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Assessing hydrological and provisioning ecosystem services in a case study in Western Central Brazil

Lars Koschke[1*], Carsten Lorz[2], Christine Fürst[3], Tobias Lehmann[1] and Franz Makeschin[1]

Abstract

Introduction: Current land use in the Federal District, Western Central Brazil, causes problems related to the water supply which are linked to the regulation of ecosystem services (ES). In scope of an Integrated Water Resources Management concept, we further developed the web-based planning support tool GISCAME for the Pipiripau river basin case study.

Methods: We introduced analyses on ecosystem potentials in the raster-based tool to assess, in a spatially explicit manner, the scenario impact on water purification, sediment retention, water retention, and provision of food and fodder in order to identify potential pathways for conserving water resources. To demonstrate the method, we assess ES depending on a number of land use/land cover change (LULCC) scenarios.

Results: We found that a considerable increase of water purification and sediment retention is difficult to achieve with realistic small scale LULCC, mainly because in areas with a low potential to provide hydrological ES and thus with a high demand for sustainable land use, such as native Savanna (Cerrado) and natural forests (Mata), favorable land uses were often already existing. We observed synergies in the response of regulating hydrological ES to LULCC but at the same time also trade-offs with provision of food and fodder.

Conclusions: Our findings suggest that further degradation and loss of Cerrado and Mata must be avoided and their restoration should be promoted in order to safeguard water resources. We suggest that restoration measures should be focused on arable land located at steep slopes near surface waters to effectively increase hydrological ES through the marginal reduction of provision services.

Introduction

Urban sprawl and intensive agriculture in Western Central Brazil have led to large scale degradation and loss of Cerrado, the native Savanna vegetation (Schmidt et al. 2009). Current land use causes high loads of suspended solids in stream water and subsequent silting of drinking water reservoirs. These processes, leading to the deterioration of (raw) water quality, the loss of some smaller reservoirs, and substantial reductions of the volume of larger reservoirs, threaten the regional water resources and especially the provision of drinking water (Felizola et al. 2001; Fortes et al. 2007; Lorz et al. 2012a). The water supply company (CAESB) of the Distrito Federal (DF) noticed increasing water treatment costs in the meso-scale Pipiripau river basin in the north-eastern part of the DF due to soil erosion and nutrient runoff from adjacent agricultural areas (Buric and Gault 2011). Adapted land use is a means to reduce diffuse pollution of water resources and sediment generation as a result of agricultural practices (Schwab et al. 1995). In this sense, the river basin is part of the Water Producer Program (Programa Produtor de Água) that has been initiated by the National Water Agency of Brazil (ANA); the program aims to implement best management practices. Strategies mentioned in this program include, for instance, the restoration and conservation of natural vegetation in priority areas such as riparian zones (Strauch et al. 2013).

From the benefits that humans gain from ecosystems (ecosystem services, ES), many are related directly or indirectly to freshwater. Those ES that are closely related to

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* Correspondence: lars.koschke@tu-dresden.de
[1]Department of Soil Science and Site Ecology, Dresden University of Technology, Pienner Str. 19, 01737 Tharandt, Germany
Full list of author information is available at the end of the article

the hydrological cycle are commonly referred to as hydrological or water related ES and comprise the provision of services such as the supply of water for drinking and irrigation, energy production, and regulating services such as water purification and erosion control (Brauman et al. 2007; de Groot et al. 2010). As the provision of drinking water mostly relies on the presence and status of native vegetation within a watershed (Pattanayak and Wendland 2007), the preservation and restoration of natural vegetation is supposed to be advantageous also for other ES and for biodiversity conservation (Pert et al. 2010). Provision of regulating hydrological ES is also governed by terrestrial characteristics of the watershed, such as slope, topography, and soil depth (Terrado et al. 2013). Further, the location of land use and land cover change (LULCC) is highly relevant for the performance of certain ES (Bryan and Crossman 2008; Rounsevell et al. 2012).

We aim to support river basin management and focus on land use planning and sediment management in the Pipiripau river basin. The research questions presented are:

i. Can generally available data on soil and topographic conditions provide a meaningful foundation for ES-based Integrated Water Resources Management (IWRM) and spatial planning support at the landscape level?
ii. Does the inclusion of spatially explicit parameters significantly enhance the spatially inexplicit assessment of ES?
iii. Does the identification of land use options for planning of sustainability support IWRM?

