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ORIGINAL PAPER

Integrated assessment of ecosystem services in response to land use change and management activities in Morocco

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Abstract

The rapid development in Morocco with an urban and agricultural expansion is putting pressure on ecosystem services. An integrated assessment of these services at different spatial and temporal scales will ensure their sustainability. This paper used Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) to quantify and map multiple ecosystem services in Morocco from 1992 to 2015. The results show that urban areas, agriculture, sparse vegetation, and forests increased by 93%, 2%, 8%, and 9% whereas grassland and bare areas decreased by 80% and 2% respectively. This caused an increase in carbon storage by 1.7% and decreases in water yield, sediment export, and nitrogen and phosphorus exports by 15.5%, 7.4%, and 0.4% respectively. The overall ecosystem services of Morocco showed high values in the north but lower values in the east and south. Land management activities which were implemented in a selected watershed in the east using the Resource Investment Optimization System (RIOS) caused carbon storage to further increase by 0.2% whereas water yield, sediment export, nitrogen export, and phosphorus export declined by 0.07%, 0.09%, 0.17%, and 0.09%. Ecosystem services could be improved at both national and watershed scales when management activities such as reforestation and pasture management are implemented at specific watersheds.

Keywords LULC change · Ecosystem services · Management activities · InVEST · RIOS

Introduction

Ecosystems have been changed by humans over the years (Millenium Ecosystem Assessment 2005). They provide benefits for the well-being of humans which is termed as ecosystem services (Costanza et al. 1997). The most important factor that influences ecosystem services apart from climate change is land use and land cover (LULC) change (Lang et al. 2017).

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Recent studies around the world have proven that LULC change is the main driving force of change in the provision of ecosystem services (Kertész et al. 2019; Milheiras and Mace 2019; Schröter et al. 2019). Urbanization and agricultural expansion are among the major anthropogenic drivers of LULC change that have direct consequences on ecosystem services (Tolessa et al. 2017). Numerous studies have shown that changes in LULC can either increase or decrease ecosystem services such as carbon storage, soil conservation, water yield, and water purification (Geneletti 2013; Stockmann et al. 2015) and eventually affect human well-being (Quintas-Soriano et al. 2016). Ecosystem services are derived from different LULCs, and managing these locations while understanding their changes is critical for their sustainability. A better way to manage ecosystem services is to have adequate knowledge on the dynamic patterns of these services and to understand the ecosystem functioning and relationships (Leh et al. 2013). Studying the relationship between LULC and ecosystem services provides evidence of the current status of these services, and policies could be established to protect the lands and manage the ecosystems for the well-being of the society (Peng et al. 2015). The ecosystem services framework is useful for land use management and reshaping national development policy and planning (Goldstein et al. 2012).

Mediterranean countries have been experiencing anthropogenic LULC change over the past decades (Grove and Rackham 2003). The Mediterranean area has been intensely affected by human activity for millennia which caused only 4.7% of its primary vegetation to remain untouched (Geri et al. 2010). Agricultural expansion, urbanization and industrialization, population growth, development of tourism activities, and rural exodus are some of the main reasons leading to the alterations of the Mediterranean ecosystems (Serra et al. 2008). Rapid urban growth due to rural urban migration is putting enormous pressures on natural resources in the southern Mediterranean particularly Morocco (García-Ruiz et al. 2011). Marraccini et al. (2015) stated that transformation of natural vegetation into agriculture is prevalent in the southern Mediterranean region. Morocco's significant urban growth is creating LULC competition especially between housing and agricultural demands (Debolini et al. 2015). Agricultural activities within the country are also expanding to other LULCs which is affecting other vegetation and water resources (Johannsen et al. 2016). These changes are having impacts on the provision of ecosystem services in the country (Schilling et al. 2012).

Most of the studies on ecosystem services in Morocco have targeted one of the services (e.g., carbon storage by Maanan et al. (2019), water yield by Rochdane et al. (2012), and sediment export by Simonneaux et al. (2015)) whereas the rest with multiple ecosystem services focus on single watershed or specific locations within the country (e.g., Bouahim et al. (2015), Ghazi et al. (2018), Kusi et al. (2020)). Multiple ecosystem services are not sufficiently documented in Morocco especially at the national scale. Out of the 52 ecosystem services assessment studies conducted by Wangai et al. (2016) in Africa, only 11 of them were carried out at national scales and none was from the northern part of the Sahara Desert. The few ecosystem services assessment studies conducted at the national scale rarely incorporate the different watersheds of the country, and few of them provide enough information on areas of intervention at the watershed scale. Since the impacts of LULC change and management on ecosystem services are strongly reflected at the watershed scale, it is crucial to incorporate studies at the watershed scale into national ecosystem services assessment in order to better understand and improve human well-being (Jiang et al. 2016). This would also facilitate implementation of policies and strengthen sustainable governance (Colvin et al. 2016). Numerous studies concluded that ecosystem services assessments need to be conducted at various spatial and temporal scales (de Groot et al. 2010). A study done by Willcock et al. (2016) after surveying stakeholders in sub-Saharan Africa also concluded that there is a need for more information on ecosystem services at national scales in Africa. Information provided from multiple ecosystem services assessment at the national scale improves policies and decision-making on LULC management in developing countries like Morocco (McKenzie et al. 2011). The analysis at the local stage within the national assessment of ecosystem services is of great importance since the local people are highly dependent on ecosystem services for their livelihoods.

In this study, we assessed the impacts of LULC change and management activities on multiple ecosystem services in Morocco, North Africa. During this process, Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) (Tallis and Polasky 2009) was used to quantify and map five ecosystem services: carbon sequestration, sediment export, water yield, nitrogen export, and phosphorus export for the years 1992, 2003, and 2015. InVEST is a spatially explicit modeling tool which uses maps and biophysical tables of land use together with other ecological factors such as climate, soil, and topography as data inputs to quantify, map, and value multiple ecosystem services at different scales (Polasky et al. 2011). It is more convenient for assessing the impacts of the changes of LULC on multiple ecosystem services (Bagstad et al. 2013) since it provides a large documentation that is adequate, simple, and sufficient enough to help anyone to use while using different approaches to address the scarcity of data. InVEST has been used in different parts of the world by several authors with much success (Goldstein et al. 2012; Hamel et al. 2015). Another tool, Resource Investment Optimization System (RIOS) (Vogl et al. 2015), was also used to select appropriate areas at the watershed scale where activities focused on restoration and conservation could be implemented in order to improve ecosystem services. RIOS uses information from biophysical conditions such as land use, climate, soil, and topography, and social information from a given location to help with interventions and management (Vogl et al. 2017). RIOS generates land use scenarios from the implemented land management activities and investment alternatives. InVEST and RIOS models are often used together in ecosystem services assessment (Lüke and Hack 2018).

This paper aims to assess the effects of the principal LULC changes and management activities on five selected ecosystem services. The objectives of this study were (1) to analyze changes in LULC in 1992, 2003, and 2015; (2) to quantify and map changes in the five ecosystem services (carbon sequestration, sediment export, water yield, nitrogen export, and phosphorus export) at both watershed and national scales; (3) to analyze the overall ecosystem services combined at the national and watershed scales; and (4) to improve ecosystem services at the national and watershed scales through the implementation of land management activities.

Materials and method

Study area

Morocco is located in the northwestern part of Africa ranging between 21 N and 36 N latitude and between 1 and 17 W longitude (Fig. 1). It is bordered by the Mediterranean Sea on the north, the Atlantic Ocean on the west, Algeria on the east, and Mauritania on the south. The total surface area is 710,820 km^2 with 62% occupied by the pre-Saharan or Saharan area. Morocco has a mountainous landscape with the highest altitude of 4414 m at Toubkal and the lowest altitude of − 55 m at Sebkha Tah. The climate which is diverse varies from humid and sub-humid to Saharan and desert, also including arid, semiarid, and high mountain regions of the Rif, Middle Atlas, Anti Atlas, and High Atlas. The country has two major seasons: a hot and dry summer and a short winter with concentrated precipitation which are characteristics of a Mediterranean climate. The average maximum and minimum temperatures reach 50 °C in the Sahara and − 4 °C in the mountainous regions with a yearly average that can reach 10 °C. Precipitation is high in the north (more than 500 mm), medium in the center (between 100 and 500 mm), and low in the south (less than 100 mm). Precipitation falls between the periods of September and May, with November and December having the wettest months, but falls in the High and Middle Atlas as snow (Knippertz et al. 2003; Weisrock et al. 2006). Morocco has a bioecological diversity and important natural habitats which are divided into three main zones (Benabid 1985). The Mediterranean vegetation zone which consists of forests, bushland and thickets, shrublands, and matorral; the Mediterranean–Saharan transition zone which includes the argan scrub forest and steppes; and the Saharan zone which consists of sparse desert vegetation with Chenopodiaceae, grasses, and acacia trees. The grazing lands which are found in the south are the most dominant land use occupying more than 54 M ha (Sobrino and Raissouni 2000). Arable lands are about 22% of the land use in Morocco (Maliha et al. 2008).

Ecosystem services modeling

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool was used in this study to model, map, and quantify ecosystem services in the study area (Tallis 2011). This study selected five ecosystem services to model: water yield, sediment export, carbon storage, nitrogen export, and phosphorus export. These services were selected because they are the most studied services in Morocco and data to model these services are easily accessible. All the services are related to water which is crucial to Morocco except carbon storage which would help with climate regulation because climate change will strongly affect Morocco (Simonneaux et al. 2015). All the data inputs necessary for this tool and their source are shown in Appendix 2. LULC maps for 1992, 2003, and 2015 were obtained from the ESA/CCI Landcover Project database (https://www.esa-landcover-cci.org) at 300 m resolution. This study aimed to analyze changes in LULC of Morocco for over 20 years, and the ESA/CCI LC maps cover a period of 24 years from 1992 to 2015 which allows us to assess annual LULC change dynamics (Kirches et al. 2017). Although the full time series of ESA/CCI LC maps provide a better temporal coverage for changes in LULC compared to other global land cover maps, its overall accuracy is 71.5% (Bontemps et al. 2011) which is lower than Global Land Cover (Globeland30) (83.5%) (Chen et al. 2015) and Moderate Resolution Imaging Spectroradiometer (MODIS) (74.8%) (Friedl et al. 2010). The maps were reclassified into eight LULC (agriculture, forest, grassland, wetland, urban areas, sparse vegetation, bare areas, and water bodies) to facilitate the calculation of the tool (Appendix 1). The MODIS land cover type (MCD12Q1; Friedl et al. 2002) datasets from 2001 to 2010 were also analyzed to compare with the results from the ESA/CCI LC maps. The 30 m digital elevation model (DEM) was downloaded using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) from the Earth Observing System Data and Information System of NASA. The Department of Water and Forests of Morocco has divided the country into different watersheds for a proper management of natural resources while the larger basins are managed by the regional basin authorities. This study used the same division but divided the largest watershed, Saquia El Hamra, into 9 sub-watersheds (watersheds 20–28) for easy comparison and analysis using the DEM (Fig. 1). Other authors also used the same watersheds in their studies (FAO 2015; Schyns and Hoekstra 2014). All data was resampled to a 30-m spatial resolution and transformed into the same Universal Transverse Mercator (UTM) coordinate system.

