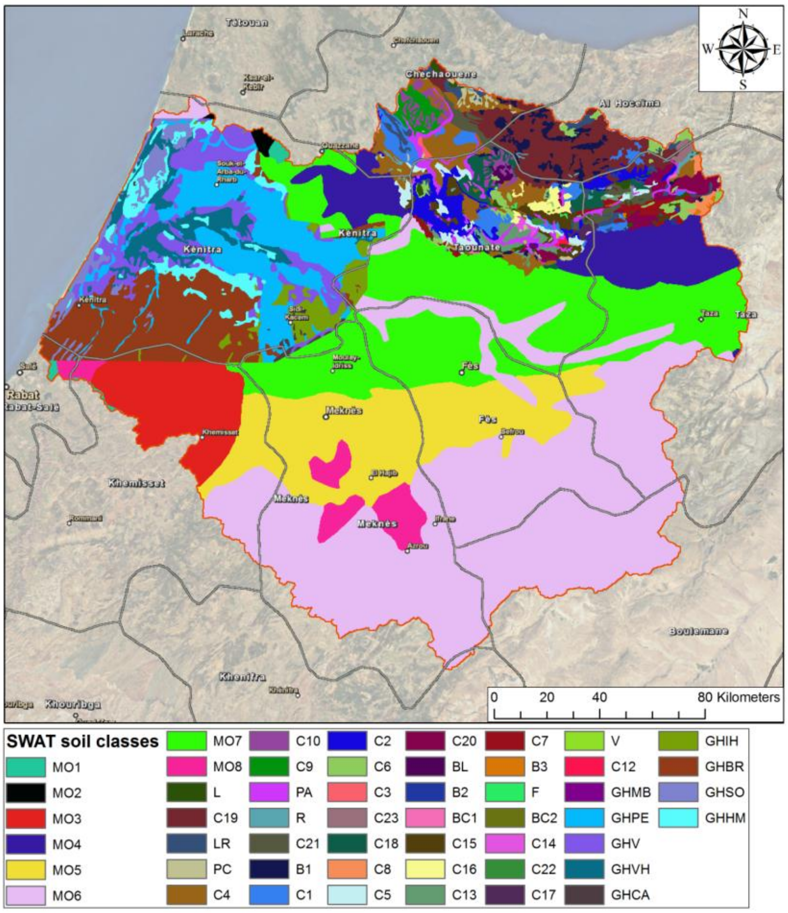


Figure 28: SWAT soil classes.

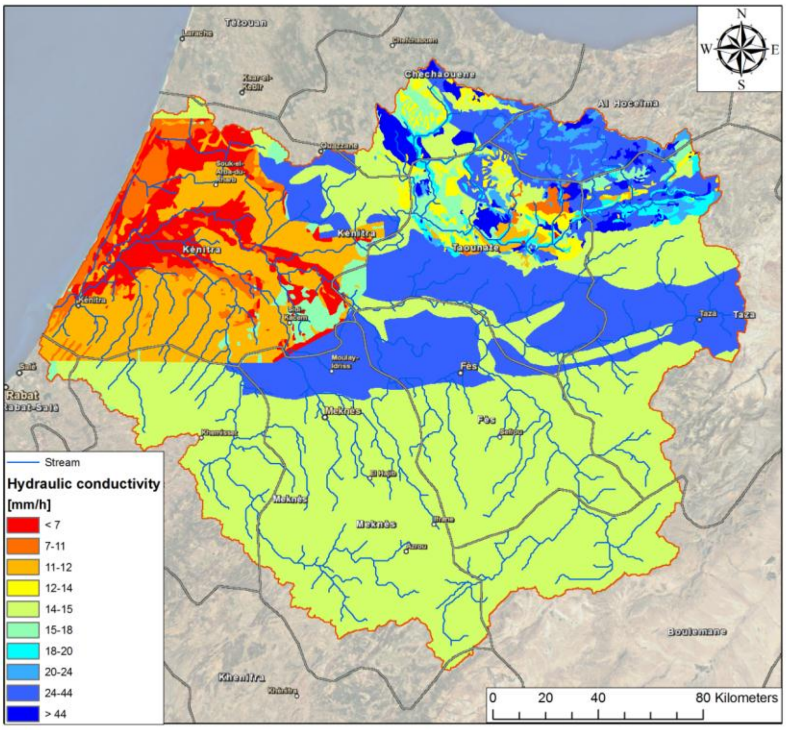


Figure 29: Saturated hydraulic conductivity.

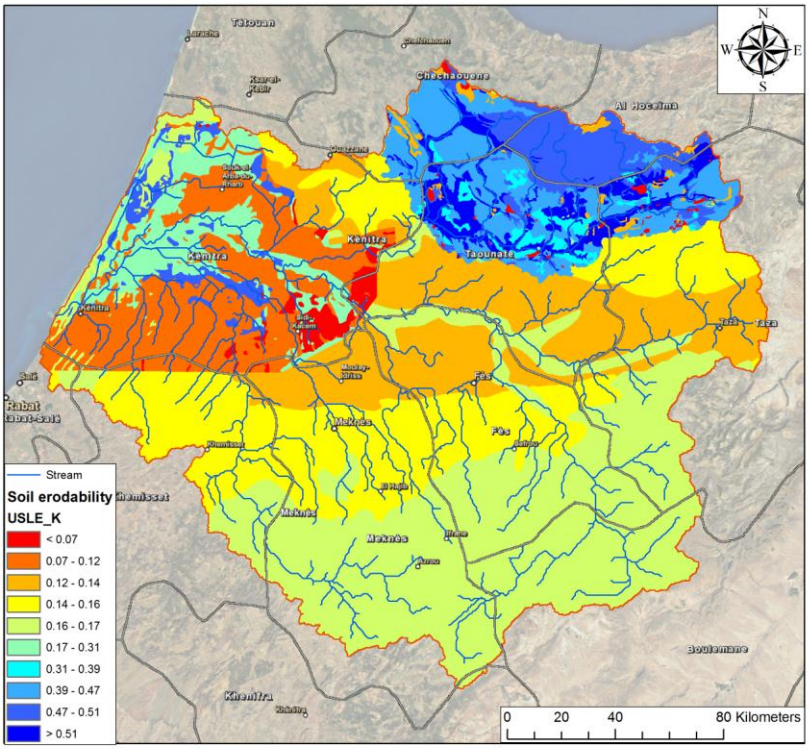


Figure 30: Soil erodibility map (USLE_K).

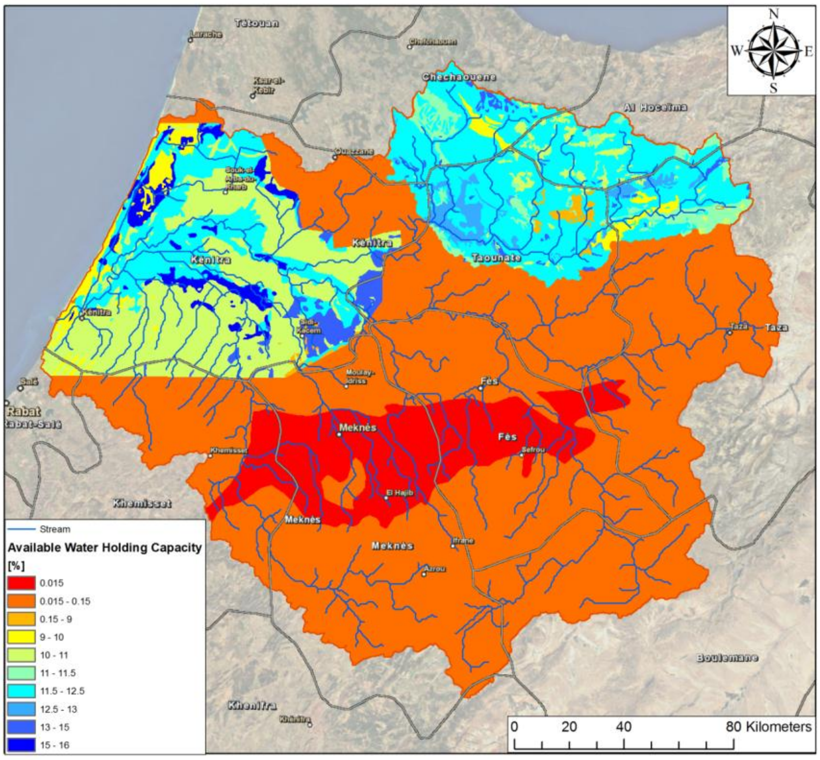


Figure 31: Available Water Holding Capacity (AWC).

3.5 Discharge

Several discharge gauging stations are present in the Sebou river basin: station data was provided by ABHS. These stations provide discharge data on a monthly basis. Table 5 shows the characteristics of the discharge gauging stations present in the Sebou basin. For the calibration we need stations which cover the same period of time as the climate-forcing data (2001-2010). The discharge data, which was made available to us by the ABHS, covered the period up to 2006. These stations (18 in total) are shown in red and blue triangles in Figure 32. The station IDs correspond to the station numbers in Table 5. It is clear that these stations are reasonable well distributed over the basin. For the calibration, as discussed in Section 4.3, we selected the discharge stations marked by the blue triangles (7 stations). These were selected for the following reasons:

1. They are located upstream of the large reservoirs. This means that the management of the reservoirs does not influence the streamflow pattern recorded by these stations. The discharge stations downstream of the large reservoirs are highly sensitive to reservoir outflow;
2. They are located in the upstream areas which comprise the target zone for the *green water* management measures. If these areas are simulated well, then the downstream results will also be are more accurate;
3. The spatial distribution of these stations is good;

Table 5: Characteristics of 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	16,143	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	25,779	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

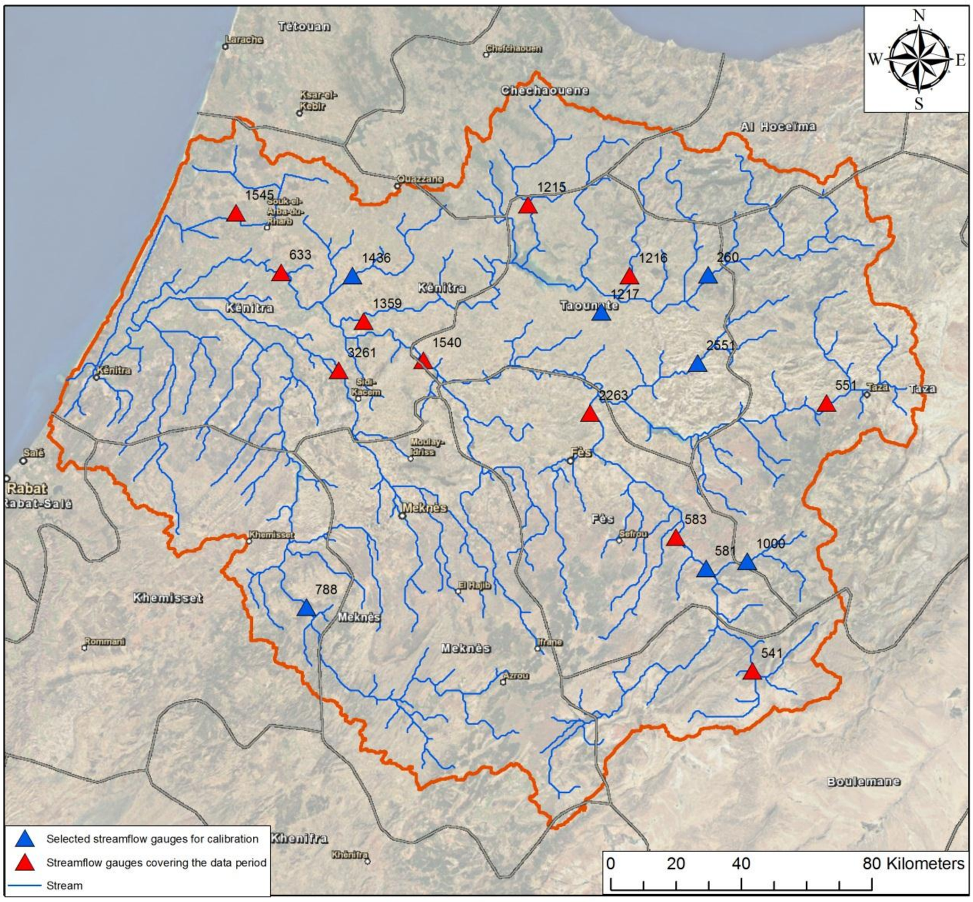


Figure 32: Location of streamflow gauges in the Sebou basin (blue and red triangles). Blue triangles indicate the selected gauges (out of the red triangles) for calibration. Red triangles indicate streamflow gauges covering the period 2001-2006.

3.6 Reservoirs

The Sebou river basin encompasses several large reservoirs as well as various smaller 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 restrain floods but now also stores water. By 1973, there were at least 15 dams with 5 large reservoirs and 10 smaller ones. 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 33), constructed on the Ouerrha river between 1991 and 1996, is the second largest 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 33: Al Wahda dam, Sebou river basin, Morocco.

Snoussi *et al.* (2007) underline the impact of the dam:

"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 US $27 million yr^{-1}."

The impact of the reservoirs on runoff is also indicated with Figure 34: 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, began in the 1960s 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 area and production, control floods and provide power generation. The completed infrastructure now includes 10 large dams, 44 smaller dams (with a total storage capacity of 5872 MCM, for regularisation of a total volume of 2970 MCM), and four hydropower stations. Moreover, thousands of wells have been drilled to supplement the water provided by groundwater sources (Minoia and Brusarosco 2006).

The characteristics of the 10 principal reservoirs in the Sebou basin are shown in Table 6. Besides hydropower generation these reservoirs serve for irrigation and as sources for drinking and industrial water. The locations of these reservoirs within the Sebou river basin are shown in Figure 35. As was shown in Figure 34, the reservoirs have a large influence on the discharge in the streams, and thus it is desirable to know the monthly outflow for each of the reservoirs during the simulation period. Fortunately, the ABHS provided monthly outflow of the 10 largest reservoirs as denoted in Table 6. This will improve the model simulations significantly.