In order to support decisions for adapted land use, we used the planning support tool *Letsmap do Brasil* (Lorz et al. 2012b), developed within the GISCAME framework (Fürst et al. 2010a,b, 2011,2012; Koschke et al. 2012, 2013). As an assessment framework, we made use of the ES approach (e.g., MA 2005; Haines-Young and Potschin 2010), which we intended to adopt for IWRM. We assessed the regulating ES water purification, sediment retention, and water retention and provision of food and fodder to analyze the impact of land use scenarios to mitigate pressure on water resources.

In order to allow the inclusion of site-specific conditions within the assessment, we implemented GIS-based analyses to identify areas with differing ecosystem potential (EP) into GISCAME. With EP, we mean the site-specific suitability or capacity of a natural ecosystem to provide a specific ES. Combining EP with the land use type-specific ES potential yields the hypothetical maximum provision of selected ES (Burkhard et al.: Ecosystem service potentials, flows and demands – concepts for spatial localisation, indication and quantification, in review; Burkhard et al. 2012; Bastian et al. 2012).

The spatially explicit mapping and assessment of ES was called for in previous applications of the GISCAME modeling approach (Fürst et al. 2013; Koschke et al. 2012, 2013) as it contributes to the identification of priority areas that are in need for special attention from land and resource managers and are very effective in delivering the desired services if used/managed appropriately.

Methods

The Pipiripau river basin

The study area is the Pipiripau river basin situated in the north-eastern part of the DF (Figure 1). The river basin area extends over 215 km^2 and is mainly covered by well-drained Ferralsols which are low in nutrients (EMBRAPA, Empresa Brasileira de Pesquisa Agropecuária (The Brazilian Agricultural Research Corporation) 1978). The Pipiripau river basin is situated within the Brazilian Central Plateau. Its altitude ranges from 920 to 1,230 m asl. The study region is categorized as a semi-humid tropical climate. Precipitation amounts on average to 1,300 mm and occurs mainly during the rainy season from November to March (Strauch et al. 2012).

The basin is mostly rural, with only a few small settlements. Predominant land uses in the catchment area are arable land, which comprises foremost intensive cropping of soybean and corn (47% surface area share), and Brachiaria pasture (23%). To a smaller extent irrigated horticulture is being conducted and also remnants of Mata (natural gallery forests) can still be found along the watercourses. Mata and the different types of Cerrado, ranging from fairly dense woody Savanna of shrubs and small trees to treeless subtypes (Campo) (Oliveira-Filho and Ratter 2002), have been reduced in the last 50 years from nearly 100% to 20% of the area (Strauch et al. 2013).

Although the Pipiripau river basin is relatively small, it is the main source of drinking water for Planaltina and Sobradinho, which are satellite cities inside of the DF, and for irrigation. The river basin belongs to the project *Produtor de Água* (www.ana.gov.br), which aims to introduce best management practices and a better integration of stakeholders, e.g., by introducing Payments for Environmental Services (Lorz et al. 2012a,b).

Assessing ecosystem services (ES) with GISCAME

GISCAME is a web-based software which allows a comparative assessment of ES. It consists of three components: a Geographic Information System, a Cellular Automaton, and a Multi-criteria Evaluation (Fürst et al. 2010a,b). GISCAME calculates – based on raster data – the contribution of all land use types to the provision of ES on a relative scale from 0 (no provision of ES) to 100 (maximum regional provision of ES) (Fürst et al. 2010a,b; Koschke et al. 2012, 2013). The mean value of all cells of the case study area and simulated LULCC