Carbon storage

The InVEST Carbon model was used to quantify the carbon storage in Morocco. This model aggregates the amount of carbon stored in four different pools: aboveground biomass (all living plant material above the soil such as trunks and branches), belowground biomass (living root systems), soil organic matter (soil), and dead organic matter (litter and dead wood) (Sharp et al. 2018). The model demands a raster dataset for the current LULC map and biophysical data comprising four carbon pools for each LULC. The carbon values were estimated through the InVEST guide and a set of average literature values for each LULC category shown in Appendix 2 (Maanan et al. 2019; Oubrahim et al. 2015; Zaher et al. 2020). Aboveground biomass, belowground biomass, and soil organic carbon were the pools considered for

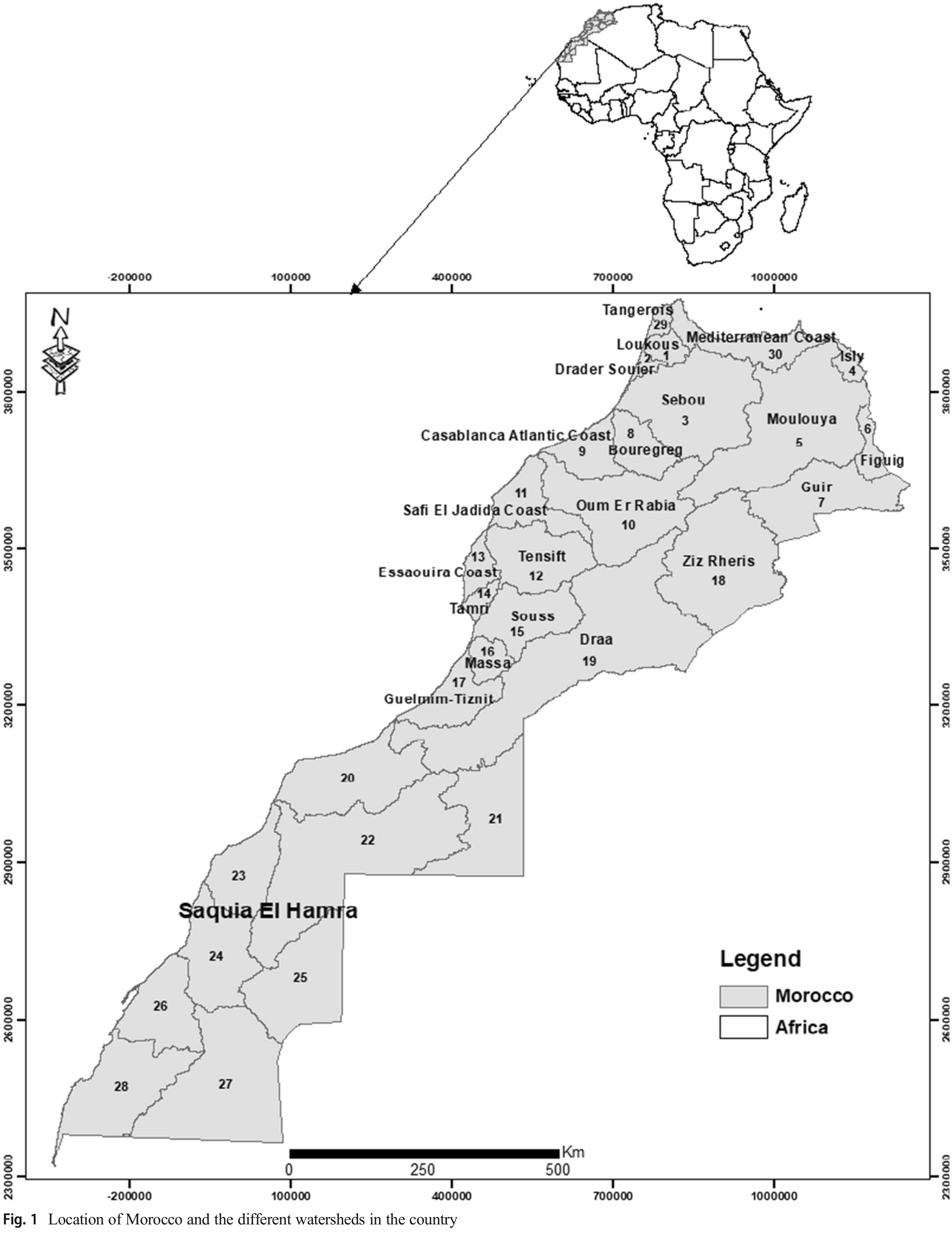

Fig. 1 Location of Morocco and the different watersheds in the country

this study. Lack of data and limited literature for dead wood carbon values partly due to restrictions from the authorities were the reasons why it was not considered for this study.

Sediment retention

Sediment retention refers to the ability of the watershed to keep the soil, and when soil loss is controlled, water quality is improved. The universal soil loss equation (Wischmeier and Smith 1978) is used for this model in predicting the potential soil loss for each pixel on the study area.

$$\mathrm{USLE} = R \times K \times \mathrm{LS} \times C \times P \quad (1)$$

where USLE is the average annual soil loss, R is the erosivity factor, K is the soil erodibility factor, LS is the field topography factor, C is the cropping and management factor, and P is the factor for supporting conservation practices. The values for cover management (C) and the practice factor (P) for each land use category were obtained from literature (Chadli 2016; Gaubi et al. 2017; Gourfi et al. 2018). Soil export was used as the main output for this model.

Water yield

In InVEST, water yield refers to the amount of water that runs off the landscape which will be useful for humans. The annual water yield which the model calculates uses mean annual precipitation, annual reference evapotranspiration, and correction factors for vegetation type, soil depth, and plant-available water content as data inputs (Sharp et al. 2018). All data source can be found in Appendix 2. The model estimates the total annual water yield (Y) for each pixel (x) of the watershed as total annual precipitation (P) minus total annual actual evapotranspiration (AET) (Eq. 2).

The water yield is determined for each pixel x by using this equation:

$$Yx = \{1 - \mathrm{AET}x/Px\}\ Px \quad (2)$$

where Yx is the water yield, AETx is the annual actual evapotranspiration, and Px is the annual precipitation. Using the methodology developed by Budyko (1974) and Zhang et al. (2004), the model relates AET to potential evapotranspiration (PET) since the measurement of AET is difficult at the watershed scale (Eq. 3). PET is estimated as the product of the reference evapotranspiration and the plant evapotranspiration coefficient for each pixel.

$$\mathrm{AET}x/Px = 1 + \mathrm{PET}x/Px - \{1 + [\mathrm{PET}x/Px]\ \omega\}\ 1/\omega \quad (3)$$

$$\omega = Z\ \{\mathrm{AWC}x/Px\} + 1.25 \quad (4)$$

where ω is an empirical parameter which is related to the plant available water content (AWC), precipitation, and the constant Z (Eq. 4) (Sharp et al. 2018). The evapotranspiration coefficients (KC) were estimated based on literature and the land use category (Hou et al. 2016; Redhead et al. 2016; Sharp et al. 2015).

Nitrogen retention

The model which has interest in water quality is used to estimate the quantity of nutrients retained by different land uses for water purification. The model uses a three-step procedure to estimate the amount of nutrients exported from one landscape to the streams (Leh et al. 2013). Firstly, it calculates the annual average water yield based on the method used for the water yield model. Then, the nitrogen and phosphorus export coefficients supplied by the user for each land use category are used to calculate the average annual amount of nutrients exported from each pixel. The loading value of nutrients at each pixel is adjusted by the inclusion of a hydrological sensitivity score.

$$\mathrm{ALV}x = \mathrm{HSS}x \cdot \mathrm{pol}x \quad (5)$$

where ALVx is the adjusted loading value of the nitrogen and phosphorus at pixel x, pol$x$ is the nitrogen and phosphorus export coefficient at pixel x, and HSSx is the hydrologic sensitivity score at pixel x which is calculated as

$$\mathrm{HSS}x = \lambda x/\lambda w \quad (6)$$

where λw is the mean runoff index for the watershed and λx is the runoff index at pixel x calculated using the formula

$$\lambda x = \log\ (\textstyle\sum Y) \quad (7)$$

where Y is the sum of water yield pixels along the flow path from pixel x and above. Finally, the quantity of nutrient load retained by the landscape is calculated using the retention capacity of nitrogen and phosphorus of each LULC class as

$$\mathrm{retention} = \mathrm{ALV}x \times \mathrm{filtration} \quad (8)$$

where filtration is the nitrogen and phosphorus retention capacity of a given LULC class. The data on nutrient export coefficients for Morocco is rare, so we used data from literature outside of the country (Berg et al. 2016; Gunaratne et al. 2017).

Total ecosystem services analysis at different scales

The study did an integrated assessment of ecosystem services at the watershed scale in order to find specific watersheds that need appropriate management activities to help improve the overall ecosystems in the country. The data outputs from the InVEST model were processed and analyzed to determine the performance of ecosystem services at the watershed scale.

Data processing

A hotspot analysis was performed using the Getis-Ord Gi* hotspot analysis method in ArcGIS 10.2 (ESRI, Redlands, CA) in order to identify hotspots for each ecosystem services for the study area. The Getis-Ord Gi* hotspot analysis determines where the features with high and low *z* scores and *p* values tend to form a cluster in the study area. *z* score output represents the statistical significance of clustering for a specified distance, whereas the *p* value indicates the probability that the observed spatial pattern was created by some random process. The *z* score and the *p* value calculated by the analysis tool for each ecosystem service help to indicate cold and hot spots in the study area. The study also combined the five services for the year 2015 where each service was reclassified into a unitless value in order to visualize the current state of ecosystem services at the watershed scale in Morocco using ArcGIS 10.2. All ecosystem services were reclassified into five classes (very low, low, moderate, high, and very high) based on the study of Arunyawat and Shrestha (2016). Carbon storage and water yield were reclassified from 1 (very low ecosystem service), 2 (low), 3 (medium), 4 (high), and 5 (very high) whereas sediment export and nitrogen and phosphorus exports were reclassified the opposite way in ArcGIS. Finally, all the reclassified maps were put together to determine the overall performance of the ecosystem services using the weighted sum tool in ArcGIS. The zonal statistics tool in ArcGIS was used to determine the degree of the overall ecosystem services for each watershed at the national scale. Moreover, a percentage change of ecosystem services for each watershed at the national scale was also performed to analyze the watersheds that had the highest change between 1992 and 2015.

Land management activities in a selected watershed

One watershed was selected in order to perform specific land management activities to help improve ecosystem services at this location and Morocco. The selection was based on the watersheds with the lowest performance of the overall ecosystem services and higher percentage decreases from 1992 to 2015 of the total ecosystem services (Figs. 7 and 8). The study selected the RIOS tool which is used for making investments with the aim of attaining the greatest ecosystem service returns regarding multiple objectives (Vogl et al. 2015). The tool is made up of two modules known as the Investment Portfolio Adviser and the Portfolio Translator, which offers the opportunity to select cost-effective locations for management activities with the aim of protecting, maintaining, or restoring ecosystem system services for human well-being at low costs. The tool permits the user to select different activities linked to seven transitions supported by RIOS (keeping native vegetation, assisted or unassisted revegetation, agricultural vegetation management, ditching, fertilizer management, and pasture management) (Vogl et al. 2015). This study selected three main activities—protection (keeping native vegetation), reforestation (assisted or unassisted revegetation), and silvo-pasture (pasture management)—and all other inputs were selected based on the management and investment program of the Department of Water and Forests aimed at conserving water and soil within the selected watershed shown in Appendix 3 (HCEFLCD 2013). The RIOS tool gives three different maps as output, but the transitioned map was selected for this study. The transitioned map is the LULC map that was generated as a result of implemented activities showing the new LULC combinations and protected areas. This tool has been used by several authors, and it is mostly used in conjunction with the InVEST model (Esmail and Geneletti 2017; Lüke and Hack 2018; Vogl et al. 2015). The transitioned map was used as the main LULC input for the InVEST model in order to compare and contrast the differences in the five ecosystem services to the base map of 2015.

Results

Land use/land cover change between 1992 and 2015 in Morocco

The major changes in LULC over the years are shown spatially at the national scale and the watershed scale in Figs. 2 and 3. The most predominant land use in Morocco is the bare area which occupies more than half of the total surface area, followed by sparse vegetation and agriculture (Fig. 2). From 1992 to 2015, there were changes in all the LULC categories except wetlands. There were increases in forests by 1858.7 km^2 (0.25%), sparse vegetation by 9420.7 km^2 (1.3%), agriculture by 2250.6 km^2 (0.3%), and urban areas by 1076.9 km^2 (0.14%) while grasslands and bare areas decreased by 2853.6 km^2 (0.4%) and 11812.7 km^2 (1.6%) respectively (Appendix 1). The increase in forests came mostly from agriculture and sparse vegetation whereas that of agriculture came from sparse vegetation, bare areas, forests, and grasslands respectively. The increase in sparse vegetation was as a result of a decline in bare areas, agriculture, and grasslands while the decline of agriculture, sparse vegetation, and bare areas provoked the increase in urban areas respectively. At the watershed scale, all the watersheds experienced changes with the highest coming from the northeastern part of the country and the least coming from the southern part. The watersheds that were highly altered were Moulouya, Souss, Ziz Rheris, and Guir, whereas Saquia El Hamra, Loukous, and Drader Souier were slightly altered (Fig. 3).

The expansion of forests happened in Sebou (493.7 km^2), Oum Er Rabia (159.1 km^2), and Loukous (117.8 km^2) while the increase in agriculture mainly took place in Moulouya

(1004.5 km^2), Souss (712.7 km^2), and Isly (649.5 km^2). The increase in sparse vegetation occurred in Moulouya (5205.7 km^2), Guir (2086.9 km^2), and Ziz Rheris (1722.6 km^2) whereas the increase in urban areas occurred in Sebou (108.5 km^2), Casablanca Atlantic Coast (68 km^2), and Tangerois (20.4 km^2). The decline in grassland happened in Oum Er Rabia, Draa, and Tensift whereas the decrease in bare areas took place in Moulouya, Guir, and Ziz Rheris. The results of LULC change using the ESA/CCI LC datasets were compared with the MODIS datasets from 2001 to 2010 (Appendix 1). The results from MODIS datasets showed increases in forests (227.6 km^2), sparse vegetation made up of shrublands and woodlands (4327.4 km^2), agriculture (9217.2 km^2), and urban areas (45.1 km^2) but a decrease in bare areas (14,942 km^2). The major difference between these two datasets was the grasslands which increased using the MODIS datasets but decreased when the ESA/CCI LC datasets were used.

Changes in ecosystem services

The changes in LULC from 1992 to 2015 affected all the ecosystem services in Morocco. The study showed decreases in all the ecosystem services except carbon storage in 2003 and 2015. Carbon storage increased at 1.66% in 2003 whereas water yield, sediment export, nitrogen exports, and phosphorus exports decreased at 6.2%, 0.21%, 0.88%, and 0.78% respectively. Between 1992 and 2015, there was an increase in carbon storage at 1.69% but there were decreases in water yield at 15.5%, sediment export at 7.4%, nitrogen export at 0.43%, and phosphorus export at 0.4% (Table 1). The highest change in carbon storage, water yield, and sediment export at the national scale occurred in the year 2015 whereas the year 2003 saw the highest decrease in nitrogen and phosphorus exports.