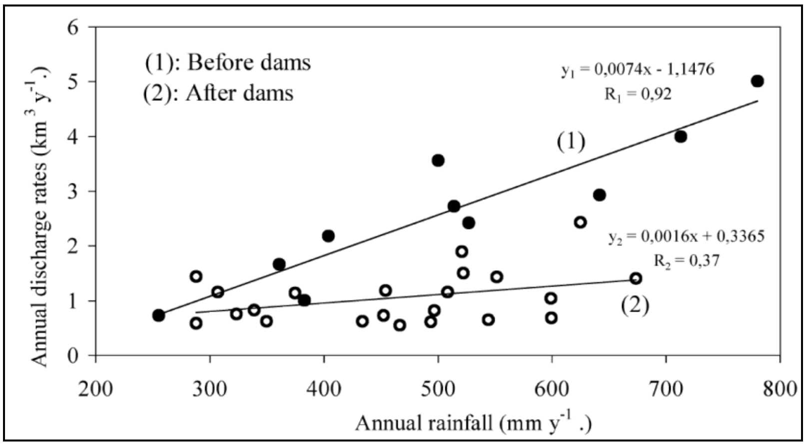


Figure 34: Relationship between the annual water discharge and annual rainfall before (solid circles) and after (open circles) the construction of dams for station Azib Es Soltane (source: Snoussi *et al.* 2002).

Table 6: 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)
Allal El Fassi	1990	AEPI, T, I	5	61	64	26,000	270
Idriss 1er	1973	E, I	68	72	1152	72,000	66
El Kansera	1935	E,I,AEPI	18	68	230	29,050	30
Sidi Chahed	1996	AEPI, I	11	51	170		
Sahla	1994	I, AEPI	4	55	62		
Al Wahda	1996	E, I, T	123	88	3714	115,000	400
Barrage de Garde	1991	I, BS	0.07	18	37		
Bouhouda	1998	AEPI , I	3	55	55.5		
Asfalou	1999	AEP, I	9	112	317		
Bab Louta	1999	AEP	-	54	35		

* T: Hydropower, I: Irrigation, AEPI: Drinking water and industry, E: flood control, BS: Preventing salination.

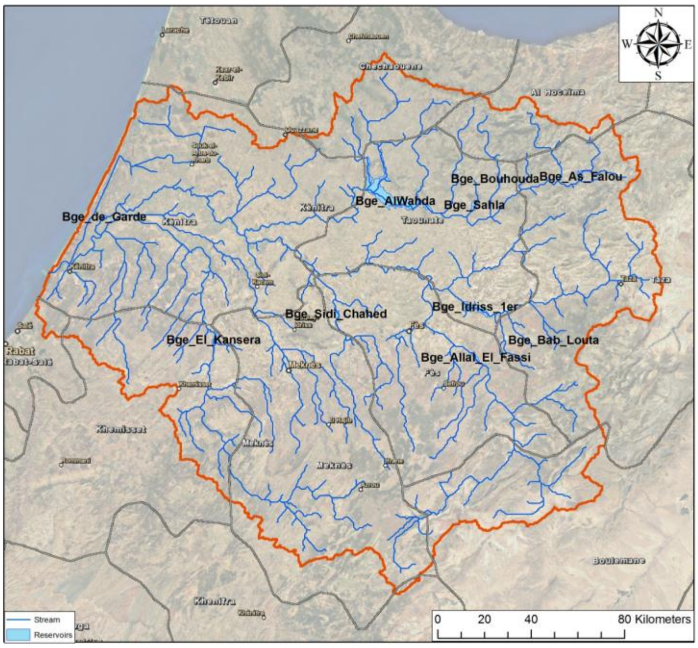


Figure 35: Location of the 10 main reservoirs.

4 Baseline modelling assessment

4.1 Introduction

This chapter describes the set-up of the SWAT model to serve as the quantitative tool for exploring Green Water Credits. The most relevant land use classes regarding GWC have also been explored in a crop-based assessment. These are the crops with potential for the implementation of *green water management* practices. Furthermore, the spatial distribution of the SWAT model output has been analysed at the level of Hydrological Response Units (HRUs).

The SWAT model has been set-up for a period of 10 years (2001-2010). Justification of data used to build the model was provided in the previous section. To summarise:

- DEM: NASA SRTM dataset.
- Climate: for precipitation corrected TRMM data is used. For temperature the GSOD dataset is used (4 stations).
- 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 set-up

4.2.1 Basin delineation

Under SWAT, the basin outlet is defined as the lowest point of the Sebou river, which is located west of Kenitra: thus all upstream tributaries are included in the analysis.

The DEM forms the base to delineate the catchment boundary, stream network and sub-catchments. This is performed by the pre-processing module of SWAT and requires a threshold area. This refers to a critical source 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 found an appropriate threshold of 5000 ha, which provides a good balance between the level of detail and computational constraints. This resulted in a total of 417 sub-catchments. A first trial was performed with a threshold area of 10,000 ha, but this led to a total of 207 sub-catchments, which lacks the desired detail for this study. A threshold of 10,000 ha also results in elongated sub-catchments with large elevation differences (>2000 m) within the sub-catchment. This has negative effects on the simulation of the orographic precipitation regimes. The delineation of the 417 sub-catchments is shown in Figure 36. It can be seen that the sub-catchments are more or less equally sized, and that they are not too stretched. The average sub-catchment area (with the defined threshold of 5000 ha) is 9358 ha.

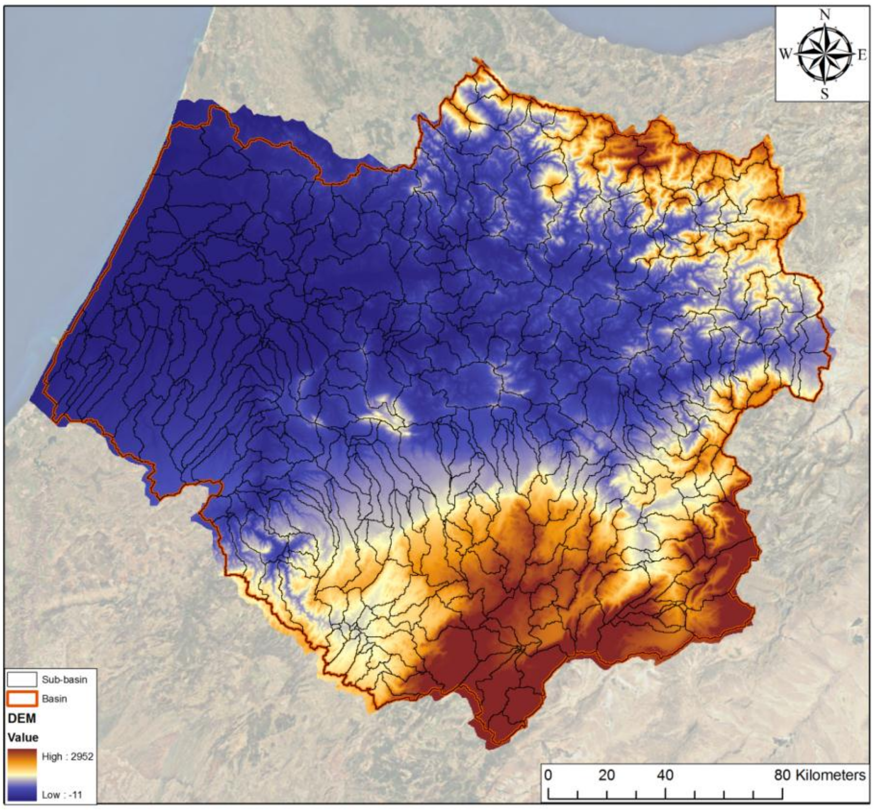


Figure 36: Locations of the 417 delineated sub-catchments along with the derived streams. The threshold for delineation was set at 5000 ha.

4.2.2 Hydrological Response Units

For the spatial disaggregation of the sub-catchments, SWAT uses the concept of Hydrological Response Units (HRUs) (Neitsch *et al.* 2000): these are portions of a sub-catchment that possess unique land use, management, and soil attributes. In other words, an HRU is the total area within a sub-catchment 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-catchment. Loadings (runoff with sediment, nutrients, etc. transported by the runoff) from each HRU are calculated separately and then summed to determine the total loadings from the sub-catchment. If the interaction of one land use area with another is significant, rather than defining those land use areas as HRUs they should be defined as sub-catchments. It is only at the sub-catchment level that spatial relationships can be defined. The benefit of HRUs is the increase in accuracy this adds to the prediction of loadings from the sub-catchment. The growth and development of plants can differ greatly substantially among species. If the diversity in plant cover within a sub-catchment is accounted for, then the net amount of runoff entering the main channel from the sub-catchment will be much more accurate.

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

- Sub-catchments;
- Land use;

- Soils;

Based on these three data layers 4349 HRUs (Figure 37) were determined for the Sebou river basin.

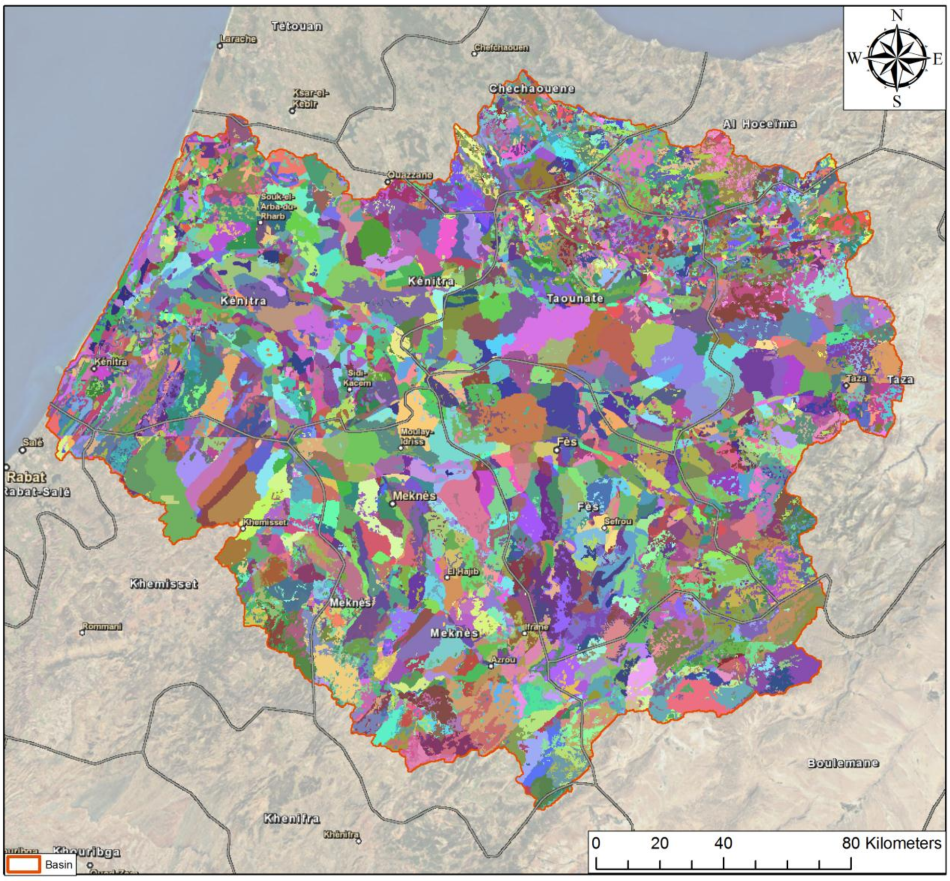


Figure 37: The defined hydrological response units (HRUs).

4.3 Calibration and model performance

As mentioned before, seven discharge gauging stations were selected (Figure 32) for the calibration of the SWAT model. These stations have an overlapping period, namely 2001-2006 with the climate-forcing data. The calibration will be evaluated over the period 2002-2006, while 2001 will be used to initialise the model. For the Proof-of-Concepts, the key focus is to assess the impact of the *green water* management practices on the water and sediment fluxes in the basin, quantifying the differences between the studied scenarios and the current management situation (i.e. baseline scenario). In this sense, it is crucial to note that conclusions drawn from scenario analysis are much more reliable than absolute model predictions (relative vs. absolute model accuracy, e.g. Droogers *et al.* (2008)).

To determine the calibration parameters, a sensitivity analysis was first carried out using the parameters shown in Table 7. These five parameters were altered within realistic ranges (Neitsch *et al.* 2005), showing that the model was most sensitive to ALPHA_BF, GW_DELAY, SOL_AWC, and SOL_K.

ALPHA_BF is the baseflow recession coefficient, and is a direct groundwater flow response to changes in recharge. Values range from 0.1-0.3 for land with slow responses to 0.9-1.0 for land with fast responses. The GW_DELAY parameter determines the time lag between the moment the water leaves the soil storage and the moment it becomes available in the aquifer storage. It is difficult to infer this parameter from measurable soil and hydro-geological characteristics, especially at the basin-scale. The SOL_AWC and SOL_K parameters are also known to be very heterogeneous. In Section 3.4.3 it was mentioned that the SOL_AWC parameter is extremely low for a very large part of the basin. With the calibration this parameter will be adjusted to a more realistic value.

Table 7: Parameters used for sensitivity analysis.

Parameter	Unit	Variable
ALPHA_BF	Days	Baseflow alpha factor
GW_REVAP	-	Groundwater “revap” coefficient
SOL_AWC	mm water/mm soil	Available water holding capacity of the soil layer
GW_DELAY	Days	Groundwater delay time
SOL_K	mm/hr	Saturated hydraulic conductivity

The calibration was performed for the upstream sub-catchments (Figure 38) of each of the selected streamflow gauges. The calibration was performed on a monthly basis, because observations were only available on a monthly time-scale. The SWAT model was calibrated using three performance coefficients, and visual comparison of the observed and simulated discharges. The performance coefficients which were used are the Nash-Sutcliffe coefficient, the Normalized Root-Mean-Squared-Error (NRMSE), and the bias.