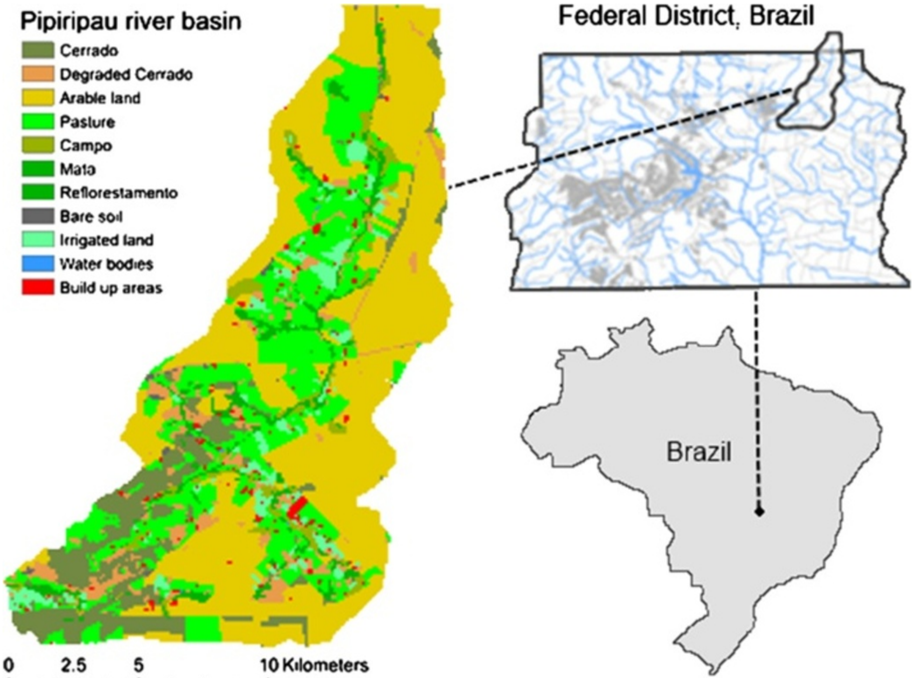

Figure 1 Location and land use/land cover of the case study area.

scenarios are provided as feed-back to the user. For the Pipiripau case study, the assessment of land use types vs. ES was based on the indicator values of nitrogen load (applied fertilizer in kg ha^{-1} a^{-1}) for water purification, C-Factor of the Universal Soil Loss Equation (USLE; Wischmeier and Smith 1978) for sediment retention, CN value for water retention, and yield (mg ha^{-1} a^{-1}) for provision of food and fodder. All values were standardized to the 0–100 point scale. We used the indicator values for land use types provided in Lorz et al. (2012b), IBGE, Instituto Brasileiro de Geografia e Estatística (The Brazilian National Institute of Geography and Statistics) (2006), and EMBRAPA (2012).

The presented assessment approach includes three main steps:

(i) Assessment of the land use type-specific contribution to ES
(ii) Estimation of the EP (e.g., nitrogen retention potential, yield potential) based on the site-specific ecosystem properties (cf. Bastian et al. 2012)
(iii) Combination of land use and EP maps (Figure 2)

Thus, besides the land use map which is the primary information layer, a second layer that relates EP as a function of site-specific conditions to each ES was introduced in GISCAME. The secondary layer enables a

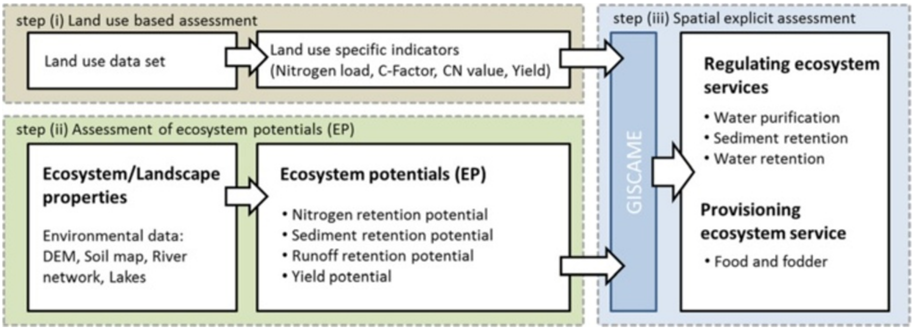

Figure 2 Assessment components and general workflow. Trough combination of land use (step i) with ecosystem potentials (EP, step ii) in GISCAME (step iii), ES can be assessed in a spatially explicit manner. Land use is the driving force which can be changed within GISCAME. Adapted from Haines-Young and Potschin (2010) and Bastian et al. (2012).

spatial explicit assessment of ES by taking into account the cell-specific potential to provide individual ES. In order to couple the land use related assessment of ES (step i) with EP (step ii), we produced, for each of the ESs, a respective layer showing the related EP. According to the indicators used to assess ES we investigated the nitrogen retention potential (for water purification), the sediment retention potential (for sediment retention), the runoff retention potential (for water retention), and the yield potential (for provision of food and fodder). For the different ESs, individual assessment approaches were applied to identify EPs. The methodical approach has been operationalized already for sediment retention and water retention (Lorz et al. 2012b) (Figure 3b,c). We therefore focus on water purification and food and fodder provision and explain the methodical approaches we applied to derive maps on the nitrogen retention and yield potential.