Figure 4 shows the spatial presentation of the ecosystem services at the national and watershed scales for the

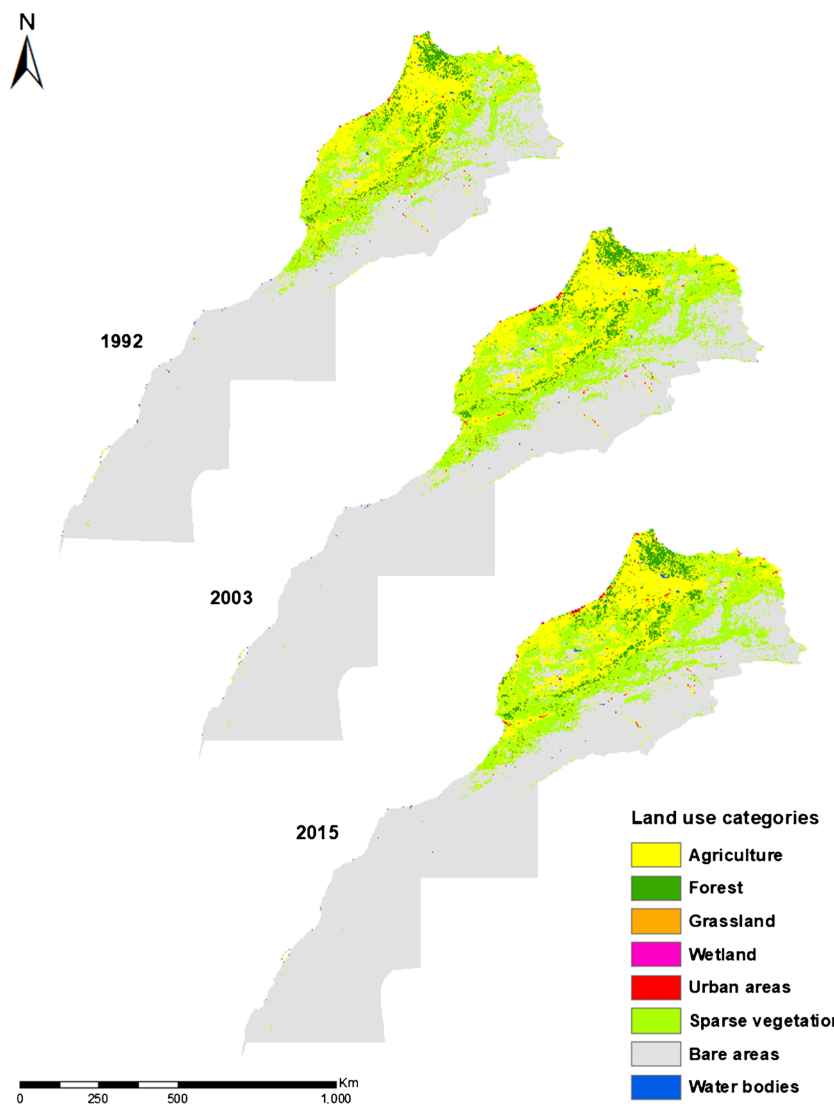

Fig. 2 Land use maps for 1992, 2003, and 2015

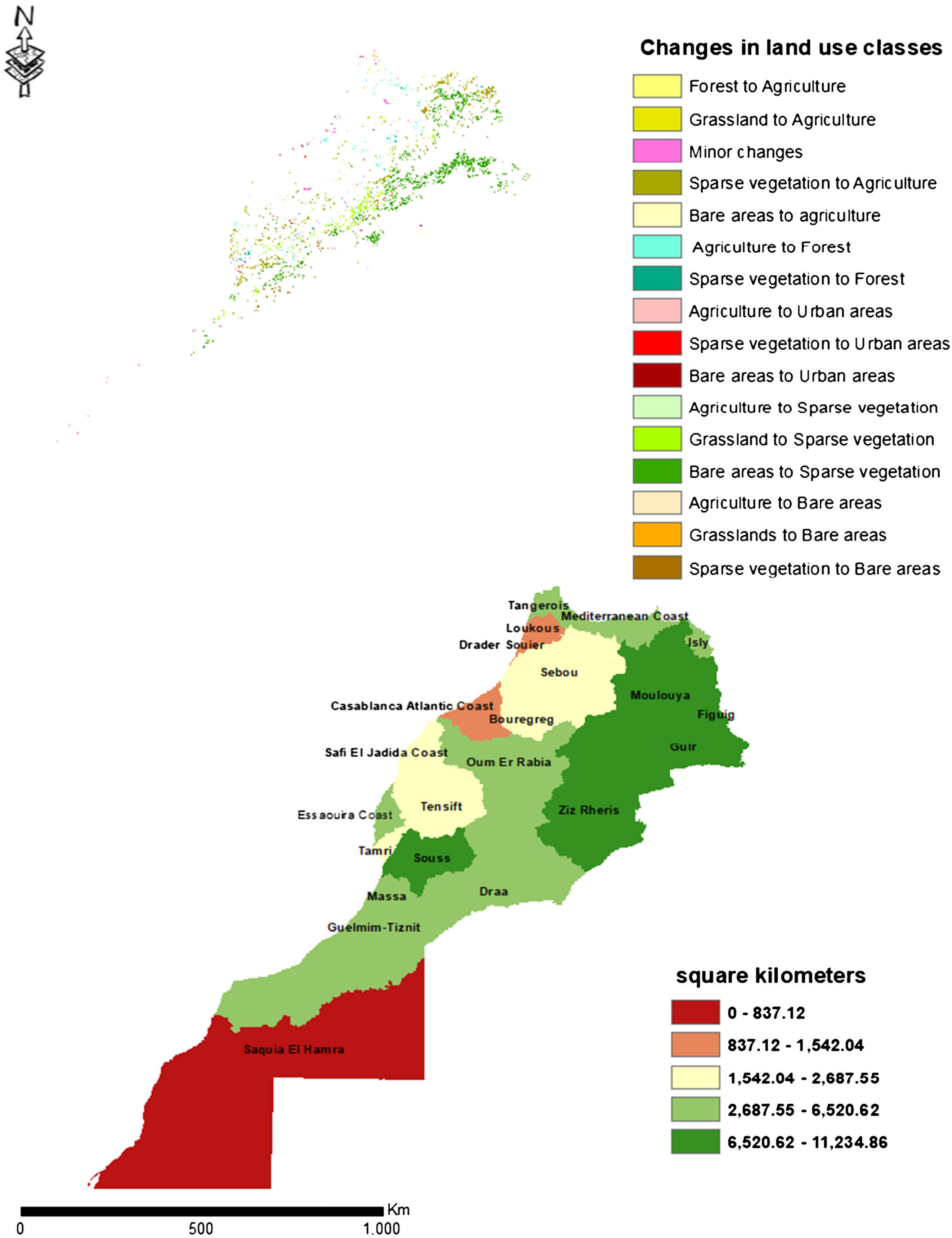

Fig. 3 Specific changes in the land use maps from 1992 to 2015 at the national and watershed levels

Table 1 Total values of ecosystem services estimated by the InVEST model in 1992, 2003, and 2015

	Water yield	Sediment export	Carbon storage	Nitrogen export	Phosphorus export
	$m^3 \times 10^6$	$t \times 10^6$	$t \times 10^6$	$kg \times 10^6$	$kg \times 10^6$
1992	8482.51	4751.10	3253.09	139.58	11.39
2003	7956.59	4740.98	3307.05	138.37	11.30
2015	7247.23	4391.04	3363.01	137.77	11.26

different years used in this study. Carbon storage was high in the northwestern parts of the country but low in the southern watersheds for all the years. Water yield was very high at the northeastern watersheds and very low at the southern parts of the country. Sediment export was high at the central parts toward the south whereas nitrogen and phosphorus exports were higher at the southern parts and low within the northern watersheds. The hotspot analysis shows that the watersheds in the red zone are the hotspots of a given ecosystem service which has high values of z score whereas the watersheds in blue are the cold spots of an ecosystem service with low values of z score (Fig. 5). The watersheds in red show statistically significant clustering or dispersion, an evidence of underlying spatial processes at work.

Changes in ecosystem services at the watershed scale of 2003 and 2015 are presented in Fig. 6 in the form of percentage change from 1992. Carbon storage saw the highest increase in the northern watersheds, with the Guir watershed showing the highest increase at 4% in 2003 and 25% in 2015. The highest decrease for carbon storage was found in Isly which is also found in the northeastern part of Morocco. The highest decline in water yield was found in Souss at 22% in 2003 and Moulouya at 28% in 2015, with other watersheds showing similar decreases such as watersheds Sebou, Guir, Mediterranean Coast, and Ziz Rheris. Safi El Jadida Coast, Saquia El Hamra, and Loukous were the only watersheds that showed increases in water yield for both years, with the highest increase coming from Ziz Rheris in 2003 and Safi El Jadida Coast in 2015. The highest increase in sediment export was found in Isly whereas the highest decrease was located in Ziz Rheris in 2015 (Fig. 7). The nitrogen and phosphorus exports presented higher increases in Isly for both years and higher decreases in Guir for 2015 and Saquia El Hamra for 2003.

Integrated ecosystem services assessment and management synergies

Figure 8 shows the performance of the overall ecosystem services at the watershed scale. The overall ecosystem services assessment shows that the northwestern and western watersheds showed higher levels of ecosystem services whereas the northeastern, the eastern, and the southern watersheds displayed moderate to lower levels of ecosystem services. More than half of the country (over 60%) has medium level of ecosystem services in 2015 whereas about 30% has high ecosystem services (Fig. 8). The total percentage changes in the overall ecosystem services from 1992 to 2015 for each watershed are shown in Fig. 7. There were higher decreases in Moulouya, Ziz Rheris, Souss, Guir, and Tamri watersheds whereas watersheds such as Massa, Essaouira Coast, Safi El Jadida Coast, and Saquia El Hamra presented the only increase for the overall ecosystem services in Morocco. Since almost all the watersheds located in the southern part are bare areas, Guir watershed which is located in the northeast was selected as the watershed that requires management activities in order to improve the state of the overall ecosystem services in the future.

Implementation of land management activities

The selected output from the RIOS model which shows the implementation of the selected activities on the base map is shown in Fig. 9. The transitioned map shows the conversion of sparse vegetation to forests based on the reforestation activity through assisted revegetation and the conversion of sparse vegetation to agriculture from the silvo-pasture activity through pasture management (Fig. 9). This caused an increase in carbon storage at 7.6% and decreases in sediment export, nitrogen export, and phosphorus export at 3.6%, 4.5%, and 2.6% but a negligible decrease in water yield for the transitioned scenario at the watershed scale (Table 2). At the national scale, the management activities implemented in the Guir watershed caused an increase in carbon storage at 0.2% (6,762,668 t) whereas water yield, sediment export, nitrogen export, and phosphorus export decreased at 0.07% (4,780,879 m^3), 0.09% (4,014,833 t), 0.17% (227,382 kg), and 0.09% (10,124 kg) respectively. The highest change occurred in carbon storage whereas the least change occurred in water yield.