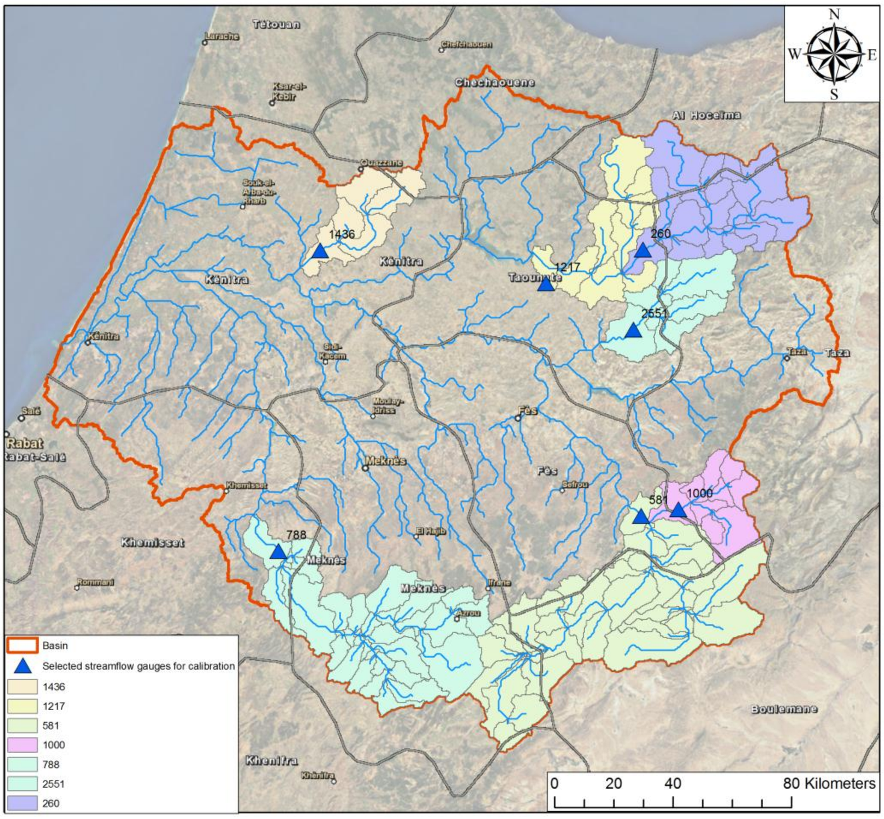


Figure 38: Sub-catchments which were used for calibration of the SWAT model.

The Nash-Sutcliffe coefficient is defined as:

$$E = 1 - \frac{\sum_{t=1}^{T} (Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T} (Q_o^t - \overline{Q_o})^2}$$

where Q_o is observed discharge, and Q_m is modelled discharge. Q_o^t is observed discharge at time t. Nash–Sutcliffe efficiencies can range from −∞ to 1. An efficiency of 1 ($E = 1$) corresponds to a perfect match of modelled discharge to the observed data. An efficiency of 0 ($E = 0$) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($E < 0$) occurs when the observed mean is a better predictor than the model.

The Normalized Root-Mean-Squared-Error is the RMSE divided by the maximum difference in the observed streamflow values, and is expressed by the following equation:

$$NormalizedRMS = \frac{RMS}{(X_{obs})_{\max} - (X_{obs})_{\min}}$$

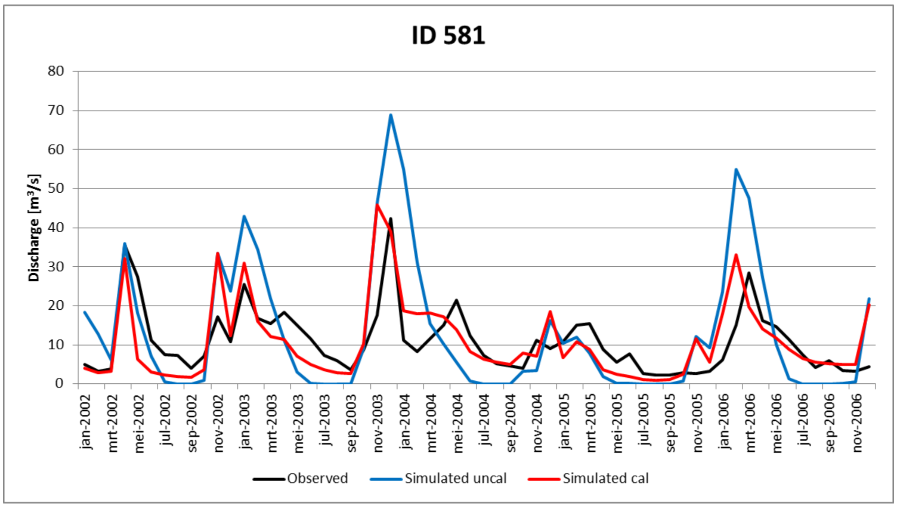
The Normalized RMSE is expressed as a percentage, and is a more representative measure of the fit than the standard RMSE, as it accounts for the scale of the potential range of data values. For example, an RMSE value of 1.5 will indicate a poor calibration for a model with a range of observed values between 10 and 20, but it will indicate an excellent calibration for a model with a range of observed values between 100 and 200. The Normalized RMSE value for the first model would be 15%, while the Normalized RMSE for the second model would be 1.5%.

The BIAS is defined as the average simulated streamflow divided by the average observed streamflow. This performance coefficient indicates whether the model simulates too much or too little streamflow in comparison with the observed streamflow.

Table 8 shows the performance coefficients of the calibrated streamflow gauges. It is clear that the calibration is quite satisfactory; all stations show improved NS-coefficients, BIAS coefficients and Normalized RMSE. Stations with the IDs 788, 581 and 2551 had negative NS-coefficients before calibration took place. This implies that the observed mean is a better predictor than the model. Considering the BIAS coefficient of these stations, it can be seen that the average simulated streamflow is greater than the average observed streamflow. This can also be seen in Figure 39, which shows the observed and simulated streamflow for gauges 581 and 2551. Graphs with observed and simulated streamflow from the remaining stations are shown in Appendix A. One explanation for the larger simulated streamflow is that the soil layers hold little water (low AWC, see Section 3.4.3), resulting in little evapotranspiration, and more surface runoff. By increasing the AWC, more water is available for evapotranspiration, resulting in a decrease in simulated streamflow. Due to the calibration, the NS-coefficients improved considerable. For station 581, however, the NS-coefficient improved, but is still very small (0.13). The model seems unable to capture both the high and low observed flows, in the situation where the observed low flows are relatively high compared to the other stations. Currently this remains unclear and needs to be further investigated during future phases of GWC. As can be seen in Table 8, the NS-coefficients of the remainder of the streamflow gauges are good - even above 0.70 for some stations. The Normalized RMSE also decreased for all stations, meaning that the difference between the monthly observed and simulated streamflow has been minimised.

Table 8: Performance coefficients of the streamflow gauges before the calibration, and after the calibration (denoted with cal).

Station ID	788		1000		581		2551		1436		1217		260	
Simulation	uncal	Cal	uncal	cal	uncal	cal	uncal	cal	uncal	cal	uncal	cal	uncal	cal
Normalized RMSE	0.21	0.10	0.15	0.13	0.32	0.19	0.31	0.08	0.20	0.17	0.16	0.11	0.21	0.18
NS-coefficient	-0.13	0.77	0.41	0.54	-1.59	0.13	-2.04	0.77	0.05	0.33	0.41	0.71	0.21	0.44
BIAS	1.53	1.11	0.86	0.96	1.20	1.00	2.76	1.29	0.94	0.62	1.53	1.33	1.13	0.99



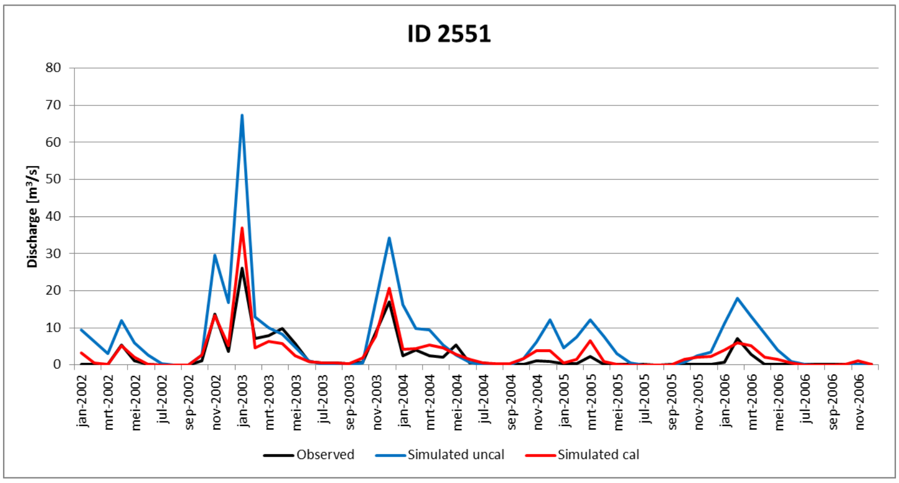


Figure 39: Observed and simulated monthly streamflow for station IDs 581 and 2551.

A further analysis evaluates the average observed monthly discharge and average simulated monthly discharge for each of the stations. These are shown in Appendix B. When comparing these results, it is obvious that for most stations, the average calibrated monthly streamflow is closer to the average observed streamflow than the uncalibrated. As a final result, the average observed monthly streamflow of all stations has been plotted (Figure 40) against the average simulated monthly streamflow (calibrated). This figure shows that there is a good relationship (R^2 = 0.81) between the observed and simulated average monthly streamflow.

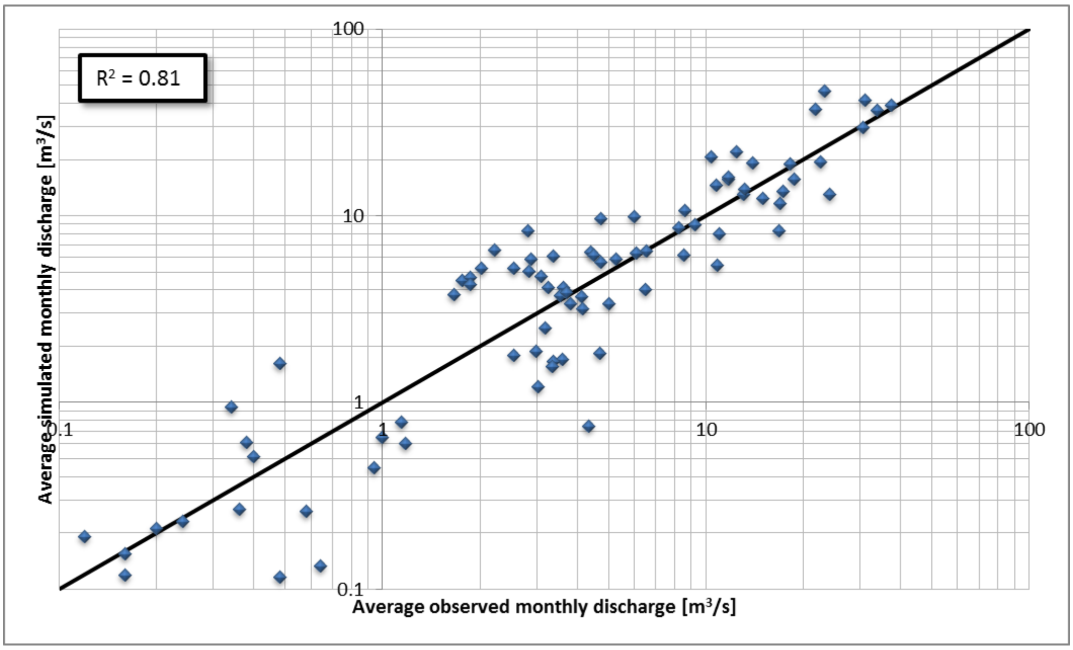


Figure 40: Scatter plot (log axis) of average observed monthly discharge vs. average (calibrated) simulated monthly discharge.

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 have been plotted:

- The total amount of water consumed by vegetation (transpiration) and water lost by soil evaporation (Figure 41).
- T-fraction: percentage of total evapotranspiration used for crop transpiration (*green water*). This factor indicates the effectiveness of the vegetation in using the *green water* source (Figure 42).
- *Blue water*: water entering the streams by surface runoff, drainage and return flow (i.e. groundwater discharge) (Figure 43).
- Erosion: gross erosion rates (Figure 44).

Evapotranspiration is the sum of water consumed by the plants (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 a non-beneficial loss of water from the system. The water gained by reducing soil evaporation can be either used for crop transpiration or can infiltrate and serve as groundwater recharge.

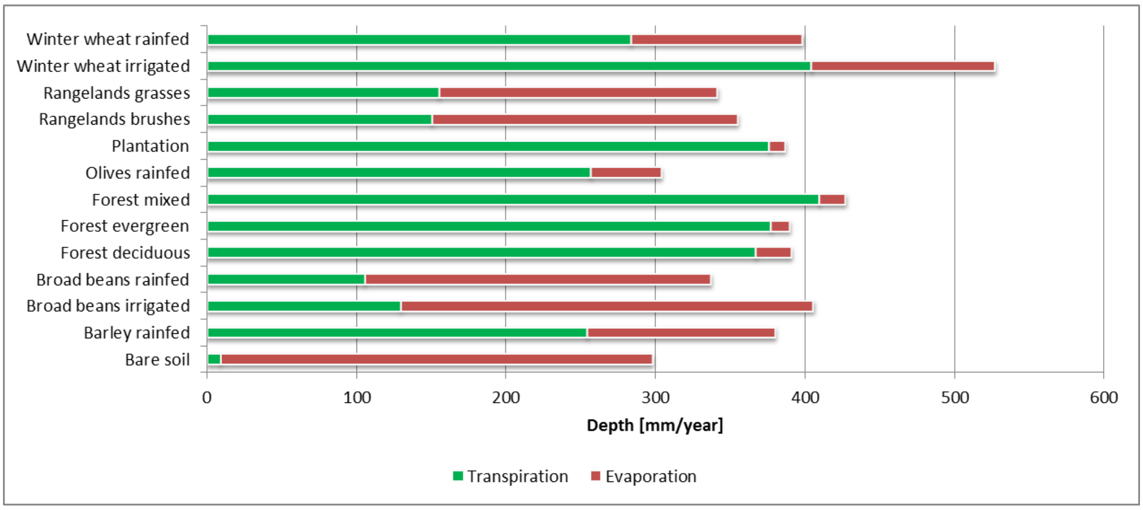


Figure 41: Annual evapotranspiration split into transpiration and soil evaporation for each land cover class, averaged over 2001-2010.

The crops with the highest potential to respond to the implementation of *green water* management practices are those that are cultivated in the upstream areas. The crops of interest should also demonstrate the potential to reduce the amount of soil evaporation and reduce erosion. Figure 41 and Figure 42 provide insight into which part of total evapotranspiration is used beneficially for the crops and which part is lost through soil evaporation. From these figures it can be concluded that the main agricultural crops that show potential for the implementation of *green water* management practices are:

- Wheat
- Barley
- Broad beans

It is clear that losses are especially large from the areas where broad beans are grown. Only 30-33% of the total evapotranspiration in these areas is used for crop transpiration.