Ecosystem potentials (EP)

Biophysical structures and processes influence the potential of a landscape to retain nitrogen (NO_3^-) and to support provisioning of food/fodder from arable land. To assess the EP for nitrogen retention, we applied an approach modified from Orlikowski et al. (2011). The approach has been developed for river basins with low data availability and differs from other approaches (Terrado et al. 2013) in the way that it allows a qualitative estimation of the EP. We assessed the yield potential in a similar manner and developed an approach based on the available data. For soil parameters, we used data of 16 soil profiles which were the basis for a regionalization to the study area (EMBRAPA, 2012; Tomasella and Hodnett 2004). We utilized ArcMap10 to compile the data and to finally classify the parameters as well as the resulting EP maps into the three classes (i) high, (ii) intermediate, and (iii) low potential for nitrogen

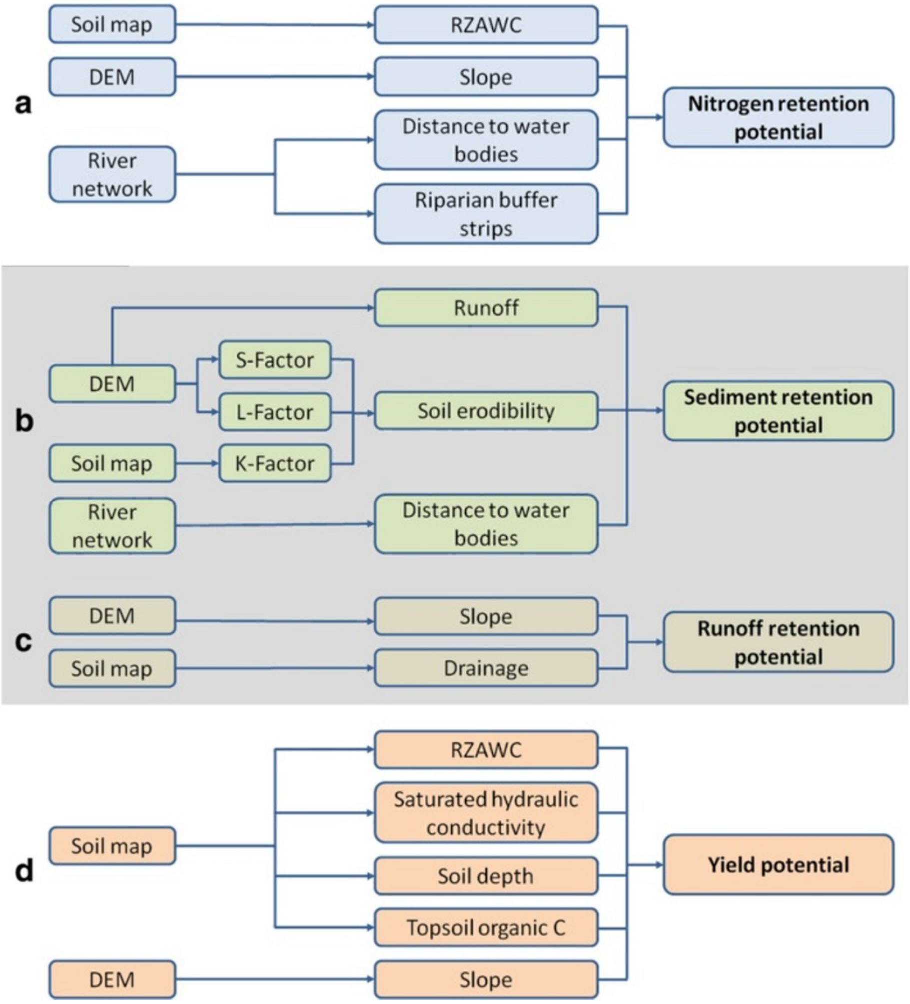

Figure 3 Scheme for the calculation of the ecosystem potentials (EPs). (a) Nitrogen retention potential (Orlikowski et al. 2011). **(b)** Sediment retention potential (Halbfass and Grunewald 2008). **(c)** Runoff retention potential (USDA, 2004), and **(d)** yield potential (Baja et al. 2001; Bartolini and Borselli 2009; Mueller et al. 2010). Grey background indicates that **(b)** and **(c)** were implemented in Lorz et al. (2012b).

retention and yield production, respectively. A cell with low nitrogen retention potential would therefore exhibit a strong need for adapted land use in order to support water purification.