Discussion

Principal LULC changes in Morocco

The LULC changes in Morocco revealed increases in forests and agriculture and urban areas between 1992 and 2015. This corresponds with the other studies on land use change in Morocco (e.g., Maanan et al. 2019; Simonneaux et al. 2015;

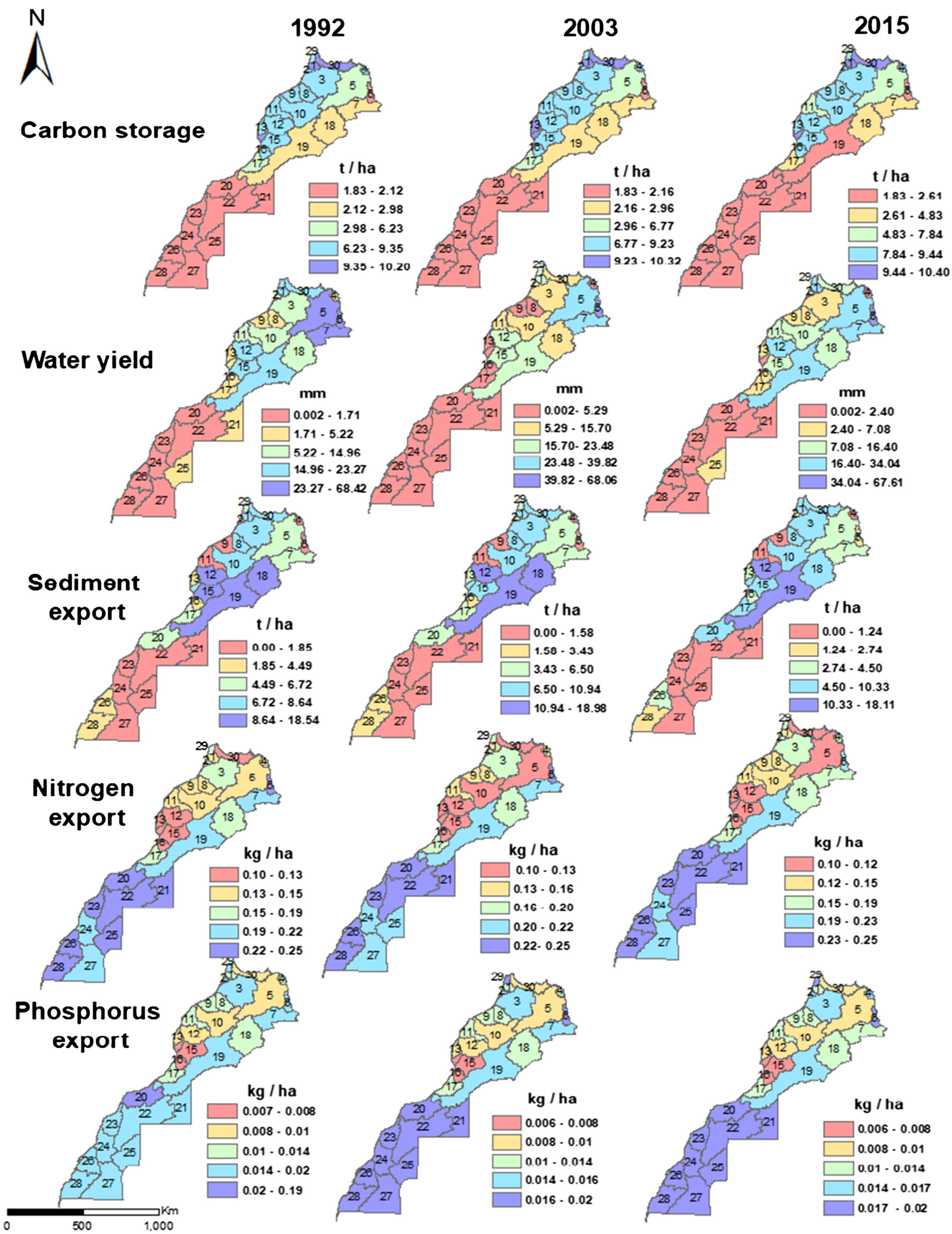

Fig. 4 Ecosystem services in the various watersheds at different years in Morocco

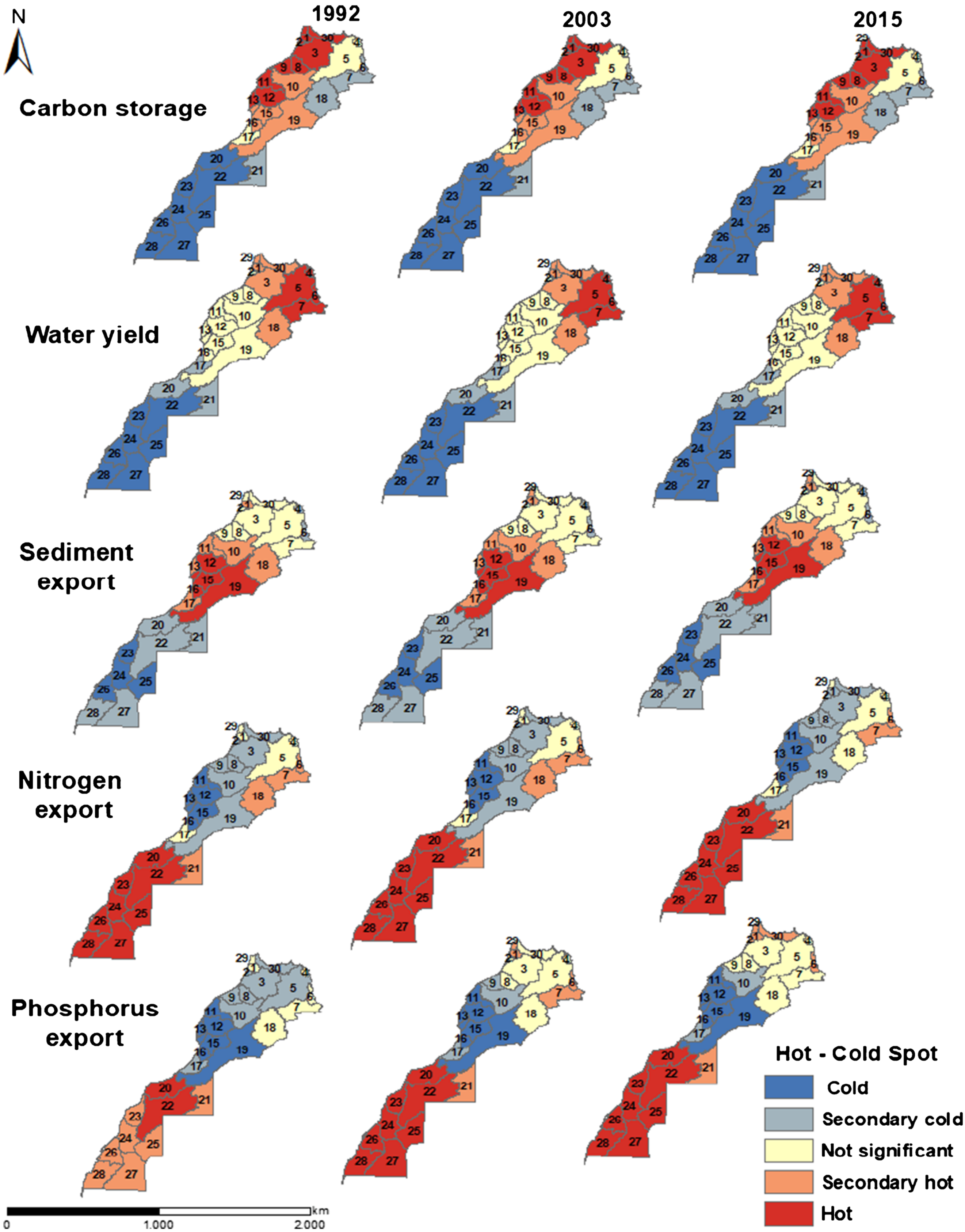

Fig. 5 The distribution of hotspots for the ecosystem services in the different watersheds in Morocco

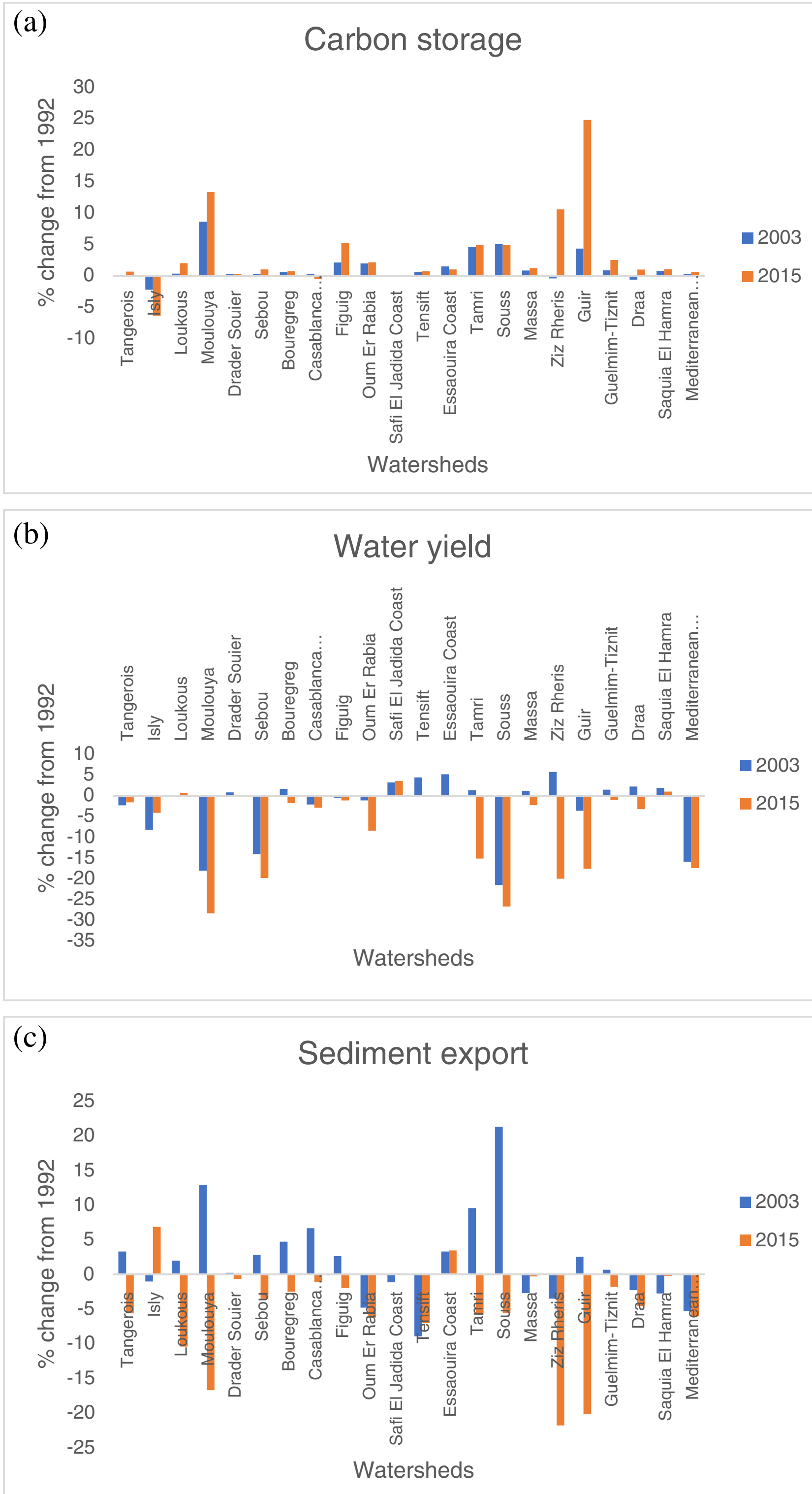

Fig. 6 Percentage change of ecosystem services from 1992 within the main watersheds of Morocco in 2003 and 2015. **a** Carbon storage, **b** water yield, **c** sediment export, **d** nitrogen export, **e** phosphorus export

Sobrino and Raissouni 2000). The results from the MODIS datasets also showed increases in forests and agriculture and urban areas which validates the LULC changes from the ESA/CCC LC results. Morocco is a country where rangeland, pasture, and forest occupy over half of the land area and agriculture or livestock raising is the source of livelihood of almost half of the working population (Barrow and Hicham 2000). The country is experiencing significant urbanization

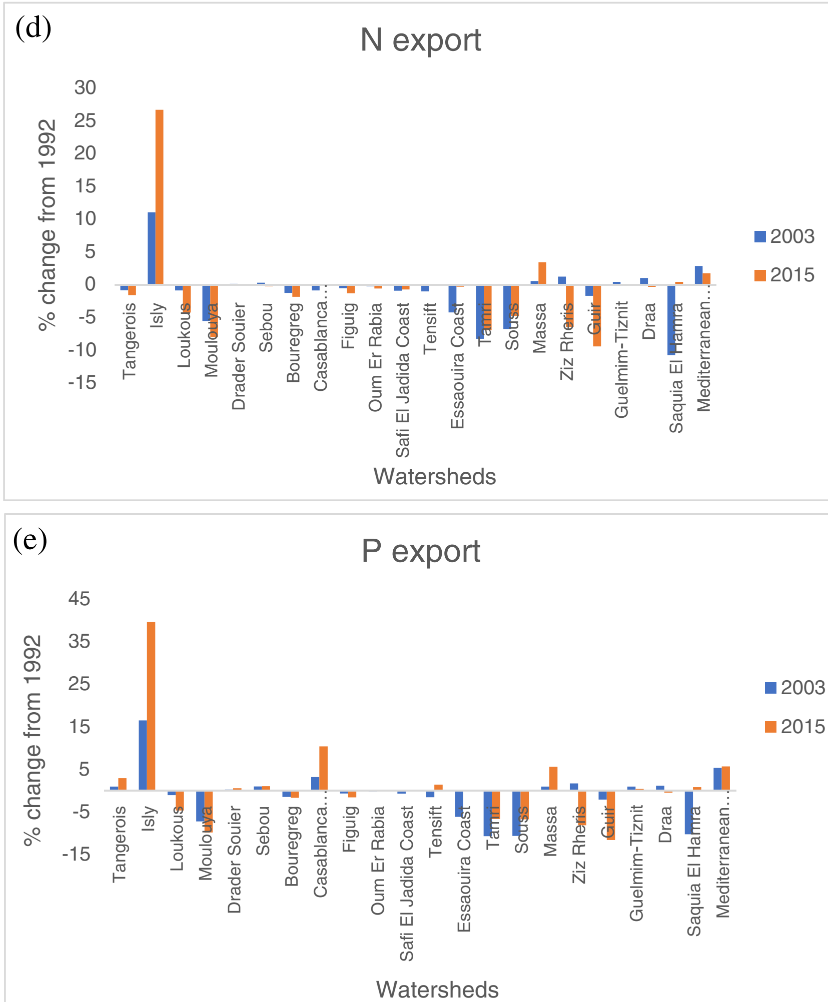

Fig. 6 (continued)

and urban growth like other southern Mediterranean countries where two thirds of the inhabitants already live in urban areas with an annual growth rate of 4.3% (Debolini et al. 2015). The urban population increased from 12.6 million in 1992 to 20.8 million in 2015 compared to the rural population which increased from 12.5 million to 13.4 million. The annual growth