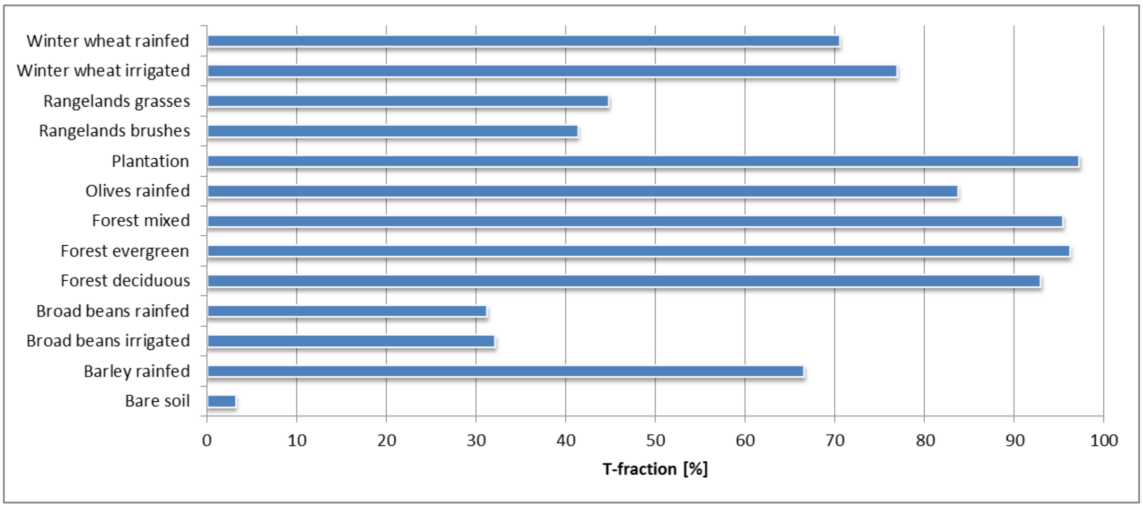


Figure 42: Percentage of total evapotranspiration used for crop transpiration, averaged over 2001-2010.

Figure 43 shows the large differences between different land covers in terms of groundwater recharge, runoff, and drainage (all *blue water* sources). Part of the water that reaches the ground surface is routed as rapid 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 longer travel times, but secure a more continuous and reliable water source. Enhancement of groundwater recharge is therefore of importance, 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. Surface runoff is undesirable, because this often results in erosion and thus sedimentation in the reservoirs. More surface runoff also means less infiltration, and thus less groundwater recharge. Therefore areas with a considerable proportion of runoff (in relation to groundwater recharge) are also potential areas for effective implementation of *green water* management measure. Considering Figure 43 it is clear that – as noted above – wheat, barley and broad beans are the crops where there is the greatest potential for benefits accruing from the implementation of *green water* management practices.

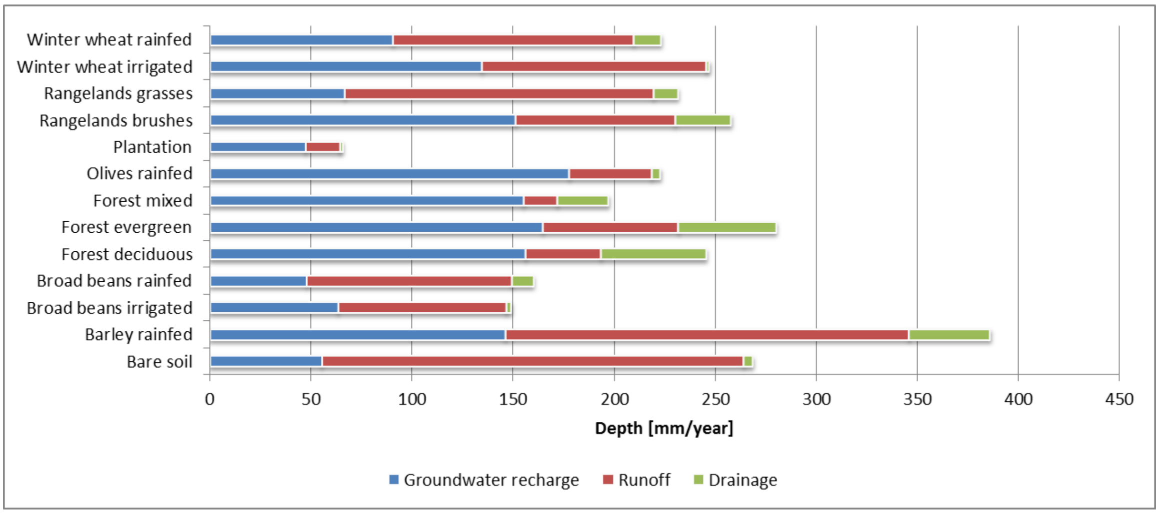


Figure 43: Water entering the streams by groundwater recharge, surface runoff, and drainage, averaged over 2001-2010.

Figure 44 shows the sediment yields for the different land covers, where it is clear that bare soil shows the highest erosion rate. Considering the agricultural crops, potential *green water* management practices which reduce soil erosion, will be most effective under wheat and barley and to a lesser extent broad beans. Barley is mainly grown in the northern region of the basin, which is very mountainous and receives large amounts of rainfall. Therefore this region is very prone to soil erosion. The gross erosion rate for barley is roughly 47 t ha^{-1} yr^{-1}. If we take the unit weight for soil as 1600 kg/m^3, then this corresponds to a gross erosion rate of 2.9 mm yr^{-1} soil depth. These numbers confirm that there is a great potential for *green water* management measures 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. According to the ABHS (ABHS 2006) gross erosion rates can be up to 60 t ha^{-1} yr^{-1} in the Riff mountains. This corresponds well to our results for bare soil.

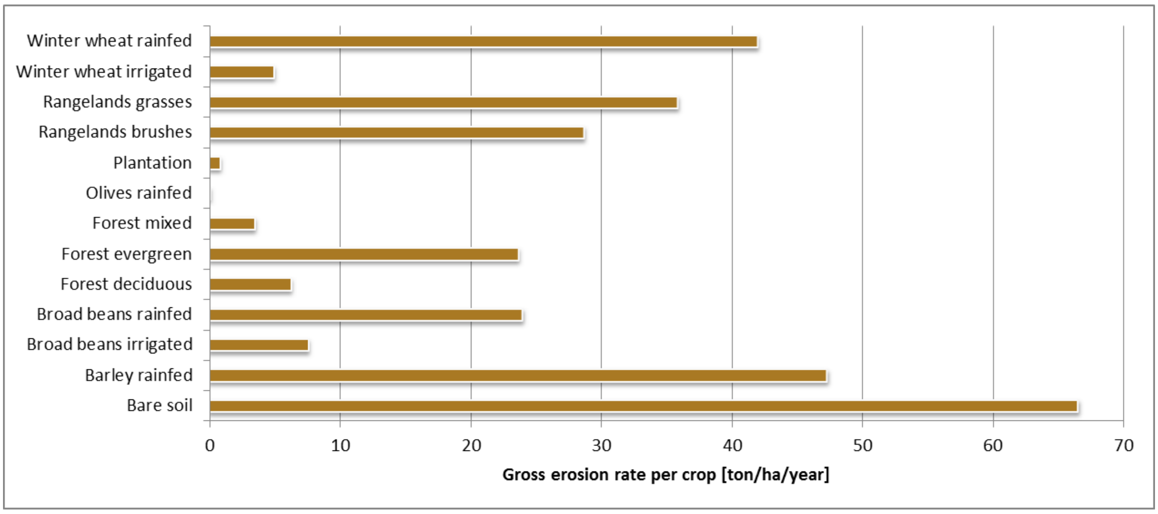


Figure 44: Total actual sediment loss per crop, averaged over 2001-2010.

4.5 Spatial analysis

The distributed modelling approach that was chosen for the bio-physical 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 give insight into the areas where *green water* management implementation is most significant in terms of benefits. To provide insight into the output that will form the basis for the *green water* management biophysical analysis, the following maps have been plotted, based on averages from 2001-2010:

- Annual precipitation: spatial distribution of the annual precipitation sum;
- Annual evapotranspiration: total amount of water consumed by vegetation and water lost by soil evaporation;
- Annual actual transpiration: total amount of water that is used by vegetation (agricultural as well as natural vegetation) to produce biomass;
- Annual 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 crop to use the *green water* source;
- Annual water yield: water entering the streams by surface runoff and sub-surface drainage;
- Annual groundwater recharge: water that contributes to the groundwater aquifer and eventually becomes baseflow;
- Annual erosion rate: total actual sediment loss.

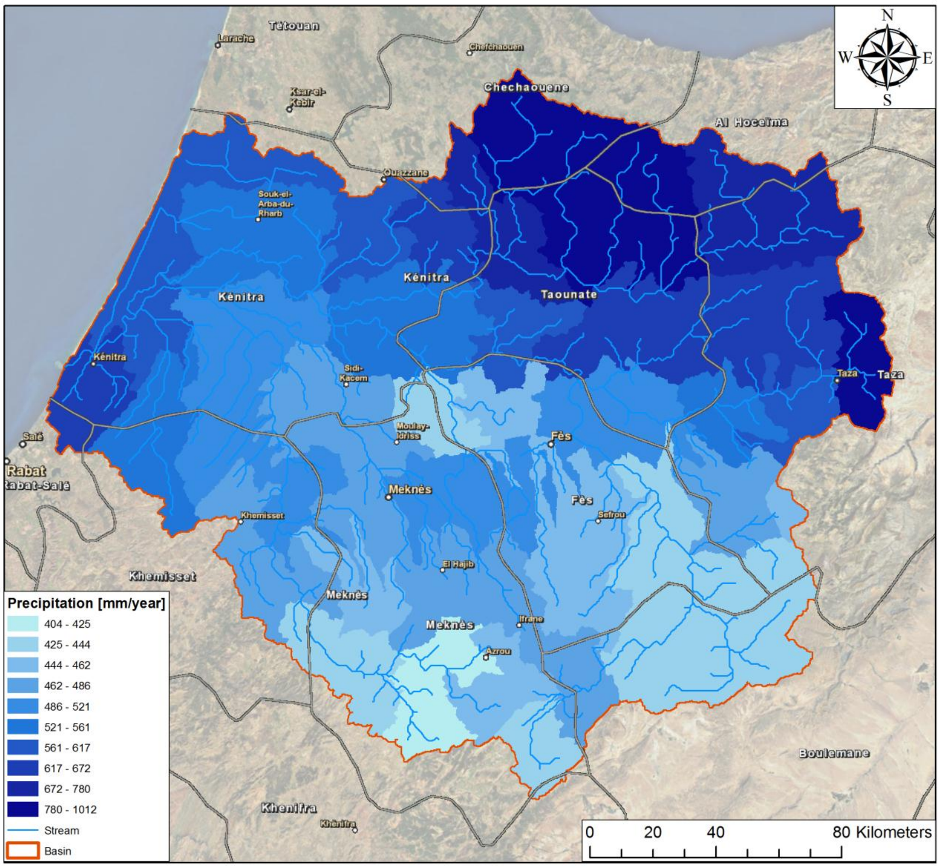


Figure 45: Annual precipitation, averaged over the period 2001-2010.

The spatial pattern of annual precipitation is shown in Figure 45. The distribution of annual precipitation is based on the corrected TRMM precipitation data. It is clear that the largest precipitation rates are found in the northern part of the basin. Annual precipitation in this area can be up to 1000 mm. The western coastal area also receives reasonably large amounts of precipitation, while the southern part of the basin is the driest area. This area receives 400-450 mm per year.

The distribution of annual evapotranspiration rates, averaged over the period 2001-2010, is shown in Figure 46. This is the sum of water consumed by vegetation (transpiration) and water lost by evaporation. The largest evapotranspiration rates are found in the Riff mountains, and in the irrigated areas. The main crop type in these regions is winter wheat. It is, however, more interesting to know which part is transpiration and which part is evaporation, because evaporation from the soil surface can be considered as a loss. Therefore, the average annual transpiration and evaporation are shown in Figure 47 and Figure 48, respectively. The areas with the greatest potential for *green* water management practices are the areas with high evaporation rates. From Figure 48, it is clear that areas with high evaporation rates are located in the south-eastern and central part of the basin. This is where broad beans and winter wheat are the main crops. These areas were already marked in Section 4.4 as having potential for *green water* management practices. The cities of Rabat, Meknes, Fes and Taza are also clearly visible in Figure 48. This is because there is almost no transpiration from these cities because of the lack of vegetation in urban areas.

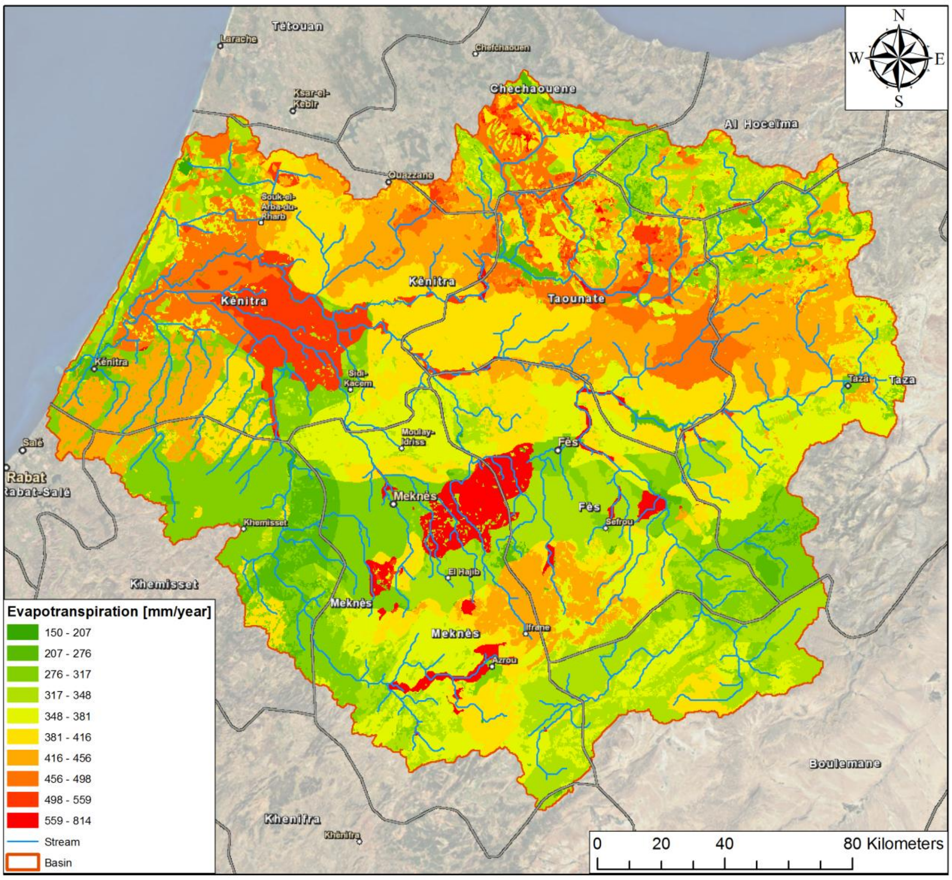


Figure 46: Annual evapotranspiration, averaged over 2001-2010.