Nitrogen retention potential Required input parameters are land use, soil (root zone available water capacity (root zone available water capacity, RZAWC)), slope, riparian buffer strips, and distance to surface waters (Table 1, Figure 3a). Our method differs from the one presented in Orlikowski et al. (2011) as follows: in order to be consistent with the previous approach of Lorz et al. (2012b) and because of the rather large scale of soil data, we used a raster cell size of 200 m × 200 m; Orlikowski et al. (2011) produced maps referring to sub-catchment level whereas we produced cell-based values. The land use parameter was not used within the data overlay. Instead, land use was assessed separately (see step i, Figure 4a) and subsequently combined with EP maps (step ii, Figure 4b) in GISCAME. Further, classes 1–3 were assigned using individual value ranges observed in the study area and not the potential overall range of values of each parameter. The preparation of input parameters is described below.

Soil: root zone available water capacity (RZAWC) The rationale for selecting RZAWC refers to the fact that the leaching of NO_3^- from the subsoil is commonly the main pathway to surface water bodies (e.g. Gächter et al. 2004). The loss of nitrogen is therefore influenced not only by the applied amount of fertilizer but also by soil properties. We followed the assumption that, with increasing RZAWC, the retention of water by the vegetation increases as well, leading to a lower amount of dissolved NO_3^- reaching the groundwater. We calculated the $RZAWC_{total}$ values (in mm H_2O) for the entire soil profile. We defined class thresholds on the basis of the first and third quartile: >244 mm (class 1) with mainly (very) clayey and deep Latosols and Cambisols, 142–244 mm (class 2) with intermediate properties concerning soil depth and texture and including various soil types, <142 mm (class 3) with prevailing sandy to rocky and (very) shallow Cambisols and hydromorphic soils.

Table 1 Input data that have been used to conduct step (ii) of the assessment approach

Data	Source	Description
Land use	BRASIL 2010	Land use map of the Pipiripau river basin generated for program *Produtor de Água*
Digital Elevation Model (DEM)	CODEPLAN, 1999	20 m resolution grid derived from contour line map 1:10,000
Soil	EMBRAPA, 1978; Reatto et al., 2004; Strauch et al. 2013	Soil map 1:100,000 and horizon-specific soil properties for each soil type

Slope Although subsurface loss of NO_3^- is supposed to be the predominant process, transport through surface runoff, which is driven by slope steepness, might occur as well (Brunet et al. 2008; Mayer et al. 2005; Orlikowski et al. 2011). We have chosen a classification of slope different from the one proposed in Orlikowski et al. (2011) in order to adapt to regional characteristics. The slope was calculated from the DEM as proposed for the S-factor of the USLE. Classes were defined according to natural breaks given in ArcMap10: 0° to 4.26° (class 1), 4.27° to 12.99° (class 2), and 13.0° to 60.43° (class 3).

Riparian buffer strips Land use neighboring surface waters is important for how much NO_3^- can actually enter the water bodies. Less intensive, near-to-nature land uses such as natural vegetation, forests, and pasture in the immediate vicinity inhibit input of NO_3^- (and other nutrients) while intensively managed arable land tends to augment input of nutrients (Mayer et al. 2005).

Again, we had to deviate from the original approach because of the given resolution. Instead of the 25 m width of riparian buffer strips applied by Orlikowski et al. (2011), we used the minimum width possible, i.e., 200 m. Evaluation of land uses in terms of their ability to remove NO_3^- was conducted in accordance with Orlikowski et al. (2011). Hence, land uses Cerrado (tree Savanna), Mata (natural forest), and afforestation have the highest potential to retain NO_3^- (class 1), degraded Cerrado, pasture and meadows, and Campo (grass savanna) have an intermediate potential (class 2), and arable land (general), irrigated land, bare soil, and built up areas have a low potential (class 3, no buffer strip).

Distance to surface waters The definition of classes had to be adapted to raster cell size as well. After having conducted "Euclidean distance" calculation in ArcGIS the distance to surface waters was divided into >800 m (class 1), 200–800 m (class 2), and <200 m (class 3).

Yield potential To detect main potential constraints for agricultural production such as water availability, water logging, and nutrient availability, we identified five main parameters (RZAWC, saturated hydrological conductivity (Ks), soil depth, topsoil organic carbon content, and slope) which are commonly used for soil productivity classification at national or regional level (e.g., Baja et al. 2001; Bartolini and Borselli 2009; Mueller et al. 2010).