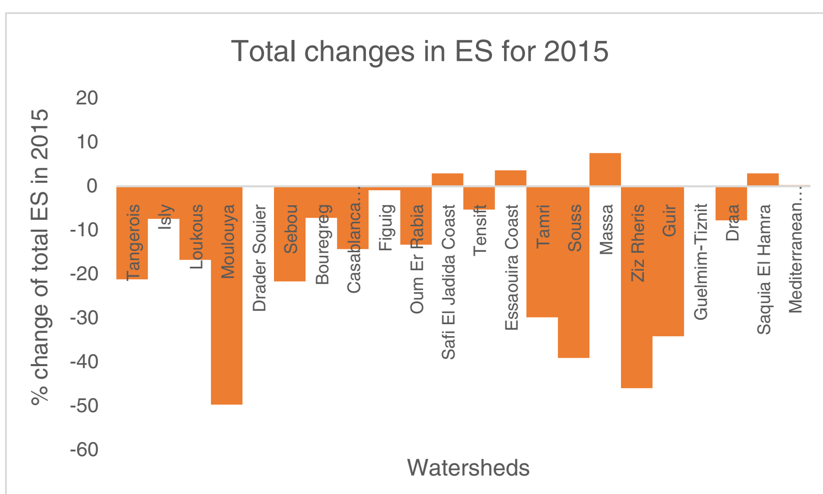

Fig. 7 Percentage change of the total ecosystem services for the different watersheds of Morocco for the latter year 2015

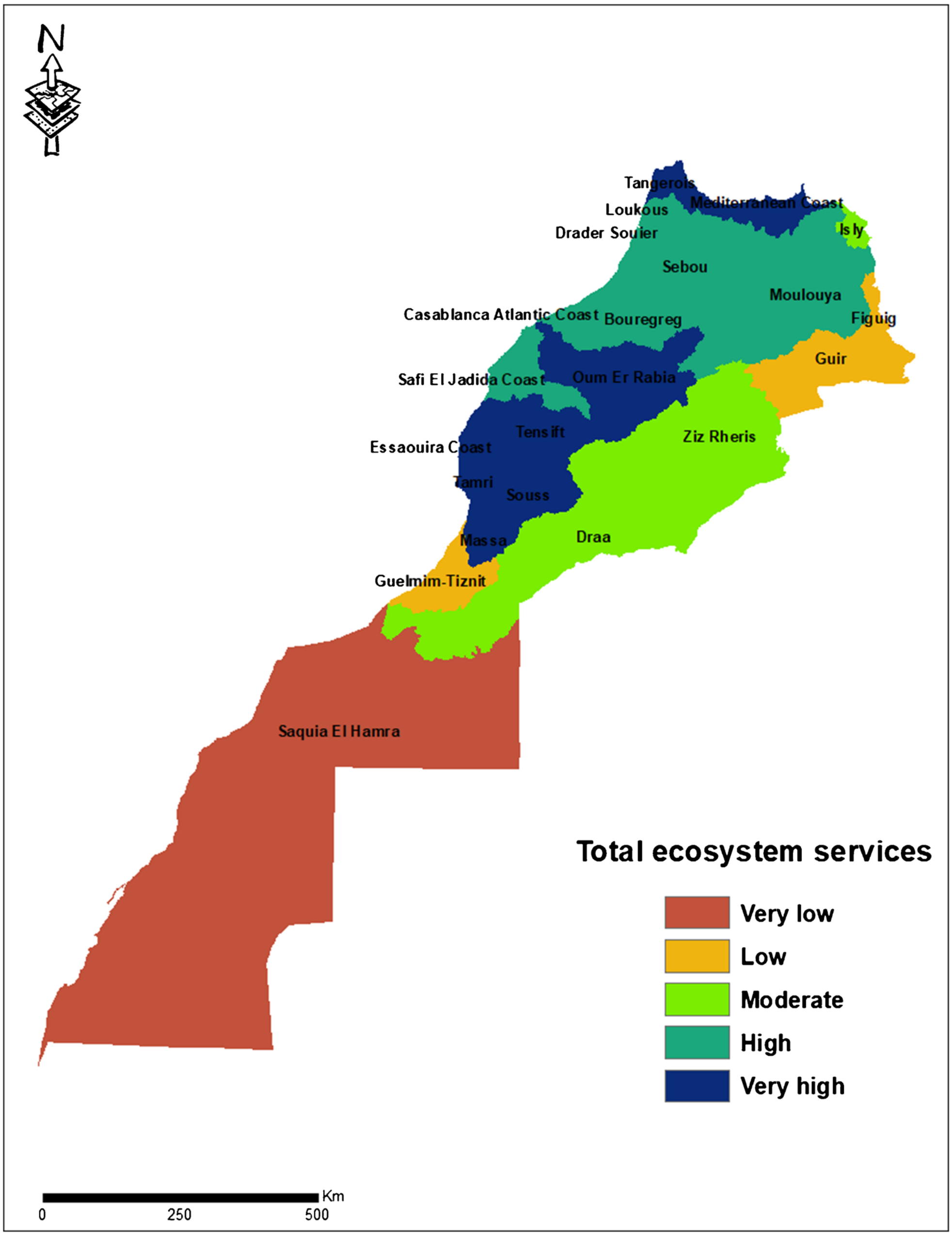

Fig. 8 Overall ecosystem services in Morocco for the latter year 2015

rate for the urban population was 3.27% and that of the rural population was 0.5% in 1992; it was 1.96% for the urban population and − 0.33% for the rural population in 2015 (HCP 2015). The population increase in urban areas had five regions (Casablanca-Settat, Rabat-Sale-Kenitra, Tanger-Tetouan-Al Hoceima, Sous-Massa, Marrakech-Safi) contributing to over 70% of the urban population. This is putting a lot of pressure on the land uses and creating land use competition between housing and other land uses. It is estimated that the southern regions of the country will have an annual growth rate at 1.4%, higher than the national average at 0.96% in 2030 (de Miras et al. 2005). Our results revealed that urban areas had the highest change rate between 1992 and 2015 at 93%, and these changes were observed mostly in the aforementioned five main regions.

Agricultural lands keep increasing because agriculture accounts for about 17% of the country's gross domestic product and employs about 40% of the country's labor force (Diao et al. 2008). Schilling et al. (2012) compared the importance of the agricultural sector to both the GDP and employment of the North African countries and Morocco ranked very high with Egypt. Agricultural lands have been increasing at the expense of grassland (McGregor et al. 2009). Agriculture expansion is driven by the need of raw material for national and international agro-processing industries. Transformation from traditional agriculture to huge agro-industrial plantations of

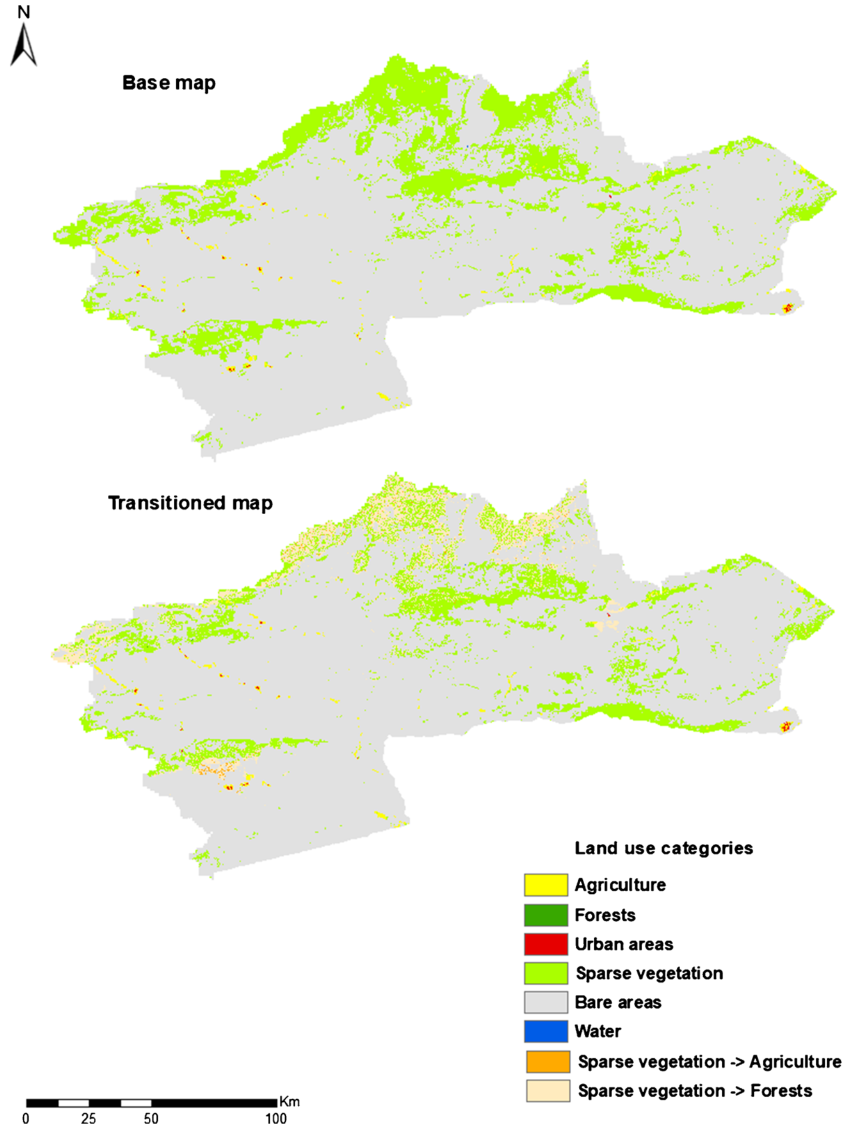

Fig. 9 Land use maps of the Guir watershed including the base and the transitioned maps

vegetables, citrus fruits, and bananas is common in the southern part of Morocco (Peter et al. 2014). The government's aim to increase agricultural productivity by up to 59% till 2020 through intensification of production and extension of cropland also caused the increase in agricultural lands in the country (Schilling et al. 2012).

The increase in forests is as a result of policies on climate change and desertification by the Moroccan government (Maanan et al. 2019). Increases in forests were seen in the Rif and Middle Atlas mountains (similar to Maliha et al. 2008). Rudel et al. (2005) stated that 38% of the world's countries had begun to experience sustained increases in forest cover after earlier periods of deforestation. A study done by Barakat et al. (2018) on the changes in LULC from 2001 to 2015 in the central and eastern parts of Morocco showed an increase in forest areas. Even though there has been deforestation in the country, increases in the forest areas through reforestation have caused an overall increase in the forests. Another study by Haboudane (2007) in the Middle Atlas of Morocco revealed that the total increment of the cedar

Table 2 Total values of ecosystem services for the Guir watershed

	Carbon storage	Sediment export	Water yield	Nitrogen export	Phosphorus export
	$m^3 \times 10^6$	$t \times 10^6$	$t \times 10^6$	$kg \times 10^6$	$kg \times 10^6$
Base	96.97	111.72	861.09	5.03	0.39
Transitioned	104.32	107.60	861.08	4.80	0.38

and holm forests (21%) had exceeded the effects of deforestation (17%). Mohajane et al. (2018) also concluded that the forest cover in Azrou, Middle Atlas, remained stable between 1987 and 2017. The reforestation projects by the Department of Water and Forests in Morocco contributed to the increase of forests in the country. For example, regeneration of natural species such as cedar, atlas cypress, cork oak, carob, and argan was 167,500 ha in 2003 (Allaoui 2004). The protection of national parks and reserves also contributed to the increase of forest cover. For example, the department of water and forestry established 2 national parks in the 1990s and 6 other parks between 2004 and 2008 as part of their conservation strategies which covered about 750,000 ha including the ones established in the past (Taleb 2016). One hundred fifty-four sites of biological and ecological interest classified as nature reserves covering an area of 2.5 million ha were also established beginning in 1996 to support sustainable management of the forests (Taleb 2016). The department also created the sector for protection of forests in 1999 to ensure the sustainability of forest ecosystems (Saintonge et al. 2011).

The main LULC that decreased drastically from 1992 to 2015 was grassland with a change rate of 80%. All over the world, grasslands are being degraded and transformed to other LULC categories such as agriculture (Egoh et al. 2011). This is evident in the temperate grasslands which have lost more than 70% of their natural cover by 1950 (Millenium Ecosystem Assessment 2005). In Morocco, most of the grasslands are used as rangelands for grazing and for collecting medicinal and aromatic plants (Mahyou et al. 2010). The level of degradation of grasslands, their conversion to agriculture, and the overexploitation for medicinal plants are evident in Morocco (Fennane 2004; Linstädter and Baumann 2013) and in the world (Claassen 2011; Tang et al. 2019). Grassland in the southern and the northeastern parts of the country are being converted to agriculture whereas conversion to urbanization is common in the remaining parts of the country (Mahyou et al. 2010). Water bodies also increased from 1992 to 2015 because Morocco doubled its number of dams from the 1990s to 152 in total by 2015 (Gourfi et al. 2018).