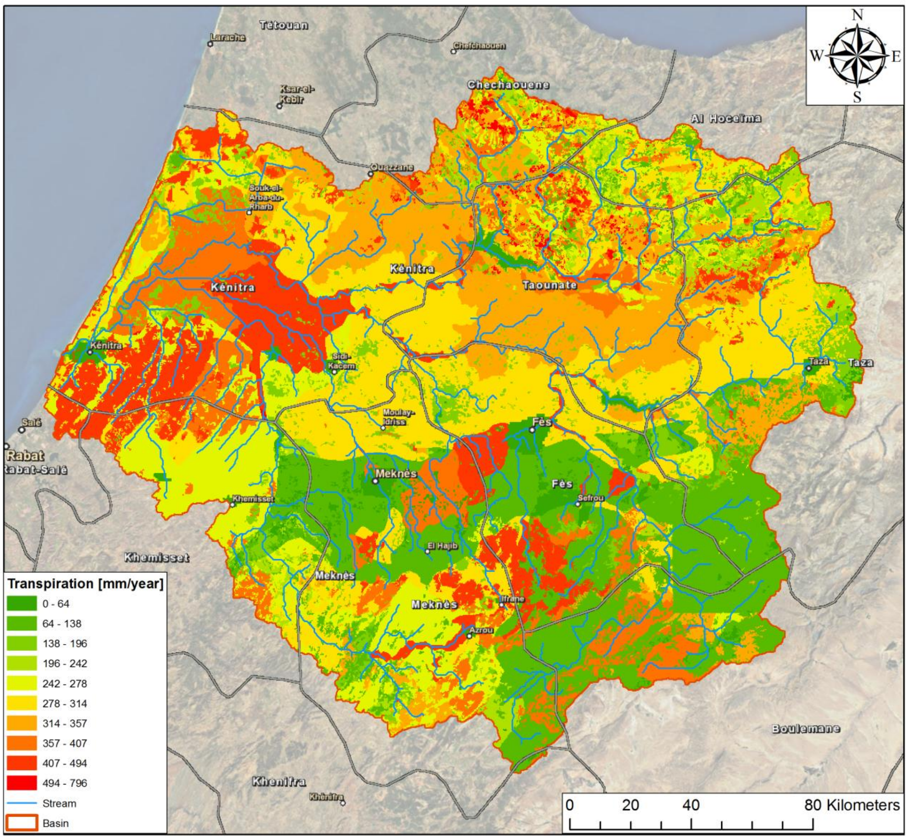


Figure 47: Annual transpiration, averaged over 2001-2010.

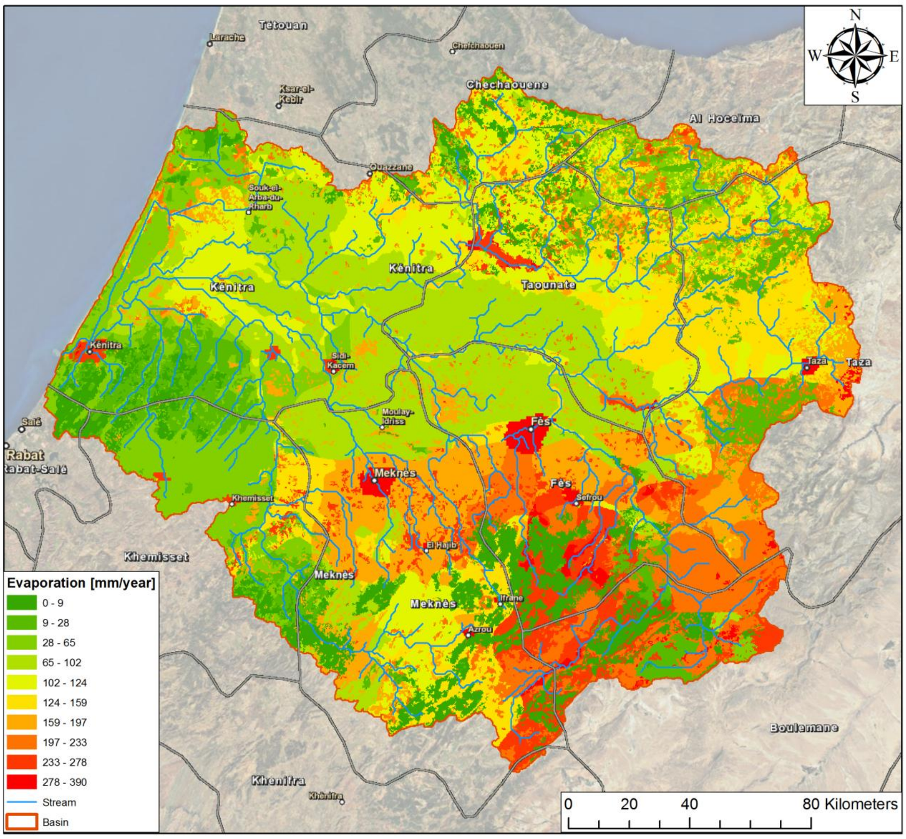


Figure 48: Annual soil evaporation, averaged over 2001-2010.

The proportion of transpiration relative to total evapotranspiration is defined here as the T-fraction. The lower this percentage, the more water is lost by evaporation. The average annual T-fraction is shown in Figure 49. Again the south-eastern region with mainly broad beans, and the central region with mainly winter wheat, is clearly visible. In these areas, more water is lost through evaporation than through transpiration.

The average annual water yield (sum of runoff, sub-surface flow and baseflow) is shown in Figure 50. The largest water yields are found in the northern part of the basin (Riff mountains). Water yield is closely correlated with annual precipitation. Figure 45 already showed that the Riff mountains receive the largest amount of annual precipitation. That explains the large water yields in these areas. Besides the high water yield in the Riff mountains, the irrigation area, located east of Meknes, also shows high water yields. This can be explained by the fact that the soils in this area have a lower AWC, causing more water stress in crops. This leads to greater irrigation demand in this area, and as a result the water yield will be higher as well.

The average annual groundwater recharge is shown in Figure 51. Again, these are very closely correlated with the rainfall amounts. Thus large groundwater recharge volumes are found in the regions with high rainfall amounts. The groundwater recharge also depends on the land use and soil type. Soil types with low permeability hardly allow the water to percolate to the saturated zone. A large part of the groundwater recharge will eventually become baseflow and finally enter the streams.

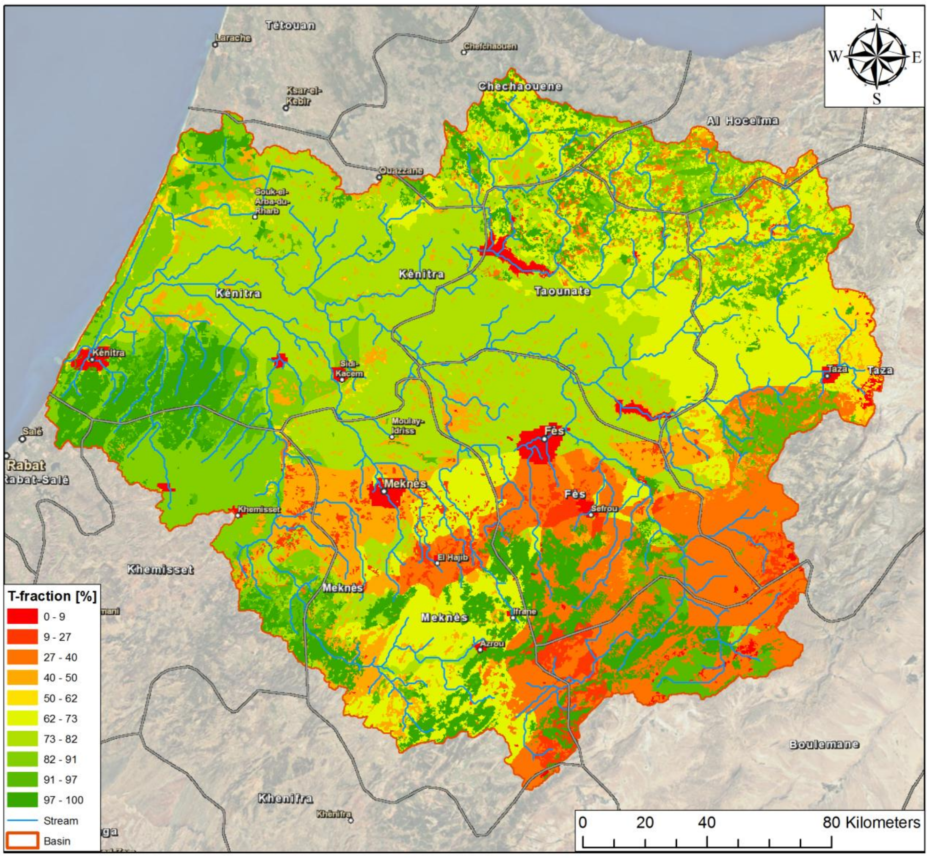


Figure 49: Transpiration as percentage of total evapotranspiration, averaged over 2001-2010.

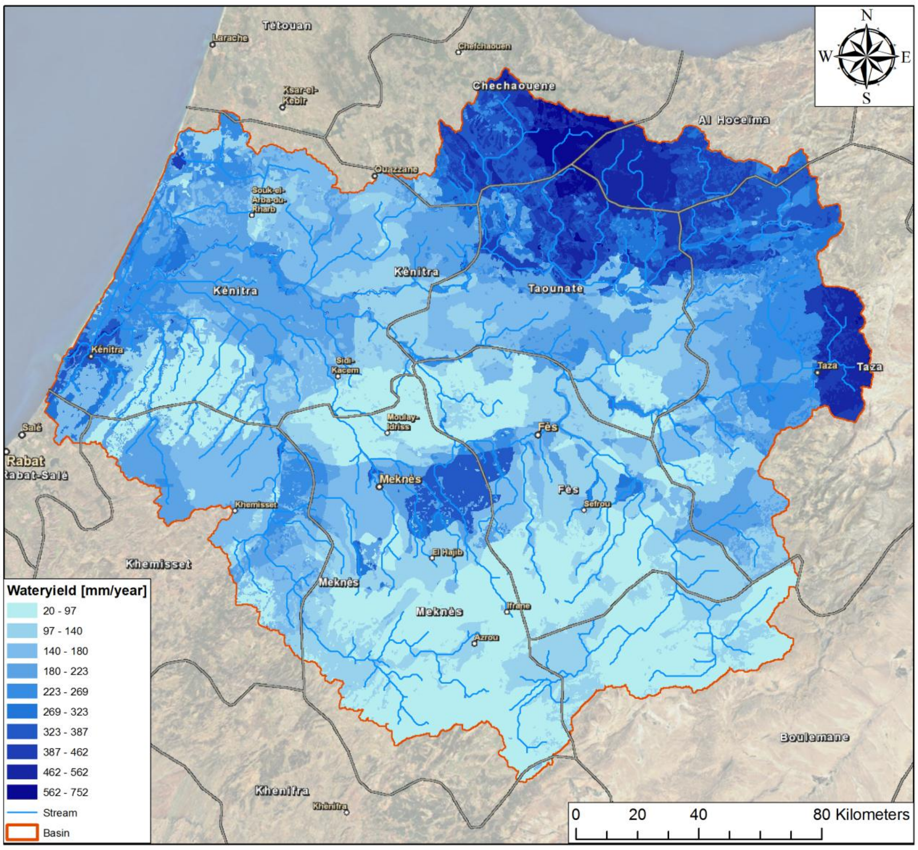


Figure 50: Annual water yield (runoff, sub-surface flow and baseflow), averaged over 2001-2010.

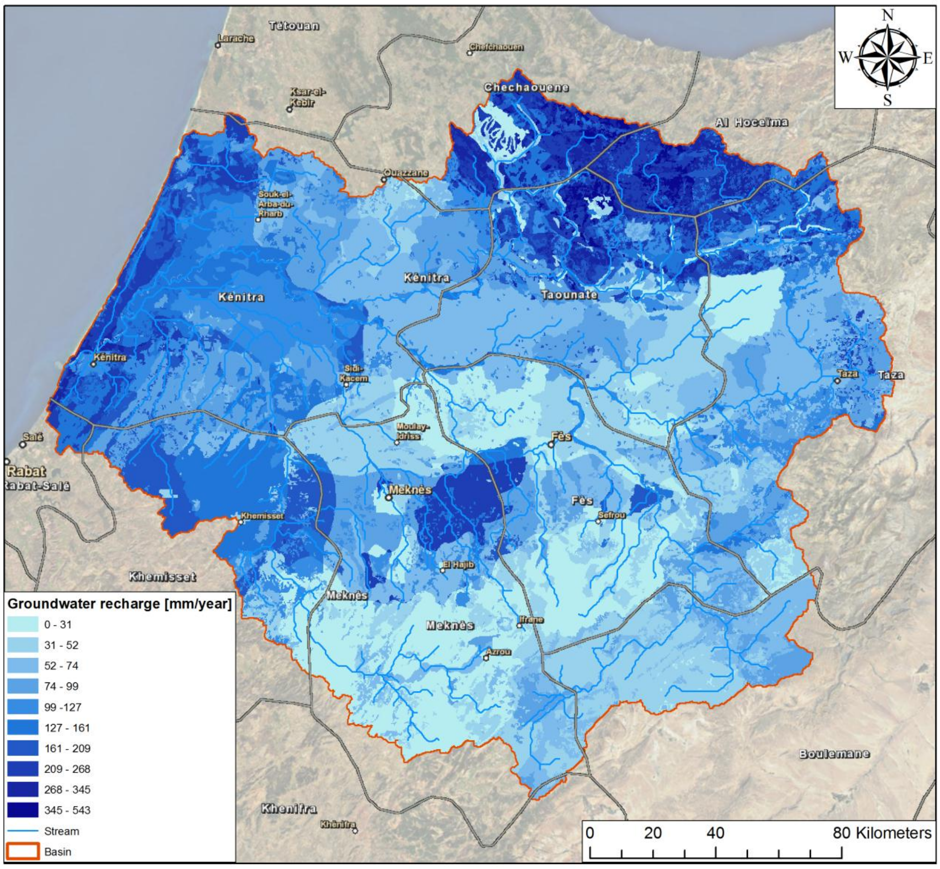


Figure 51: Annual groundwater recharge, averaged over 2001-2010.