RZAWC The water which is available for uptake by plants is a major factor for plant growth. We took the $RZAWC_{total}$ values (in mm H_2O) and applied the same classes as for the estimation of the nitrogen retention potential.

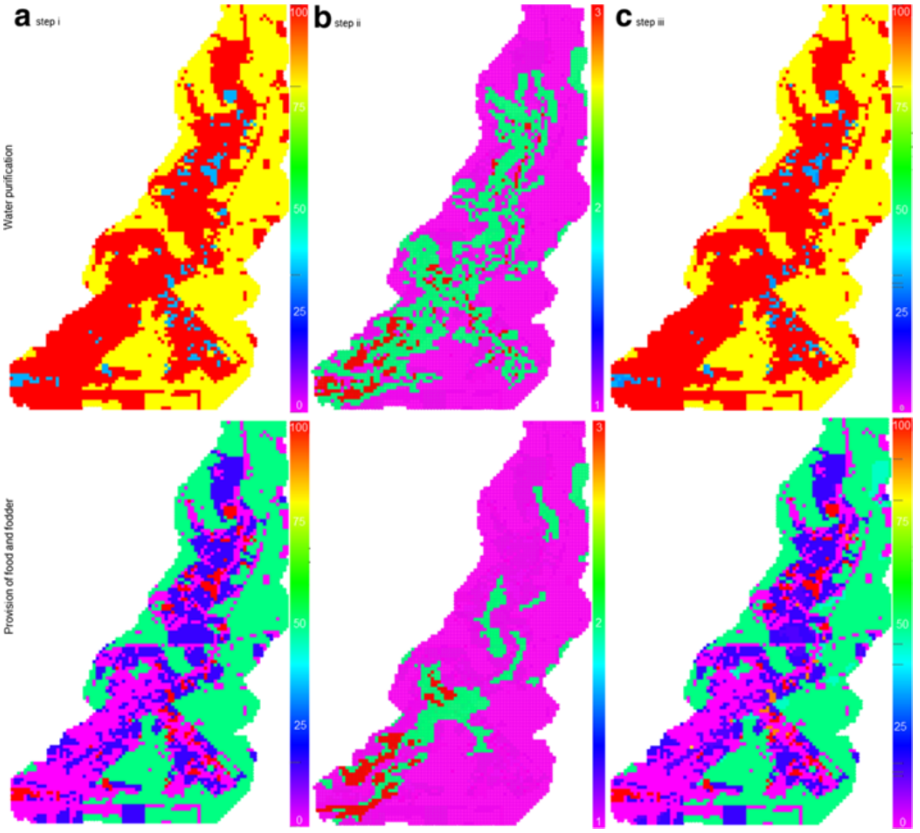

Figure 4 Resulting maps for spatial explicit assessment of water purification (above) and provision of food and fodder (below). Maps of land use based assessment (**a**, step i), nitrogen retention potential and yield potential (**b**, step ii), and combined, spatial explicit assessment (**c**, step iii) for the current land use pattern (Business as usual, BAU). Values in **(a)** and **(c)** range between 0–100 points, **(b)** comprises classes 1 (high EP, pink), 2 (intermediate, green), and 3 (low, red).

Saturated hydrological conductivity (Ks) We calculated the mean saturated hydrological conductivity for the representative soil profiles in order to account for drainage conditions and potential water logging problems. Also, low Ks values are likely to cause runoff and induce a decreased amount of available water for plant growth (Verhoef and Egea 2012). We defined classes as follows: >42 mm h^{-1} (class 1), 15–42 mm h^{-1} (class 2), and < 15 mm h^{-1} (class 3).

Soil depth Soil depth defines the rooting depth and the volume of soil available for water and nutrient uptake. While shallow soils tend to constrain plant growth, deeply weathered soils generally provide better growing conditions for agriculture (Blume et al. 2002). Applied soil depth classes were: >1,500 mm (class 1), 500–1,000 mm (class 2), and < 500 mm (class 3).

Topsoil organic carbon content Organic carbon in soil has various effects on soil fertility both with respect to physical as well as to chemical properties. In tropical soils, organic carbon has an even greater importance as these soils are characterized through a generally low cation exchange capacity (Blume et al. 2002). A high content of organic carbon in the upper soil is therefore assumed to indicate increased nutrient availability and favorable soil structure. We classified average carbon content of uppermost soil horizons in >2.8% (class 1), 1–2.8% (class 2), and <1% (class 3).