Ecosystem services and LULC change

Our results reveal a link between ecosystem services and LULC change and the way ecosystem services are affected by alterations in LULCs. Figures 4 and 7 show the impact changes in LULC have on multiple ecosystem services over the years. An integrated ecosystem assessment offers enough evidence to ensure a sustainable management of natural resources.

The increase in forests and sparse vegetation from 1992 to 2015 resulted in the improvement of carbon storage and a decline in nitrogen export, phosphorus export, sediment export, and water yield (Table 1). The contribution of forests to the improvement of carbon storage has been confirmed by several authors both in Morocco (Ghazi et al. 2018; Kusi et al. 2020; Maanan et al. 2019; Oubrahim et al. 2015) and in other parts of the world (Delphin et al. 2016; Martínez et al. 2009; Ouyang et al. 2016). This is confirmed in the hotspot analysis as the northwestern parts which are dominated by forests had higher carbon storage than anywhere else in the country (Fig. 5). The watersheds in red (Fig. 5) show the areas with the most protected forests and natural reserves. Other studies concluded that protected forests offer more ecosystem services especially carbon storage (García-Nieto et al. 2013; Palomo et al. 2013). This should help reduce the threats to forest ecosystems in the country such as firewood which is the main source of energy for the rural communities in Morocco (El Moudden 2004). Felling of trees and overgrazing constitute about 80% of crimes committed in the forest ecosystems in the country (Ellatifi 2012). Guir and Ziz Rheris had the highest increase in carbon storage due to the conversion of bare areas to sparse vegetation, 2086.9 km^2 and 1722.6 km^2 respectively, whereas Isly had the highest decline in carbon storage due to the conversion of sparse vegetation to agriculture (649.5 km^2) and a negligible increase in forests.

Soil export had a higher decrease at 7.4% from 1992 to 2015 due to the expansion of natural vegetation. Soil export was higher in the central parts of the country which are dominated by bare areas and sparse vegetation. The southern watersheds had lower values of sediment export as compared to the northern parts since the northern watersheds presented expansion of agriculture and urban areas. The expansion of agriculture and urban areas caused Isly to have the highest increase in soil export, but the increase in sparse vegetation and forests caused Guir, Ziz Rheris, and Moulouya to have the highest decline in soil export in 2015. Agriculture and less protective vegetation generally have higher rates of soil export than other LULCs (Simonneaux et al. 2015). Morocco's Mediterranean climate facilitates soil erosion due to the influence of concentrated precipitation in certain months with a warm and dry summer (Ramos and Martínez-Casasnovas 2009). The government's effort to increase perennials such as olives and citric fruits especially in agricultural lands contributed to the decrease in soil export (Schilling et al. 2012). Conservation agriculture and non-tillage systems which have been introduced in the arid watersheds of the country over the years also caused the reduced soil export, greater soil water conservation, and improved soil quality (Mrabet et al. 2012).

Water yield declined in 2003 and 2015 with a percentage decrease of 6.2% and 15.5% respectively, and this was due to the steady expansion of forest and sparse vegetation in these years (similar to Gao et al. 2017; Wu et al. 2018). Moulouya and Souss watersheds had the highest decline in water yield due to the high increase in forests. Forest expansion produces an increase in evapotranspiration which reduces water yield (Geneletti 2013; Zhan et al. 2015). The expansion of natural vegetation over the years helped to reduce nitrogen and phosphorus exports from 1990 to 2015. The decline of forests or sparse vegetation and the expansion of urban areas and agriculture caused the Isly watershed to have the highest increase in nitrogen and phosphorus exports.

Land management activities and ecosystem services

The eastern and southern watersheds of Morocco would need an implementation of activities to improve the state of ecosystem services for the whole country. Activities are feasible conservation strategies or measures taken to create realistic plans for watershed interventions in order to ensure sustainable management of watersheds. Most of the watersheds in Morocco presented decreases in the overall ecosystem services, and proper land management would help to enhance the ecosystem services in the country. Activities such as reforestation, protection of native forests, and pasture management were implemented in the Guir watershed, and this resulted in the improvement of ecosystem services at the watershed scale and at the national scale. The transitioned LULC map which incorporated the implementation of all these activities showed a decrease in sediment export and nitrogen and phosphorus exports but an increase in carbon storage and a negligible decrease in water yield at the watershed scale.

At the national scale, water yield declined by 0.07% as compared to the other ecosystem services and this was due to the incorporation of pasture management activities in the watershed. Zhan et al. (2015) also concluded that pasture planting is one of the ways to improve water yield. Kusi et al. (2020) found that the combination of forest and agricultural activities will help to stabilize water yield in the future. Carbon storage had the highest increase at the national scale by 0.2% which was mainly caused by the implementation of protection of native forests and reforestation activities. The decrease in sediment export was due to the reforestation, pasture management, and forest protection activities. Debolini et al. (2018) stated that forests and silvo-pastoralism facilitate the regulation of soil erosion and maintenance of soil fertility. Nitrogen export also had the highest decrease (0.17%) at the national scale due to the implemented land management activities. The land management activities implemented at the Guir watershed affected positively the overall ecosystem services at the watershed scale and the national scale. These activities could be encouraged in other parts of the country to ensure a sustainable management of ecosystem services both at the national scale and the watershed scale.

Improving multiple ecosystem services in Morocco

This study has shown that ecosystem services can be improved at the national scale when past LULC change is analyzed in order to follow the trend and be able to make proper decisions and policies that can improve ecosystem services in the future. The study also showed that ecosystem services can be well managed and improved at the national level when they are assessed at the watershed scale and when management activities are implemented at the watershed scale. It is important to analyze the hotspots of ecosystem services in order to know the areas of intervention either through protection or restoration of these services. The overall analysis of multiple ecosystem services gives a clear evidence of the state of ecosystem services and a well-balanced management that would reduce the impact of tradeoffs among different ecosystem services. Implementation of land management activities such as reforestation and pasture management at specific watersheds can help to improve the overall ecosystem services at both the national and the watershed scales.

Since agriculture has been the main focus of the Moroccan government for some years, policies should take into consideration sustainable agriculture and agricultural expansion at selected locations in order to ensure sustainable management of ecosystem services and LULC. Agricultural policies should integrate the assessment of overall ecosystem services to improve the well-being of the population. The Department of Water and Forests of Morocco should educate the local population about the conservation of forests and the protection of reforestation sites at the watershed scale since they contribute immensely to sustainable ecosystem services. Rural-urban migration which is causing urban expansion could be reduced if local farmers and shepherds benefit from programs such as the payment of ecosystem services. Sustainable ecosystem services could be achieved when there is active participation of local farmers, the private sector, and various government agencies in policy making and its implementation.

Conclusion

LULC change is a major driving force to the provision of ecosystem services at the national scale. Past LULC changes provide evidence that could help policy makers and stakeholders to decide on future LULC planning and ecosystem management. Future LULC management is required especially at the watershed scale to facilitate sustainable ecosystem services and land management. This study assessed the impacts of LULC change and land management activities on multiple ecosystem services in Morocco, North Africa. There were increases in natural vegetation and urban areas but decreases in grasslands and bare areas during the 23 years. These changes in LULC affected all the ecosystem services analyzed in this study, with carbon storage presenting the only increase in both 2003 and 2015. The remaining ecosystem services all decreased, with water yield revealing the highest decrease, followed by sediment export, nitrogen export, and phosphorus export in both years. The overall ecosystem services assessment at the national scale revealed a high level of ecosystem services in the northwestern watersheds of the country whereas the eastern and southern watersheds showed low levels of ecosystem services. The land management activities such as reforestation and pasture management implemented in one of the watersheds with low levels of ecosystem services caused an improvement in the overall ecosystem services at the watershed and national scales. Ecosystem services can be improved at the national scale when they are analyzed at the watershed scale whereas land management activities performed at selected watersheds generate an increase in ecosystem services both at the watershed and the national scales. This would also give a holistic knowledge for proper decision-making on ecosystem service management by stakeholders.

Appendix 1. Data inputs for InVEST

Table 3 Reclassification of land use categories adapted from Kirches et al. (2017)

	Reclassified LU type	Land use categories used in ESA /CCI LC maps	
1	Agriculture	10	Cropland rainfed
		11	Herbaceous cover
		12	Tree or shrub cover
		20	Cropland, irrigated or post-flooding
		30	Mosaic cropland (> 50%) / natural vegetation (tree shrub herbaceous cover) (< 50%)
		40	Mosaic natural vegetation (tree shrub herbaceous cover) (> 50%)/cropland (< 50%)
2	Forest	50	Tree cover broadleaved evergreen closed to open (> 15%)
		60	Tree cover broadleaved deciduous closed to open (> 15%)
		70	Tree cover needleleaved evergreen closed to open (> 15%)
		100	Mosaic tree and shrub (> 50%)/herbaceous cover (< 50%)
		170	Tree cover flooded saline water
3	Grassland	110	Mosaic herbaceous cover (> 50%)/tree and shrub (< 50%)
		130	Grassland
4	Wetland	180	Shrub or herbaceous cover flooded fresh/saline/brackish water
5	Urban areas	190	Urban
6	Sparse vegetation	120	Shrubland
		122	Shrubland deciduous
		150	Sparse vegetation (tree shrub herbaceous cover) (< 15%)
		153	Sparse herbaceous cover (< 15%)
7	Bare areas	200	Bare areas
		201	Consolidated bare areas
		202	Unconsolidated bare areas
8	Water bodies	210	Water

Table 4 Areas and percentage changes for ESA CCI LC and MODIS maps

ESA /CCI LC maps							
		1992	%	2003	%	2015	%
1	Agriculture	104,676.04	14.05	104,696.84	14.06	106,926.60	14.36
2	Forests	21,190.55	2.84	21,930.62	2.94	23,049.22	3.09
3	Grassland	3584.39	0.48	950.41	0.13	730.81	0.10
4	Wetland	1.27	0.00	1.27	0.00	1.27	0.00
5	Urban areas	1161.01	0.16	1606.74	0.22	2237.93	0.30
6	Sparse vegetation	115,712.56	15.54	121,722.04	16.34	125,133.24	16.80
7	Bare areas	497,550.98	66.80	493,037.88	66.19	485,738.25	65.21
8	Water	973.11	0.13	904.09	0.12	1032.60	0.14
MODIS maps							
		2001	%	2010	%		
1	Forests	771.43	0.11	999.05	0.15		
2	Woodlands	4600.66	0.67	6605.20	0.97		
3	Grasslands	60,011.29	8.79	61,079.05	8.94		
4	Shrublands	98,864.89	14.48	101,187.77	14.82		
5	Croplands	72,785.25	10.66	82,002.41	12.01		
6	Wetlands	87.50	0.01	97.97	0.01		
7	Urban areas	1822.28	0.27	1867.38	0.27		
8	Bare areas	443,698.38	64.97	428,756.40	62.78		
9	Water bodies	263.85	0.04	310.29	0.05		

Appendix 2. Data inputs for InVEST

Table 5 Data requirement for the InVEST model (water yield model = WY; nutrient delivery ratio model = NDR; sediment delivery ratio model = SDR; carbon = C)

Data	Type	Data source	Related model
Digital elevation model (DEM)	Raster	Earth Data NASA, https://earthdata.nasa.gov	NDR, SDR
Annual average precipitation	Raster	Global Climate and weather data, https://www.worldclim.org	WY, NDR, SDR
Reference evapotranspiration	Raster	Global Aridity and Potential Evapotranspiration Database, https://cgiarcsi.community	WY
Plant available water content	Raster	Harmonized World Soil Database, http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/	WY
Land use/land cover	Raster	ESA/CCI Landcover Project database (https://www.esa-landcover-cci.org)	WY, NDR, SDR. C
Depth to root restricting layer	Raster	Harmonized World Soil Database, http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/	WY
Watersheds	Shapefile	WWF HydroSHEDS, https://www.hydrosheds.org	WY, NDR, SDR
Rainfall erosivity index	Raster	European Soil Data Centre, https://esdac.jrc.ec.europa.eu	SDR
Soil erodibility	Raster	Harmonized World Soil Database, http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/	SDR
Biophysical table	.CSV file	Literatures, and the InVEST user's guide (cited in the methodology)	WY, NDR, SDR, C

Table 6 Biophysical table for the carbon model

Value	C_above	C_below	C_soil	C_dead	lucode	LULC_desc
1	44.43	29.3	10.45	0	1	Agriculture
2	132.4	26.14	15.67	0	2	Forests
3	31.2	1.1	18.67	0	3	Grassland
4	82	1.3	20	0	4	Wetland
5	3	0.6	13.5	0	5	Urban areas
6	88.7	1.8	25.4	0	6	Sparse vegetation
7	3.5	0.35	16.5	0	7	Bare areas
8	0	0	0	0	8	Water bodies

Table 7 Biophysical table for the water yield model

Value	root_depth	Kc	lucode	LULC_desc	LULC_veg
1	1473	1.12	1	Agriculture	1
2	1740	1	2	Forests	1
3	1560	0.56	3	Grassland	1
4	1600	1	4	Wetland	0
5	1000	0.4	5	Urban areas	0
6	2089	0.95	6	Sparse vegetation	1
7	100	0.175	7	Bare areas	0
8	1	1	8	Water	0

Table 8 Biophysical table for SDR and NDR models

usle_c	usle_p	LULC_desc	load_n	eff_n	load_p	eff_p	crit_len_p	crit_len_n	proportion_ subsurface_n	proportion _subsurface_p
0.19	1	Agriculture	7.4	0.69	1.305	0.59	150	150	0.5	0.5
0.003	1	Forests	2.89	0.8	0.07	0.74	150	150	0	0
0.003	1	Grassland	2.87	0.51	0.075	0.48	150	150	0	0
0.03	1	Wetland	2.87	0.51	0.075	0.48	150	150	0	0
0.1	1	Urban areas	11.86	0.43	2.55	0.02	150	150	0	0
0.072	1	Sparse vegetation	2.87	0.51	0.075	0.48	150	150	0	0
1	1	Bare areas	6.8	0.1	0.51	0.02	150	150	0	0
0.04	1	Water	0	0.06	0	0.61	150	150	0	0

Appendix 3. Data inputs for RIOS

Table 9 Land use classification data

lucode	LULC_desc	protection	reforestation	silvopasture
1	Agriculture	0	0	0
2	Forests	1	1	0
5	Urban areas	0	0	0
6	Sparse vegetation	0	1	1
7	Bare areas	0	0	0
8	Water	0	0	0

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Data availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication All the authors and stakeholders have agreed to this publication.