The sediment yield in a sub-catchment is mainly dependent on the rainfall intensity, the land use, the slope, and soil type. The average annual sediment yield is shown in Figure 52. Sediment yields are largest in the northern area of the basin. This is a result of the combination of high rainfall intensities, steep slopes, and erodible soils. A point of attention is the soil map used in this study. For the northern and western part, the soil map is more detailed than in other parts of the basin. That explains the high spatial detail obtained in these areas. According to the ABHS (2006), erosion rates are lower in the Middle Atlas. They mention an erosion rate of 5-10 t ha^{-1} yr^{-1}in the Middle Atlas. This corresponds very well to our results as shown in Figure 52.

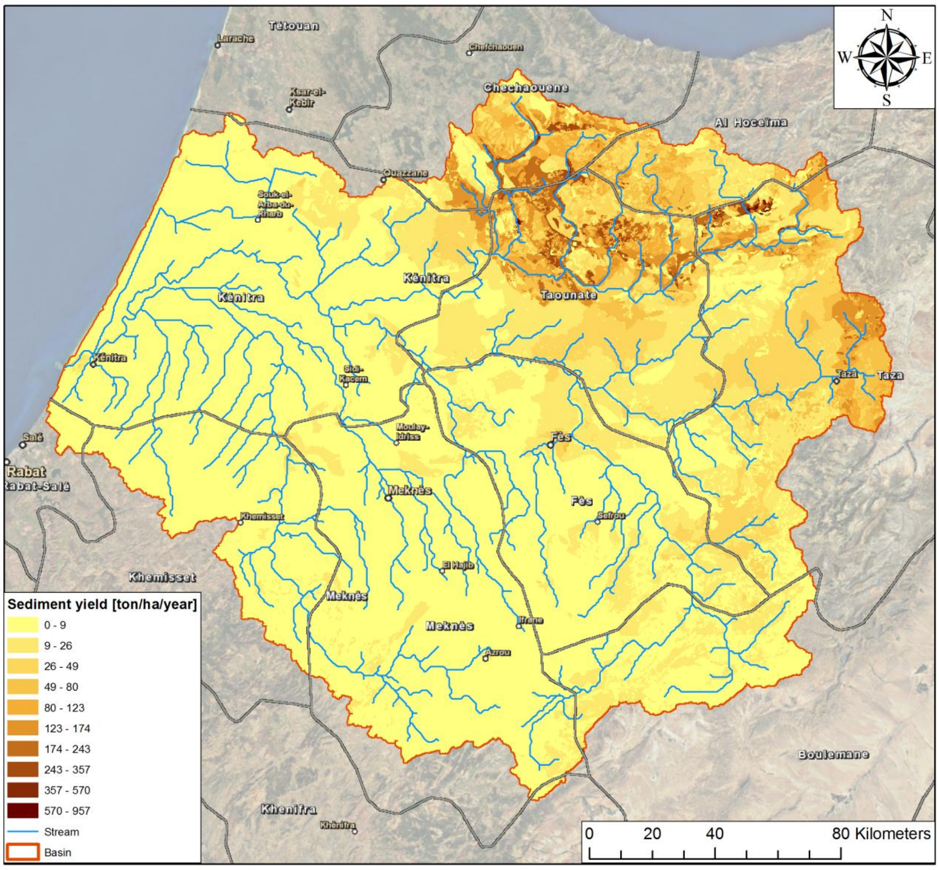


Figure 52: Annual erosion rate, averaged over 2001-2010.

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* management enhances the overall water management of the basin and benefits both parties. These potential benefits need to be quantified in order to transform them to an institutional and financial arrangement that sustains GWC implementation. Different land management options have been 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 summarised as follows:

- Total water flowing from the mountainous areas into the 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.

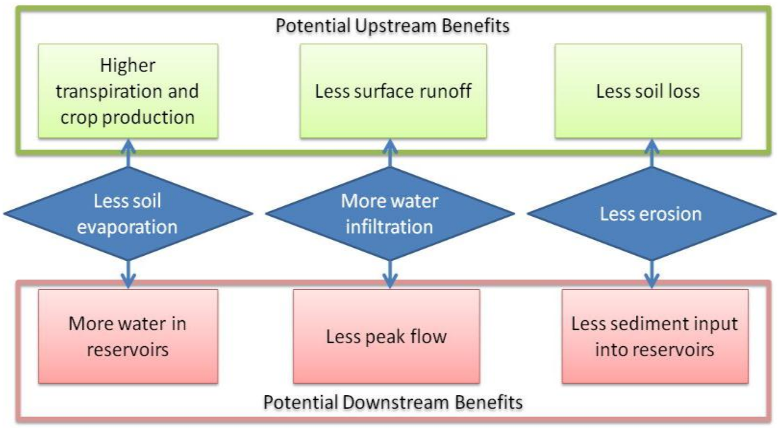


Figure 53: Example of potential upstream and downstream benefits.

A major problem in basin-scale water management is coping with the irregular rainfall and flow regimes that lead to floods in some seasons and drought in others. Infrastructural solutions such as dams, canals and diversions are able to hold certain amounts of water temporarily so as to redistribute the water available during the drier seasons and to lessen hazardous peak flows. The soil and groundwater storages regulate flows and their capacity is, in most basins, much larger 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 *green water* management 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 Sebou case. These have to be selected, studied and evaluated. A first selection has been conducted 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 Selection of management options

The World Overview of Conservation Approaches and Technologies (WOCAT) is a programme whose objective is to use existing knowledge and funds more efficiently to improve decision-making for optimising land management. It is a framework for collecting databases of successful SWC experiences concerning technologies, approaches and aerial distribution through the use of standardised and simplified questionnaires worldwide. All data are readily analysed, and can be disseminated and prepared for presentation, evaluation and monitoring. WOCAT can be used as a tool in land management for all land users (stakeholders) with benefits that are multiple and mutual through the improved WOCAT decision support system.

A 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. Stone lines (*cordons de pierres*)
2. Bench terraces (*banquettes*)
3. Contour tillage

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

5.2.1 Stone lines

Stone lines (in French: c*ordons de pierres*) (Figure 54) are small structures (WOCAT: NIG01[13] and NIG02[14]) of stones, where the stones are placed in a horizontal line across the slope. The distance between the lines is a function of the slope and availability of stone.

[13] http://www.fao.org/ag/agl/agll/wocat/wqtsum.asp?questid=NIG01

[14] http://www.fao.org/ag/agl/agll/wocat/wqtsum.asp?questid=NIG02e

Stone lines are intended to slow down runoff. They thereby increase the rate of infiltration, while simultaneously protecting the planting pits from sedimentation. Often grass establishes between the stones, which helps increase infiltration further and accelerates the accumulation of fertile sediment. Wind-blown particles may also build up along the stone lines due to a local reduction in wind velocity. The accumulation of sediment along the stone lines in turn favours water infiltration on the upslope side. This then improves plant growth, which further enhances the effect of the system.

Construction does not require heavy machinery (unless the stones need to be brought from afar by lorry). The technique is therefore favourable to spontaneous adoption. Stone lines may need to be repaired annually, especially if heavy rains have occurred.

Figure 54: Example of stone lines (source: www.wocat.net).

*5.2.2 Bench terraces (*in French*: banquettes*)

This measure (Figure 55) is an embankment constructed along the contour by the use of stone and soil as a construction material (WOCAT: ETH32[15]). The technology is used in areas where there is not sufficient stone and where the soil shallow. Terraces are established by excavating soil, and using this to shape the embankment. Stone is used to face the downslope side (the terrace "riser") for reinforcement. Vegetation is planted on the upper part of the embankment when there is sufficient soil.

[15] http://www.fao.org/ag/agl/agll/wocat/wqtsum.asp?questid=ETH32

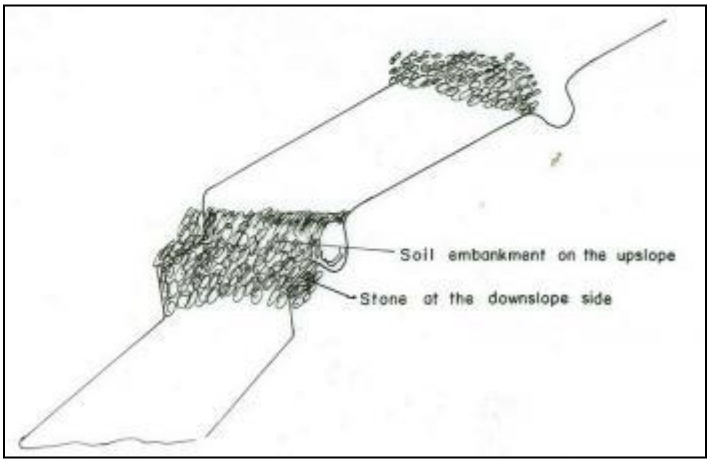


Figure 55: Example of bench (bund/*banquette*) terraces (source: www.wocat.net).

The purpose is to reduce runoff, decrease slope length, increase infiltration rate and thus minimise soil erosion. The structures require regular maintenance, since the embankments are often made of small stones, which are unstable. In order to properly stabilise the structure livestock should not be allowed to graze where the structures are placed. Checking for breaks after heavy storms is necessary.

In terms of bio-physical processes this measure will have the following impact:

- Reduction in soil loss by erosion
- Reduced overland flow

5.2.3 Contour tillage

This *green water* management option comprises contour ploughing (WOCAT: HUN2[16]) often combined with soil bunds (WOCAT: ETH43[17]). The basis of the technology is the annual ploughing. The ploughing and all other cultivation is carried out along the contour lines. This can significantly decrease erosion. Rotary cultivation aims to reduce wind and water erosion, to control weed and to develop a good seedbed. On very low slopes contour tillage may be adequate on its own without bunds.

[16] http://www.fao.org/ag/agl/agll/wocat/wqtsum.asp?questid=HUN2

[17] http://www.fao.org/ag/agl/agll/wocat/wqtsum.asp?questid=ETH43

Figure 56: Example of contour tillage (source: www.wocat.net).

On slopes of more than 3%, soil bunds can be supplemented to the contour cultivation. Stone, and stone faced, bund height depends on the availability of stones. On average the base width is 1.0 -1.2 m and height is 0.6 - 0.7 m. Bunds reduce the velocity of runoff and soil erosion, retain water behind the structure and allow it to infiltrate. This further helps in ground water recharging.

Planning is carried out by initial community/group and individual discussion, and a consensus reached on layout, spacing, implementation modalities and management requirement. The technology is applicable in areas where soil is moderately deep and stones are available.

5.3 Analysis of *green water* management options

A preliminary analysis has been carried for each of the selected *green water* management options. In order to compare these scenarios with the baseline current situation, a set of indicators is introduced that gives insight into the impact of the practices.

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

Key indicators showed the water and sediment inflow of three principal reservoirs in the basin; Allal El Fassi, Idriss 1Er, and Al Wahda. To quantify the effect of the *green water* management scenarios on these reservoirs, the change in surface runoff, sediment loss, and sediment inflow has been analysed. Besides the effect on the reservoirs, the change in plant transpiration, soil evaporation, and groundwater recharge has also been evaluated. A reduction in soil evaporation and an increase in plant transpiration will result in increased crop growth, and thus higher yields per hectare. Groundwater recharge, which eventually becomes baseflow, feeds the streams and reservoirs. Therefore, an increase in groundwater recharge will result in more water in the reservoirs and streams. This means that more water is available for the people living downstream, who utilise the water extensively for irrigation and other uses.

For the preliminary assessment, it has been assumed that the practices are implemented in all areas where the potential crops identified in Section 4.4 are cultivated, these being:

- Barley, rainfed;
- Broad beans, rainfed;
- Winter wheat, rainfed;

The SWAT model parameters, which were used for the scenario analyses, were based on expert knowledge, and previous GWC studies (e.g. Hunink *et al.* 2011). The parameters used for the baseline (current situation) scenario, and three selected *green water* management scenarios are shown in Table 9.

Table 9: Parameter values and changes for each of the *green water* management scenarios.

Nr	Scenario	Land use	ESCO	P_USLE	CN2	SLOPE	OV_N	FilterW
0	Baseline	Barley rainfed	0.90	1.0	73	100%	0.14	0.0
		Broad bean rainfed	0.90	1.0	77	100%	0.14	0.0
		Winter wheat rainfed	0.90	1.0	73	100%	0.14	0.0
1	Stone lines	Barley rainfed	0.91		71			0.5
		Broad bean rainfed	0.91		75			0.5
		Winter wheat rainfed	0.91		71			0.5
2	Bench terraces	Barley rainfed		0.8	71	80%		
		Broad bean rainfed		0.8	75	80%		
		Winter wheat rainfed		0.8	71	80%		
3	Contour tillage	Barley rainfed		0.9	66		0.42	
		Broad bean rainfed		0.9	70		0.42	
		Winter wheat rainfed		0.9	66		0.42	

The description of these parameters is as follows:

- ESCO: soil evaporation compensation coefficient: a higher value results in reduced soil evaporation, making more water available for transpiration or as *blue water*.
- P_USLE: support practice factor for soil loss: a lower value results in reduced soil erosion and increased groundwater recharge.
- CN2: runoff curve number: a lower value results in reduced soil erosion and increased groundwater recharge.
- SLOPE: average slope steepness: a lower value will reduce the overland flow and erosion, and will increase the groundwater recharge.
- OV_N: Manning's "n" value for overland flow: a higher value means more resistance to flow, lower flow velocities and less erosion.
- FILTERW: width of edge-of-field filter strip: represents buffer zone around HRU area. Higher values mean less erosion, more infiltration, and less overland flow.