Slope Topography can affect productivity by means of loss of topsoil layers and nutrients through runoff. Over time, fertility and productivity of soil can be reduced. We have chosen slope classes according to Ongaro and Sarfatti (2009), as follows: <8% (class 1), 8–16% (class 2), and > 16% (class 3).

We further processed the four maps related to the nitrogen retention potential and the five maps concerning the yield potential in ArcGIS10 and conducted a map overlay applying equal weights. That is, we calculated the mean class for every cell and assigned values to high (class 1, with mean values from 1.0 to 1.6), intermediate (class 2, 1.7 to 2.3), and low potential (class 3, 2.4 to 3.0). EP maps that result from step ii show the nitrogen retention potential and the yield potential (Figure 4b), or otherwise the sediment retention potential, and the runoff retention potential.

Combination of land use and EP

For linking EP and land use (step iii) we uploaded the maps for EP and land use into GISCAME, where the combination of both layers was achieved by percentage reductions of the initial land use-based values (Figure 4c). Percentage reductions are a result of discussion within the working group. In general, cells with a low EP are therefore subject to a higher reduction of value points than cells with a high EP (Table 2a,b). The highest reduction appears if, for example, a land use with a high fertilizer input and thus with a low value for water purification is to be found in a cell with a low potential to retain nitrogen. In terms of the yield potential, reduction was effectuated equally for all arable land uses (including pasture) as we assumed a similar effect on yield for reasons of simplicity.

LULCC scenarios

We developed and simulated LULCC strategies and assessed their effects on the basis of the EP maps developed above in order to improve the provision of hydrological ES. Thus, LULCC scenarios (Table 3a) were driven by thematic input layers, e.g., areas with low/intermediate nitrogen retention potential and hence with high/intermediate risk for nitrogen loss, areas with high and/or intermediate slope steepness, a low distance to surface waters, etc. Further, scenarios were based on current land use, e.g., change of degraded Cerrado into Cerrado, pasture or arable land. We up-loaded the different input layers in GISCAME to simulate LULCC at the respective sites. We carried out conservation and intensification scenarios, meaning, for instance, change of land use (e.g., at low potential nitrogen retention areas) toward Cerrado, Campo, Mata or afforestation and ongoing degradation of remaining Campo and Cerrado through change toward pasture, and agriculture, respectively. The current (2010) land use pattern was used as the reference scenario (Business as usual, BAU).

Results

The maps (Figure 4a,b) were processed to qualitatively estimate the spatial explicit provision of ES. Figure 4a displays the land use-specific water purification and food and fodder provision. The colors reflect the values of the respective land uses from low (pink) to high (red). The maps that result from the GIS-based identification of EPs are depicted in Figure 4b. Figure 4c shows the results of the combined assessment for the current land use pattern (BAU). Reductions of value points only appeared in areas with a low potential to provide ES. However, the area weighted mean of water purification calculated for the whole river basin was not affected by

Table 2 Reference matrix for the percentage reduction of land use type-related value points with respect to (a) the nitrogen retention potential and (b) the yield potential

(a)

Land use-specific value points		**Nitrogen retention potential**		
	Value classes	**High**	**Intermediate**	**Low**
Land use types		**1**	**2**	**3**
Coffee	0–10	0	−10	−20
-	11–20	0	−10	−20
Arable land, cotton;	21–30	0	−10	−20
Irrigated land	31–40	0	−5	−10
-	41–50	0	−5	−10
Vegetables; Fruits	51–60	0	−5	−10
Arable land, corn tillage/no tillage	61–70	0	0	−5
Arable land, general, no tillage	71–80	0	0	−5
Arable land, bean	81–90	0	0	−5
Cerrado; Campo; Arable land, sorghum; tillage/ no tillage	91–100	0	0	0

(b)

Land use-specific value points		**Yield potential**		
	Value class	**High**	**Intermediate**	**Low**
Land use types		**1**	**2**	**3**
All arable land use types	0–100	0	−10	−20

The figures in the right column refer to the percentage (%) reduction of initial value points (e.g. -10%).