Conflict of interest The authors declare that they have no competing interests.

References

Allaoui, M., 2004. Forêts et dévéloppement durable dans les provinces de Chefchaouen et d'Ifrane: Projet Forêts Méditerranéennes et Développement Durable.

Arunyawat S, Shrestha RP (2016) Assessing land use change and its impact on ecosystem services in Northern Thailand. Sustainability 8:768. https://doi.org/10.3390/su8080768

Bagstad KJ, Semmens DJ, Waage S, Winthrop R (2013) A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosystem Serv 5:27–39. https://doi.org/10.1016/j.ecoser.2013.07.004

Barakat A, Khellouk R, El Jazouli A, Touhami F, Nadem S (2018) Monitoring of forest cover dynamics in eastern area of Béni-Mellal Province using ASTER and Sentinel-2A multispectral data. Geol Ecol Landscapes 2:203–215

Barrow CJ, Hicham H (2000) Two complimentary and integrated land uses of the western High Atlas Mountains, Morocco: the potential for sustainable rural livelihoods. Appl Geogr 20:369–394

Benabid, A., 1985. Les écosystèmes forestiers, préforestiers et presteppiques du Maroc: diversité, répartition biogéographique et problèmes posés par leur aménagement. Forêt méditerranéenne.

Berg C, Rogers S, Mineau M (2016) Building scenarios for ecosystem services tools: developing a methodology for efficient engagement with expert stakeholders. Futures Model Simul Futures Stud 81:68–80. https://doi.org/10.1016/j.futures.2015.10.014

Bontemps, S., Defourny, P., Van Bogaert, E., Arino, O., Kalogirou, V., Perez, J.R., 2011. GLOBCOVER 2009-products description and validation report. URL: http://ionia1.esrin.esa.int/docs/GLOBCOVER2009_Validation_Report_22.

Bouahim S, Rhazi L, Ernoul L, Mathevet R, Amami B, Er-Riyahi S, Muller SD, Grillas P (2015) Combining vulnerability analysis and perceptions of ecosystem services in sensitive landscapes: a case from western Moroccan temporary wetlands. J Nat Conserv 27:1–9. https://doi.org/10.1016/j.jnc.2015.05.003

Budyko MI (1974) Climate and life. English ed. edited by David H. Miller., English ed. / edited by David H. Miller. ed. Academic Press, New York

Chadli K (2016) Estimation of soil loss using RUSLE model for Sebou watershed (Morocco). Model Earth Syst Environ 2:1–10

Chen J, Chen J, Liao A, Cao X, Chen L, Chen X, He C, Han G, Peng S, Lu M, Zhang W, Tong X, Mills J (2015) Global land cover mapping at 30 m resolution: a POK-based operational approach. ISPRS J Photogrammetry Remote Sensing Glob Land Cover Mapp Monit 103:7–27. https://doi.org/10.1016/j.isprsjprs.2014.09.002

Claassen RL (2011) Grassland to cropland conversion in the Northern Plains: the role of crop insurance, commodity, and disaster programs. DIANE Publishing, Darby, PA

Colvin RM, Witt GB, Lacey J (2016) Approaches to identifying stakeholders in environmental management: insights from practitioners to go beyond the 'usual suspects.'. Land Use Policy 52:266–276. https://doi.org/10.1016/j.landusepol.2015.12.032

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387:253–260. https://doi.org/10.1038/387253a0

de Groot RS, Alkemade R, Braat L, Hein L, Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol Complexity Ecosyst Serv Bridging Ecol Econ Soc Sci 7:260–272. https://doi.org/10.1016/j.ecocom.2009.10.006

Miras, C. de, Chanson-Jabeur, C., Godard, X., Rachik, A., Saloui, A., Toutain, O., Baouendi, A., El Herech, M., 2005. Intégration à la ville et services urbains au Maroc.

Debolini M, Marraccini E, Dubeuf JP, Geijzendorffer IR, Guerra C, Simon M, Targetti S, Napoléone C (2018) Land and farming system dynamics and their drivers in the Mediterranean Basin. Land Use Policy 75:702–710. https://doi.org/10.1016/j.landusepol.2017.07.010

Debolini M, Valette E, François M, Chéry J-P (2015) Mapping land use competition in the rural–urban fringe and future perspectives on land policies: a case study of Meknès (Morocco). Land Use Policy 47:373–381. https://doi.org/10.1016/j.landusepol.2015.01.035

Delphin S, Escobedo FJ, Abd-Elrahman A, Cropper WP (2016) Urbanization as a land use change driver of forest ecosystem services. Land Use Policy 54:188–199. https://doi.org/10.1016/j.landusepol.2016.02.006

Diao X, Dinar A, Roe T, Tsur Y (2008) A general equilibrium analysis of conjunctive ground and surface water use with an application to Morocco. Agric Econ 38:117–135

Egoh BN, Reyers B, Rouget M, Richardson DM (2011) Identifying priority areas for ecosystem service management in South African grasslands. J Environ Manage 92:1642–1650. https://doi.org/10.1016/j.jenvman.2011.01.019

El Moudden S (2004) Impact du prélèvement du bois de feu sur les parcours steppiques cas d'Ighil n'Mgoun, province de Ouarzazate. Institut agronomique et veterinaire Hassan II, Rabat, pp 1–138

Ellatifi M (2012) L'économie de la forêt et des produits forestiers au Maroc: bilan et perspectives (Doctoral dissertation, Bordeaux IV), pp 1–424

Esmail BA, Geneletti D (2017) Design and impact assessment of watershed investments: an approach based on ecosystem services and boundary work. Environ Impact Asses Rev 62:1–13. https://doi.org/10.1016/j.eiar.2016.08.001

FAO (2015) AQUASTAT Profil de Pays – Maroc. Organisation des Nations Unies pour l'alimentation et l'agriculture, Rome

Fennane M (2004) Propositions de zones importantes pour les plantes au Maroc (ZIP Maroc). Institut Scientifique, Rabat

Friedl, M.A., McIver, D.K., Hodges, J.C.F., Zhang, X.Y., Muchoney, D., Strahler, A.H., Woodcock, C.E., Gopal, S., Schneider, A., Cooper, A., Baccini, A., Gao, F., Schaaf, C., 2002. Global land cover mapping from MODIS: algorithms and early results. Remote Sensing of Environment, The Moderate Resolution Imaging Spectroradiometer (MODIS): a new generation of Land Surface Monitoring 83, 287–302. doi:https://doi.org/10.1016/S0034-4257(02)00078-0

Friedl MA, Sulla-Menashe D, Tan B, Schneider A, Ramankutty N, Sibley A, Huang X (2010) MODIS Collection 5 global land cover: algorithm refinements and characterization of new datasets. Remote

Sensing Environ 114:168–182. https://doi.org/10.1016/j.rse.2009.08.016
Gao J, Li F, Gao H, Zhou C, Zhang X (2017) The impact of land-use change on water-related ecosystem services: a study of the Guishui River Basin, Beijing, China. J Cleaner Production Urban Ecol Infrastructure Healthier Cities 163:S148–S155. https://doi.org/10.1016/j.jclepro.2016.01.049
García-Nieto AP, García-Llorente M, Iniesta-Arandia I, Martín-López B (2013) Mapping forest ecosystem services: from providing units to beneficiaries. Ecosystem Serv Spec Issue Mapp Model Ecosyst Serv 4:126–138. https://doi.org/10.1016/j.ecoser.2013.03.003
García-Ruiz JM, López-Moreno JI, Vicente-Serrano SM, Lasanta-Martínez T, Beguería S (2011) Mediterranean water resources in a global change scenario. Earth-Sci Rev 105:121–139. https://doi.org/10.1016/j.earscirev.2011.01.006
Gaubi I, Chaabani A, Ben Mammou A, Hamza MH (2017) A GIS-based soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) (Lebna watershed, Cap Bon, Tunisia). Nat Hazards 86:219–239. https://doi.org/10.1007/s11069-016-2684-3
Geneletti D (2013) Assessing the impact of alternative land-use zoning policies on future ecosystem services. Environ Impact Asses Rev Ecosystem Serv EIA SEA 40:25–35. https://doi.org/10.1016/j.eiar.2012.12.003
Geri F, Amici V, Rocchini D (2010) Human activity impact on the heterogeneity of a Mediterranean landscape. Appl Geogr 30:370–379. https://doi.org/10.1016/j.apgeog.2009.10.006
Ghazi H, Messouli M, Khebiza MY, Egoh BN (2018) Mapping regulating services in Marrakesh Safi region-Morocco. J Arid Environ 159:54–65
Goldstein JH, Caldarone G, Duarte TK, Ennaanay D, Hannahs N, Mendoza G, Polasky S, Wolny S, Daily GC (2012) Integrating ecosystem-service tradeoffs into land-use decisions. PNAS 109:7565–7570. https://doi.org/10.1073/pnas.1201040109
Gourfi A, Daoudi L, Shi Z (2018) The assessment of soil erosion risk, sediment yield and their controlling factors on a large scale: example of Morocco. J Afr Earth Sci 147:281–299. https://doi.org/10.1016/j.jafrearsci.2018.06.028
Grove AT, Rackham O (2003) The nature of Mediterranean Europe: an ecological history. Yale University Press, New Haven, Connecticut
Gunaratne GL, Vogwill RI, Hipsey MR (2017) Effect of seasonal flushing on nutrient export characteristics of an urbanizing, remote, ungauged coastal catchment. Hydrol Sci J 62:800–817
Haboudane D (2007) Deforestation Detection and Monitoring in Cedar Forests of the Moroccan Middle-Atlas Mountains. 2007 IEEE International Geoscience and Remote Sensing Symposium, Barcelona, Spain, pp 4327-4330. https://doi.org/10.1109/IGARSS.2007.4423809
Hamel P, Chaplin-Kramer R, Sim S, Mueller C (2015) A new approach to modeling the sediment retention service (InVEST 3.0): case study of the Cape Fear catchment, North Carolina, USA. Sci Total Environ 524–525:166–177. https://doi.org/10.1016/j.scitotenv.2015.04.027
Haut-Commissariat au Plan (HCP), 2015. Population légale des régions, provinces, préfectures, municipalités, arrondissements et communes du Royaume d'après les résultats du RGPH 2014, Rabat. Recensement Général de la Population et de l'Habitat (RGPH), Royaume du Maroc. [Consulté en ligne :http://www.hcp.ma/downloads/RGPH-2014_t17441.html].
HCEFLCD, 2013. Le Programme d'Action National de Lutte Contre la Désertification: Actualisation et adaptation aux spécificités zonales. Rapport de Synthèse.
Hou Y, Li B, Müller F, Chen W (2016) Ecosystem services of human-dominated watersheds and land use influences: a case study from the Dianchi Lake watershed in China. Environ Monit Asses 188:652
Jiang C, Li D, Wang D, Zhang L (2016) Quantification and assessment of changes in ecosystem service in the Three-River Headwaters Region, China as a result of climate variability and land cover change. Ecol Indicators 66:199–211. https://doi.org/10.1016/j.ecolind.2016.01.051
Johannsen IM, Hengst JC, Goll A, Höllermann B, Diekkrüger B (2016) Future of water supply and demand in the Middle Drâa Valley, Morocco, under climate and land use change. Water 8:313. https://doi.org/10.3390/w8080313
Kertész Á, Nagy LA, Balázs B (2019) Effect of land use change on ecosystem services in Lake Balaton Catchment. Land Use Policy 80:430–438. https://doi.org/10.1016/j.landusepol.2018.04.005
Kirches, G., Brockmann, C., Boettcher, M., Peters, M., Bontemps, S., Lamarche, C., Schlerf, M., Santoro, M., Defourny, P., 2017. Land cover cci-product user guide version 2.0. ESA Public Document CCI-LC-PUG.
Knippertz P, Christoph M, Speth P (2003) Long-term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climates. Meteorol Atmos Phys 83:67–88. https://doi.org/10.1007/s00703-002-0561-y
Kusi KK, Khattabi A, Mhammdi N, Lahssini S (2020) Prospective evaluation of the impact of land use change on ecosystem services in the Ourika watershed, Morocco. Land Use Policy 97:104796. https://doi.org/10.1016/j.landusepol.2020.104796
Lang Y, Song W, Zhang Y (2017) Responses of the water-yield ecosystem service to climate and land use change in Sancha River Basin, China. Phys Chem Earth Parts A/B/C, Phys Econ Ecosystem Serv Flows 101:102–111. https://doi.org/10.1016/j.pce.2017.06.003
Leh MDK, Matlock MD, Cummings EC, Nalley LL (2013) Quantifying and mapping multiple ecosystem services change in West Africa. Agric Ecosystems Environ 165:6–18. https://doi.org/10.1016/j.agee.2012.12.001
Linstädter A, Baumann G (2013) Abiotic and biotic recovery pathways of arid rangelands: lessons from the High Atlas Mountains, Morocco. Catena 103:3–15
Lüke A, Hack J (2018) Comparing the applicability of commonly used hydrological ecosystem services models for integrated decision-support. Sustainability 10:346
Maanan M, Maanan M, Karim M, Kacem HA, Ajrhough S, Rueff H, Snoussi M, Rhinane H (2019) Modelling the potential impacts of land use/cover change on terrestrial carbon stocks in north-west Morocco. Int J Sustainable Dev World Ecol 26:560–570. https://doi.org/10.1080/13504509.2019.1633706
Mahyou H, Tychon B, Balaghi R, Mimouni J, Paul R (2010) Désertification des parcours arides au Maroc. Tropicultura 28:107–114
Maliha NS, Chaloud DJ, Kepner WG, Sarri S (2008) Regional assessment of landscape and land use change in the Mediterranean region. In: Liotta PH, Mouat DA, Kepner WG, Lancaster JM (eds) Environmental change and human security: recognizing and acting on hazard impacts, NATO Science for Peace and Security Series C: Environmental Security. Springer Netherlands, Dordrecht, pp 143–165. https://doi.org/10.1007/978-1-4020-8551-2_8
Marraccini E, Debolini M, Moulery M, Abrantes P, Bouchier A, Chéry J-P, Sanz Sanz E, Sabbatini T, Napoleone C (2015) Common features and different trajectories of land cover changes in six Western Mediterranean urban regions. Appl Geogr 62:347–356. https://doi.org/10.1016/j.apgeog.2015.05.004
Martínez ML, Pérez-Maqueo O, Vázquez G, Castillo-Campos G, García-Franco J, Mehltreter K, Equihua M, Landgrave R (2009) Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico. Forest Ecol Manag 258:1856–1863. https://doi.org/10.1016/j.foreco.2009.02.023
McGregor HV, Dupont L, Stuut J-BW, Kuhlmann H (2009) Vegetation change, goats, and religion: a 2000-year history of land use in southern Morocco. Quaternary Sci Rev 28:1434–1448. https://doi.org/10.1016/j.quascirev.2009.02.012
McKenzie E, Irwin F, Ranganathan J, Hanson C, Kousky C, Bennett K, Ruffo S, Conte M, Salzman J, Paavola J (2011) Incorporating