The results of the three selected *green water* management scenarios and the baseline scenario are shown in Table 10. The principal water balance components of the potential *green water* management practices areas (barley, rainfed; broad beans, rainfed; and winter wheat, rainfed) are also shown, as well as the entire basin balance. It can be concluded that all three *green water* management scenarios result in a decrease in sediment inflow into the three reservoirs. Sediment inflow decreases by 22% for Allal El Fassi, by 14% for Al Wahda, and by 18% for

Idriss 1 Er. Contour tillage has the most significant effect on the decrease of sediment inflow into the reservoirs. Bench terraces, however, reduce sediment loss less than than contour tillage. It is likely that this is related to the spatial variation in sediment loss reduction. Because contour tillage leads to a greater reduction in sediment inflow into the reservoirs, this measure would probably have more effect upstream of the reservoirs, than bench terraces. Another positive effect of all the *green water* management practices is the decrease in surface runoff, and increase in groundwater recharge. The decrease in surface runoff is similar for stone lines and bench terraces, but is most significant for contour tillage. Contour ploughing allows more water to infiltrate, leading to less surface runoff. For the *green water* management measure of “contour tillage” this leads to an increase in groundwater recharge of 24% for rainfed barley, 45% for rainfed broad beans, and 28% for rainfed winter wheat.

Table 10: Key outcome indicators for *green water* management scenarios (averages 2001-2010).

Key indicators	Baseline	Stone lines	change	% change	Bench terraces	change	% change	Contour tillage	change	% change
Inflow Allal El Fassi (MCM/y)	525	535	9.9	2%	533	8.6	2%	550	25.6	5%
Sediment Inflow Allal El Fassi (Mton/y)	1.47	1.33	-0.1	-9%	1.30	-0.2	-12%	1.15	-0.3	-22%
Inflow Al Wahda (MCM/y)	2131	2141	10.4	0%	2138	7.4	0%	2152	21.3	1%
Sediment Inflow Al Wahda (Mton/y)	3.96	3.76	-0.2	-5%	3.73	-0.2	-6%	3.40	-0.6	-14%
Inflow Idriss 1 Er (MCM/y)	851	858	6.9	1%	855	3.7	0%	862	11.4	1%
Sediment Inflow Idriss 1 Er (Mton/y)	2.96	2.62	-0.3	-11%	2.46	-0.5	-17%	2.42	-0.5	-18%
Surface Runoff in mountain areas (mm/y)	151	140	-10.8	-7%	140	-11.0	-7%	114	-36.5	-24%
Crop Transpiration (mm/y)	262	263	0.4	0%	263	0.4	0%	263	0.4	0%
Soil Evaporation (mm/y)	119	119	-0.5	0%	119	-0.1	0%	119	0.0	0%
Groundwater Recharge (mm/y)	127	130	2.2	2%	130	2.7	2%	134	6.8	5%
Sediment loss (ton/ha/y)	25	22	-3.6	-14%	20	-5.0	-20%	22	-3.3	-13%
Basin Balance										
Area (km2)	39,021	39,021			39,021			39,021		
Precipitation (MCM/y)	24,178	24,178	0.0	0%	24,178	0.0	0%	24,178	0.0	0%
Transpiration (MCM/y)	10,233	10,249	16.2	0%	10,249	15.9	0%	10,249	16.4	0%
Evaporation (MCM/y)	4,656	4,636	-20.8	0%	4,654	-2.6	0%	4,657	0.5	0%
Barley rainfed										
Area (km^2)	1,242	1,242			1,242			1,242		
Crop Transpiration (mm/y)	254	255	0.4	0%	255	0.8	0%	255	0.5	0%
Soil Evaporation (mm/y)	126	125	-0.9	-1%	127	0.9	1%	127	1.0	1%
Groundwater Recharge (mm/y)	146	157	11.3	8%	162	16.0	11%	181	35.3	24%
Surface Runoff (mm/y)	200	186	-13.7	-7%	186	-13.5	-7%	154	-45.7	-23%
Sediment Loss (ton/ha/y)	47	31	-16.4	-35%	25	-22.7	-48%	33	-14.7	-31%
Broad beans rainfed										
Area (km^2)	2,494	2,494			2,494			2,494		
Crop Transpiration (mm/y)	106	106	0.3	0%	106	0.2	0%	106	0.4	0%
Soil Evaporation (mm/y)	232	231	-1.0	0%	233	1.6	1%	234	2.9	1%
Groundwater Recharge (mm/y)	48	55	7.7	16%	56	7.8	16%	69	21.4	45%
Surface Runoff (mm/y)	102	94	-7.9	-8%	93	-8.5	-8%	74	-27.2	-27%
Sediment Loss (ton/ha/y)	24	16	-8.4	-35%	13	-11.5	-48%	16	-8.3	-35%
Winter wheat rainfed										
Area (km^2)	14,887	14,887			14,887			14,887		
Crop Transpiration (mm/y)	283	284	0.8	0%	284	0.6	0%	284	0.8	0%
Soil Evaporation (mm/y)	115	114	-1.3	-1%	116	0.5	0%	116	0.8	1%
Groundwater Recharge (mm/y)	91	99	8.4	9%	100	9.6	11%	116	25.3	28%
Surface Runoff (mm/y)	119	110	-9.1	-8%	110	-9.2	-8%	89	-30.3	-25%
Sediment Loss (ton/ha/y)	42	27	-14.6	-35%	22	-19.9	-47%	29	-13.4	-32%

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 *green water* management measures. 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 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 bio-physical 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. Three *green water* management scenarios were analysed, in order to evaluate the effect of these scenarios on soil evaporation, crop transpiration, surface runoff, sediment inflow into the reservoirs, and groundwater recharge. The GWC scenarios analysed were:

- Stone lines (c*ordons de pierres*)
- Bench terraces (*banquette*)
- Contour tillage

For the scenarios analysed, Contour tillage showed the largest decrease in sediment inflow into the reservoirs. The other two scenarios also showed decreases in sediment inflow. Another positive effect is the decrease in surface runoff, and increase in groundwater recharge. The increase in groundwater recharge is especially large for the areas where rainfed broad beans are grown. The increase in groundwater recharge leads to more water inflow into the reservoirs. This increases the water availability for farmers who use the water extensively for irrigation purposes.

This report summarises the bio-physical analysis of the Proof-of-Concept for GWC Morocco. Data preparation and verification, model building, model calibration, results and *green water* management measures were analysed and described. Further improvements of the various steps have been identified and will be summarised here.

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

1. A more detailed land use dataset is in preparation with the Moroccan counterparts and should be included in the consequent follow-up analysis.
2. Currently only the northern and western parts of the basin are covered a detailed soil map (from INRA). For the future, similar detailed soil maps should be obtained from INRA for the remainder of the basin.
3. More detailed information on the crop cycles, planting, harvest dates and overall agricultural practice is needed to enhance the reliability of the assessment of the *green water* management measures.

4. For precipitation we have an accurate corrected dataset with high spatial detail. For temperature, however, only four stations with a daily maximum and minimum temperature were available (GSOD). It is desired to have more temperature stations for follow-up analysis.
5. Currently the Hargreaves method is used to calculate the reference evapotranspiration. This method was used because the more accurate Penman-Monteith method requires more climatological input (humidity, radiation, wind speed, temperature) data, which was not available at a high spatial resolution. For future analysis, it would be an improvement to have these meteorological input data to make the calculation of the reference evapotranspiration more accurate.
6. The SWAT model has the possibility of incorporating reservoir capacity at both the normal spillway, and at the emergency spillway. We only obtained the reservoir capacities and surface areas at the normal spillway. Therefore the emergency spillway capacity and surface area are taken the same as the normal spillway capacity and surface area. For future analysis, the addition of the emergency spillway capacity and surface area would improve the model results.
7. The results of the three selected GWC practices should be discussed and evaluated in detail with the stakeholders, in order to validate the results.

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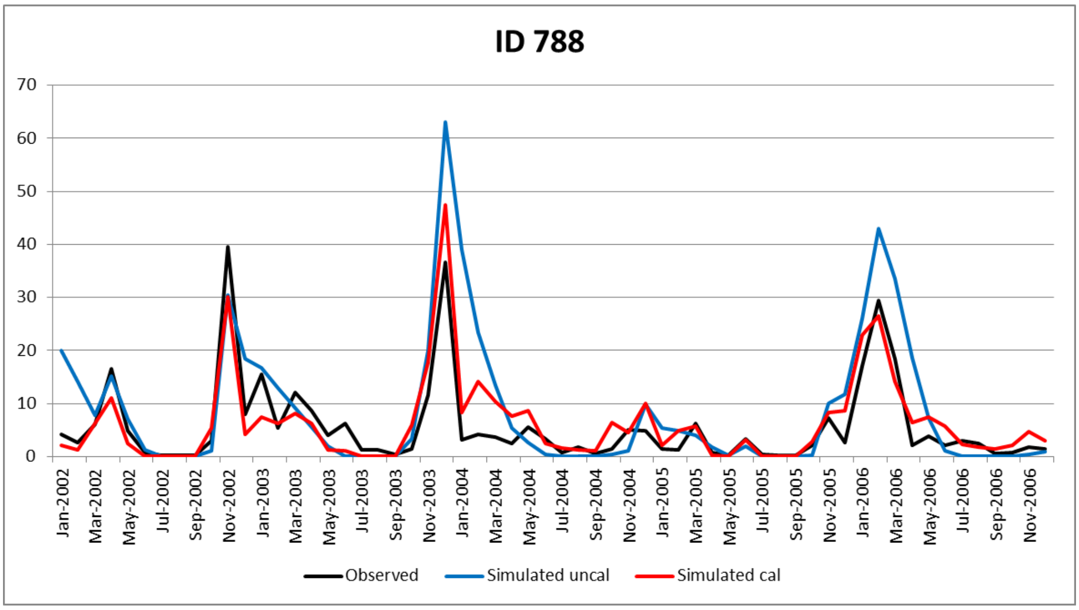
Appendix A: Observed and simulated monthly streamflow for the selected streamflow gauges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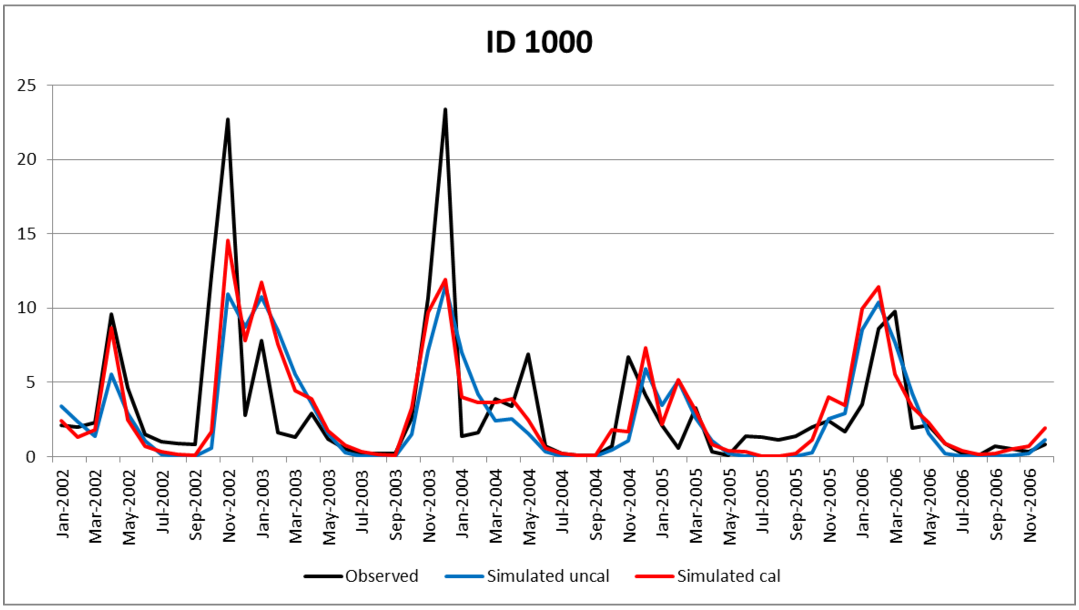
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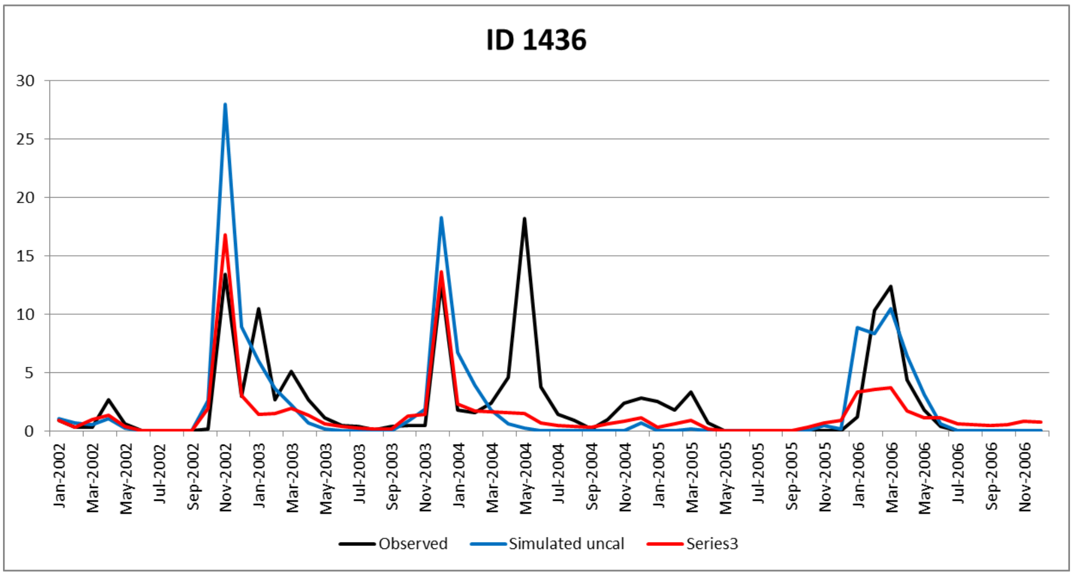
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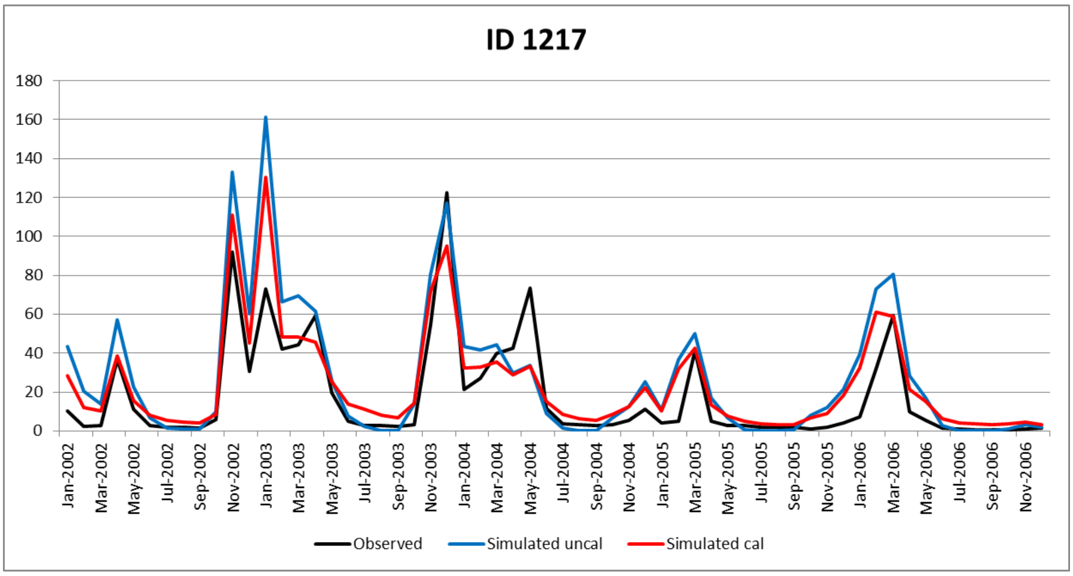
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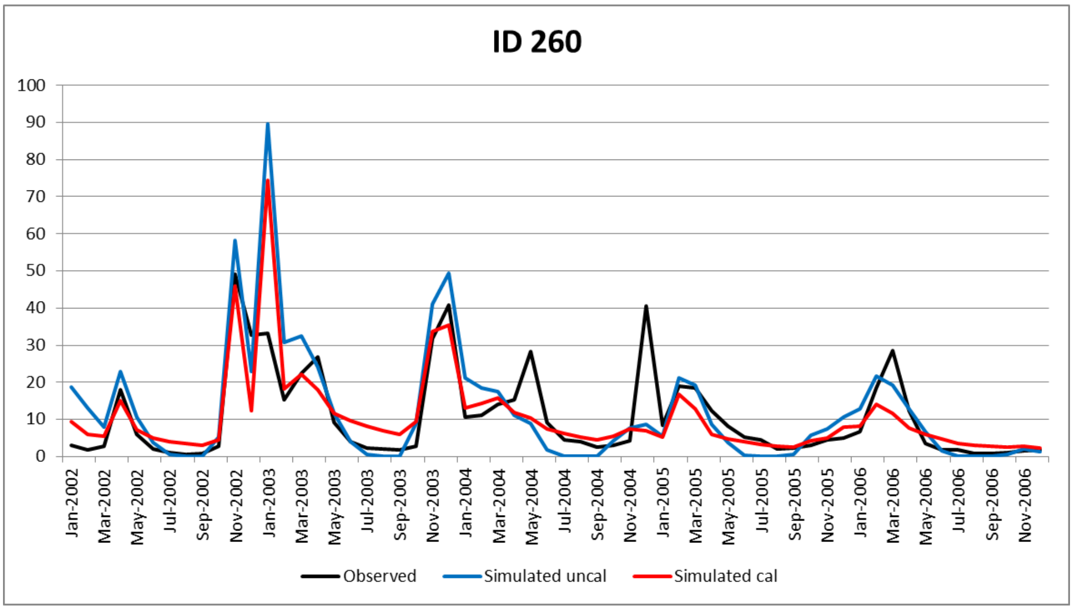
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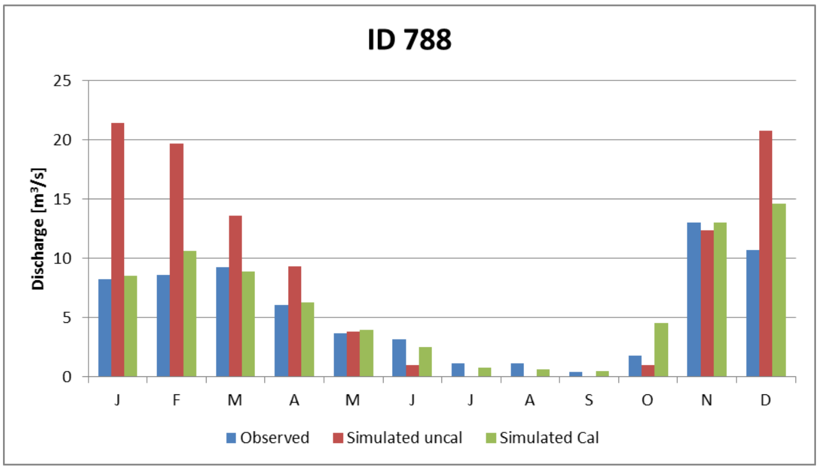
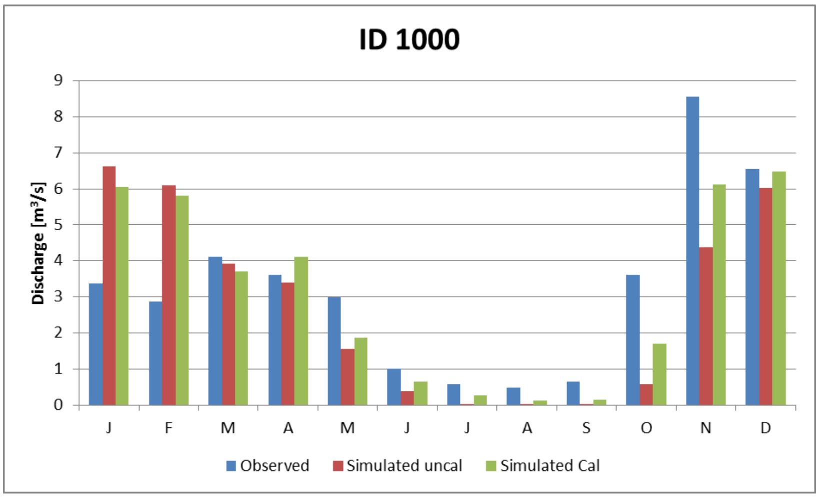
Jan-2002
Mar-2002
May-2002
Jul-2002
Sep-2002
Nov-2002
Jan-2003
Mar-2003
May-2003
Jul-2003
Sep-2003
Nov-2003
Jan-2004
Mar-2004
May-2004
Jul-2004
Sep-2004
Nov-2004
Jan-2005
Mar-2005
May-2005
Jul-2005
Sep-2005
Nov-2005
Jan-2006
Mar-2006
May-2006
Jul-2006
Sep-2006
Nov-2006
Observed
Simulated uncal
Simulated cal

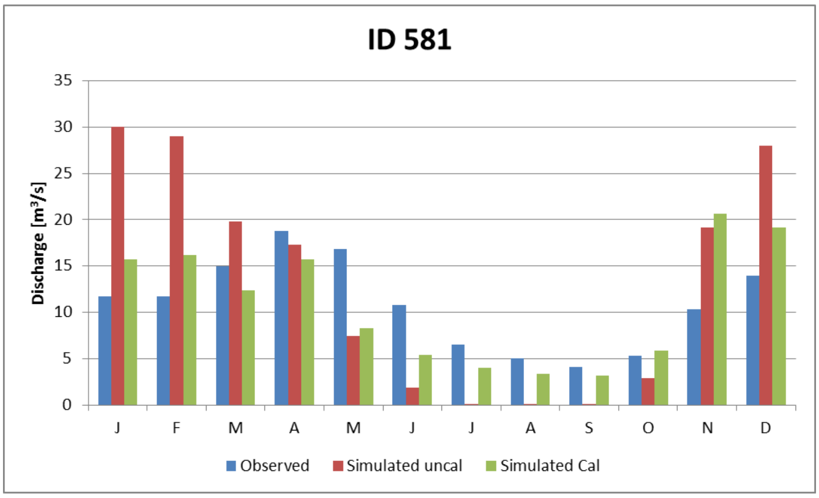
Appendix B: Average observed and simulated monthly streamflow (uncalibrated and calibrated)



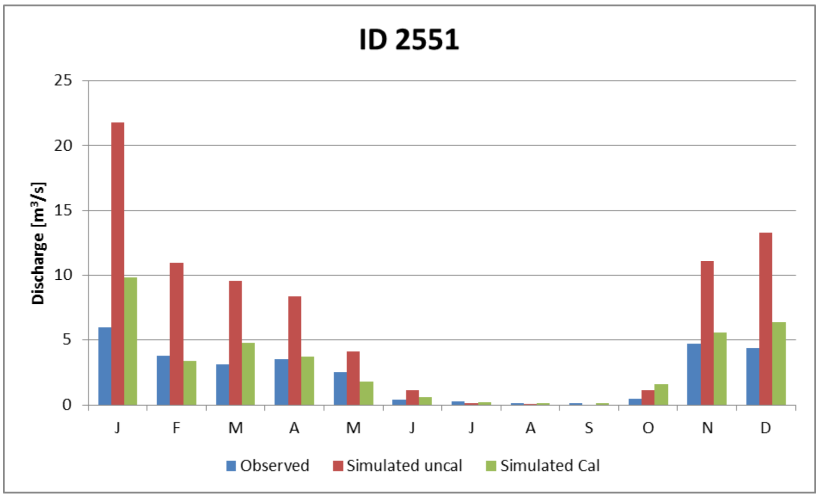
ID 788
Discharge [m³/s]
25
20
15
10
5
0
J F M A M J J A S O N D
Observed
Simulated uncal
Simulated Cal

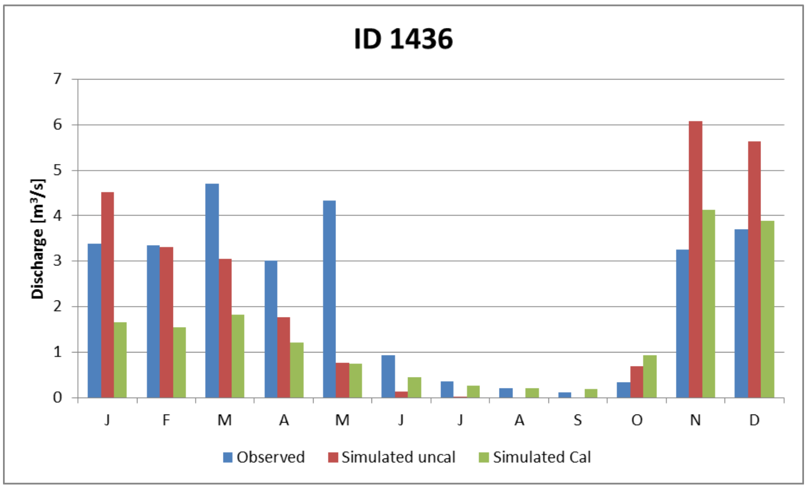


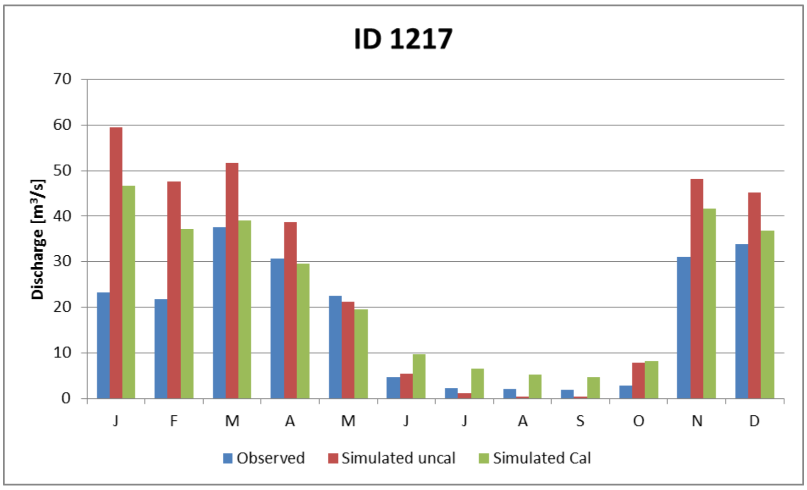
ID 1000
Discharge [m³/s]
9
8
7
6
5
4
3
2
1
0
J F M A M J J A S O N D
Observed
Simulated uncal
Simulated Cal

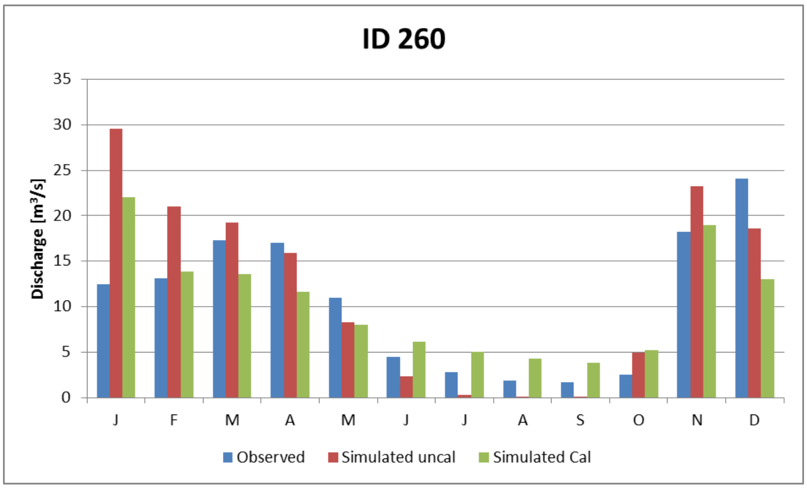


ID 581
Discharge [m³/s]
35
30
25
20
15
10
5
0
J F M A M J J A S O N D
Observed
Simulated uncal
Simulated Cal


ID 2551
Discharge [m³/s]
25
20
15
10
5
0
J F M A M J J A S O N D
Observed
Simulated uncal
Simulated Cal


ID 1436
Discharge [m³/s]
7
6
5
4
3
2
1
0
J F M A M J J A S O N D
Observed
Simulated uncal
Simulated Cal


ID 1217
Discharge [m³/s]
70
60
50
40
30
20
10
0
J F M A M J J A S O N D
Observed
Simulated uncal
Simulated Cal


ID 260
Discharge [m³/s]
35
30
25
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
Observed
Simulated uncal
Simulated Cal