ecosystem services in decisions. Natural capital: theory and practice of mapping ecosystem services. Oxford University Press, Oxford, pp 339–355
Milheiras SG, Mace GM (2019) Assessing ecosystem service provision in a tropical region with high forest cover: spatial overlap and the impact of land use change in Amapá, Brazil. Ecol Indicators 99:12–18. https://doi.org/10.1016/j.ecolind.2018.12.013
Millennium Ecosystem Assessment (Program) (Ed.) (2005) Ecosystems and human well-being: synthesis. Island Press, Washington, DC
Mohajane M, Essahlaoui A, Oudija F, Hafyani ME, Hmaidi AE, Ouali AE, Randazzo G, Teodoro AC (2018) Land use/land cover (LULC) using Landsat data series (MSS, TM, ETM+ and OLI) in Azrou Forest, in the Central Middle Atlas of Morocco. Environments 5:131
Mrabet R, Moussadek R, Fadlaoui A, van Ranst E (2012) Conservation agriculture in dry areas of Morocco. Field Crops Res Conserv Agric Dry Areas 132:84–94. https://doi.org/10.1016/j.fcr.2011.11.017
Oubrahim H, Boulmane M, Bakker MR, Augusto L, Halim M (2015) Carbon storage in degraded cork oak (Quercus suber) forests on flat lowlands in Morocco. Iforest-biogeosci Forestry 9:125
Ouyang, Z., Zheng, H., Xiao, Yi, Polasky, S., Liu, J., Xu, W., Wang, Q., Zhang, L., Xiao, Yang, Rao, E., Jiang, L., Lu, F., Wang, X., Yang, G., Gong, S., Wu, B., Zeng, Y., Yang, W., Daily, G.C., 2016. Improvements in ecosystem services from investments in natural capital. Science 352, 1455–1459. doi:https://doi.org/10.1126/science.aaf2295
Palomo I, Martín-López B, Potschin M, Haines-Young R, Montes C (2013) National Parks, buffer zones and surrounding lands: mapping ecosystem service flows. Ecosystem Serv Special Issue Mapp Model Ecosystem Serv 4:104–116. https://doi.org/10.1016/j.ecoser.2012.09.001
Peng J, Liu Y, Wu J, Lv H, Hu X (2015) Linking ecosystem services and landscape patterns to assess urban ecosystem health: a case study in Shenzhen City, China. Landscape Urban Plan 143:56–68. https://doi.org/10.1016/j.landurbplan.2015.06.007
Peter KD, d'Oleire-Oltmanns S, Ries JB, Marzolff I, Ait Hssaine A (2014) Soil erosion in gully catchments affected by land-levelling measures in the Souss Basin, Morocco, analysed by rainfall simulation and UAV remote sensing data. CATENA 113:24–40. https://doi.org/10.1016/j.catena.2013.09.004
Polasky S, Nelson E, Pennington D, Johnson KA (2011) The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota. Environ Resource Econ 48:219–242. https://doi.org/10.1007/s10640-010-9407-0
Quintas-Soriano C, Castro AJ, Castro H, García-Llorente M (2016) Impacts of land use change on ecosystem services and implications for human well-being in Spanish drylands. Land Use Policy 54:534–548. https://doi.org/10.1016/j.landusepol.2016.03.011
Ramos MC, Martínez-Casasnovas JA (2009) Impacts of annual precipitation extremes on soil and nutrient losses in vineyards of NE Spain. Hydrol Proces 23:224–235
Redhead JW, Stratford C, Sharps K, Jones L, Ziv G, Clarke D, Oliver TH, Bullock JM (2016) Empirical validation of the InVEST water yield ecosystem service model at a national scale. Sci Total Environ 569:1418–1426
Rochdane S, Reichert B, Messouli M, Babqiqi A, Khebiza MY (2012) Climate change impacts on water supply and demand in Rheraya Watershed (Morocco), with potential adaptation strategies. Water 4:28–44. https://doi.org/10.3390/w4010028
Rudel TK, Coomes OT, Moran E, Achard F, Angelsen A, Xu J, Lambin E (2005) Forest transitions: towards a global understanding of land use change. Glob Environ Change 15:23–31
Saintonge, F., Nageleisen, L., Assali, F., Aadel, T., 2011. Health status of Moroccan forests: adapting the forest health department's strategy for monitoring in the Moroccan context. [WWW Document]. URL doi:https://doi.org/10.4267/2042/43090
Schilling J, Freier KP, Hertig E, Scheffran J (2012) Climate change, vulnerability and adaptation in North Africa with focus on Morocco. Agric Ecosystems Environ 156:12–26. https://doi.org/10.1016/j.agee.2012.04.021
Schröter M, Bonn A, Klotz S, Seppelt R, Baessler C (2019) Ecosystem services: understanding drivers, opportunities, and risks to move towards sustainable land management and governance. In: Schröter M, Bonn A, Klotz S, Seppelt R, Baessler C (eds) Atlas of ecosystem services: drivers, risks, and societal responses. Springer International Publishing, Cham, pp 401–403. https://doi.org/10.1007/978-3-319-96229-0_60
Schyns JF, Hoekstra AY (2014) The added value of water footprint assessment for national water policy: a case study for Morocco. Plos One 9:e99705
Serra P, Pons X, Saurí D (2008) Land-cover and land-use change in a Mediterranean landscape: a spatial analysis of driving forces integrating biophysical and human factors. Appl Geogr 28:189–209. https://doi.org/10.1016/j.apgeog.2008.02.001
Sharp, R., Tallis, H., Ricketts, T., Guerry, A., Wood, S.A., Chaplin-Kramer, R., Nelson, E., 2018. InVEST 3.6.0 user's guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.
Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., 2015. InVEST+ VERSION+ user's guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.
Simonneaux V, Cheggour A, Deschamps C, Mouillot F, Cerdan O, Le Bissonnais Y (2015) Land use and climate change effects on soil erosion in a semi-arid mountainous watershed (High Atlas, Morocco). J Arid Environ 122:64–75
Sobrino JA, Raissouni N (2000) Toward remote sensing methods for land cover dynamic monitoring: application to Morocco. Int J Remote Sensing 21:353–366. https://doi.org/10.1080/014311600210876
Stockmann U, Padarian J, McBratney A, Minasny B, de Brogniez D, Montanarella L, Hong SY, Rawlins BG, Field DJ (2015) Global soil organic carbon assessment. Glob Food Secur 6:9–16. https://doi.org/10.1016/j.gfs.2015.07.001
Taleb MS (2016) Moroccan mountains: forest ecosystems and biodiversity conservation strategies. Int J Environ Ecol Eng 10:100–103
Tallis H, Polasky S (2009) Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. Ann New York Acad Sci 1162:265–283. https://doi.org/10.1111/j.1749-6632.2009.04152.x
Tallis H, Ricketts TH, Daily GC, Polasky S (2011) Natural capital: theory and practice of mapping ecosystem services. Oxford: Oxford University Press, pp 365
Tang S, Guo J, Li S, Li J, Xie S, Zhai X, Wang K (2019) Synthesis of soil carbon losses in response to conversion of grassland to agriculture land. Soil and Tillage Research 185:29–35
Tolessa T, Senbeta F, Kidane M (2017) The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. Ecosystem Serv 23:47–54. https://doi.org/10.1016/j.ecoser.2016.11.010
Vogl A, Tallis H, Douglass J, Sharp R, Wolny S, Veiga F, Benitez S, León J, Game E, Petry P (2015) A resource investment optimization system: introduction & theoretical documentation. Stanford University, Stanford
Vogl AL, Bryant BP, Hunink JE, Wolny S, Apse C, Droogers P (2017) Valuing investments in sustainable land management in the Upper Tana River basin, Kenya. J Environ Manag Optimizing Impact Sci 195:78–91. https://doi.org/10.1016/j.jenvman.2016.10.013
Wangai PW, Burkhard B, Müller F (2016) A review of studies on ecosystem services in Africa. International journal of sustainable built environment 5(2):225–245

Weisrock A, Wahl L, Ouammou A, Chakir L (2006) Systèmes fluviaux du Sud-Ouest marocain et leur évolution depuis le Pléistocène supérieur. Géomorphologie 12:229–248. https://doi.org/10.4000/geomorphologie.11119

Willcock S, Hooftman D, Sitas N, O'Farrell P, Hudson MD, Reyers B, Eigenbrod F, Bullock JM (2016) Do ecosystem service maps and models meet stakeholders' needs? A preliminary survey across sub-Saharan Africa. Ecosystem Serv 18:110–117. https://doi.org/10.1016/j.ecoser.2016.02.038

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses - a guide to conservation planning. Predicting rainfall erosion losses - a guide to conservation planning.

Wu X, Wang S, Fu B, Liu Y, Zhu Y (2018) Land use optimization based on ecosystem service assessment: a case study in the Yanhe watershed. Land Use Policy 72:303–312. https://doi.org/10.1016/j.landusepol.2018.01.003

Zaher H, Sabir M, Benjelloun H, Paul-Igor H (2020) Effect of forest land use change on carbohydrates, physical soil quality and carbon stocks in Moroccan cedar area. J Environ Manag 254:109544. https://doi.org/10.1016/j.jenvman.2019.109544

Zhan J, Wu F, Li Z, Lin Y, Shi C (2015) Impact assessments on agricultural productivity of land-use change. In: Zhan J (ed) Impacts of land-use change on ecosystem services. Springer Geography. Springer, Berlin Heidelberg, Berlin, Heidelberg, pp 37–78. https://doi.org/10.1007/978-3-662-48008-3_2

Zhang L, Hickel K, Dawes WR, Chiew FHS, Western AW, Briggs PR (2004) A rational function approach for estimating mean annual evapotranspiration. Water Resour Res 40. https://doi.org/10.1029/2003WR002710