Table 3 Overview and description of applied LULCC scenarios (a) and scenario results (b) according to land use-based assessment (LU) and combined land use-based and ecosystem potential (EP) assessment (LU + EP)

(a)		(b)								
		Water purification		Sediment retention		Water retention		Food and fodder		Affected area of river basin
ID	Description	LU	LU + EP	LU	LU + EP	LU	LU + EP	LU	LU + EP	[%]
BAU	Current (2010) land use distribution (baseline scenario)	88	88	86	83	48	46	31	30	-
	Change of riparian areas (Ri) with a low potential for nitrogen retention									
Ri-1	… toward native tree Savanna (Cerrado)	88	88	86	83	49	47	30	30	2
Ri-2	… toward forests (afforestation)	88	88	86	83	49	47	30	30	2
Ri-3	… toward pasture	88	88	86	83	48	46	31	30	2
Ri-4	… toward natural forest (Mata)	88	88	86	83	49	47	30	30	2
Ri-5	… toward arable land (general, no-till)	88	88	86	83	48	46	31	31	2
	Change of native grass Savanna (Campo, Ca)									
Ca-1	… toward irrigated land	86	86	85	82	46	44	34	33	3
Ca-2	… toward arable land (general, no-till)	87	87	86	82	46	44	32	32	3
Ca-3	… toward arable land (corn, till)	87	87	84	81	45	44	33	33	3
Ca-4	… toward pasture	88	88	86	82	47	45	31	31	3
	Change of areas with low nitrogen retention potential (NRP)									
NRP-1	… toward Cerrado	88	88	87	83	49	47	30	30	4
NRP-2	… toward forests (afforestation)	88	88	86	83	48	46	30	30	4
NRP-3	… toward pasture	88	88	86	83	48	46	31	30	4
NRP-4	… toward arable land (general, no-till)	88	88	86	82	46	44	32	32	4
NRP-5	… toward irrigated land	86	86	85	82	46	44	34	33	4
	Change of areas with steep slopes(Sl)									
Sl-1	… toward Cerrado	88	88	87	83	49	47	30	30	5
Sl-2	… toward forests (afforestation)	88	88	86	83	48	46	30	30	5
Sl-3	… toward pasture	88	88	86	82	47	45	31	31	5
Sl-4	… toward arable land (general, no-till)	87	87	86	82	45	44	33	32	5
Sl-5	… toward arable land (corn, till)	86	86	83	80	45	43	34	33	5
Sl-6	… toward irrigated land	85	85	85	81	45	44	35	35	5
	Change of degraded Cerrado (DC)									
DC-1	… toward Cerrado	88	88	87	84	52	50	31	30	6
DC-2	… toward forests (afforestation)	88	88	87	83	50	48	31	30	6
DC-3	… toward natural forest (Mata)	88	88	87	84	52	50	31	30	6
DC-4	… toward arable land (general, no-till)	87	87	86	82	47	45	34	34	6
DC-5	… toward arable land (corn, no-till)	86	86	83	79	46	44	35	35	6
DC-6	… toward pasture	88	88	86	82	49	47	32	31	6
DC-7	… toward irrigated land	84	84	85	81	47	45	37	37	6
	Change of riparian areas (Ri) with an intermediate potential retention function									
Ri-6	… toward Cerrado	89	89	87	84	51	49	29	29	8
Ri-7	… toward forests (afforestation)	89	89	87	83	49	47	29	29	8
Ri-8	… toward pasture	89	89	86	83	48	46	31	30	8
Ri-9	… toward natural forest (Mata)	89	89	87	84	51	49	29	29	8

Table 3 Overview and description of applied LULCC scenarios (a) and scenario results (b) according to land use-based assessment (LU) and combined land use-based and ecosystem potential (EP) assessment (LU + EP) *(Continued)*

Ri-10	… toward arable land (general, no-till)	87	87	86	82	45	43	33	33	8
	Change of riparian areas (Ri) with an intermediate and low potential retention function									
Ri-11	… toward natural Cerrado	89	89	87	84	52	50	29	28	10
Ri-12	… toward forests (afforestation)	89	89	87	84	49	47	29	28	10
Ri-13	… toward pasture	89	89	86	83	48	46	30	30	10
Ri-14	… toward natural forest (Mata)	89	89	87	84	52	50	29	28	10
Ri-15	… toward arable land (general, no-till)	87	87	86	82	45	43	34	34	10
Ri-16	… toward irrigated land	82	82	84	81	45	43	39	38	10
	Change of Cerrado(Ce)									
Ce-1	… toward irrigated land	81	81	83	79	41	39	41	40	10
Ce-2	… toward arable land (general, no-till)	86	86	85	81	41	39	36	35	10
Ce-3	… toward arable land (corn, till)	84	84	80	76	39	37	38	37	10
Ce-4	… toward degraded Cerrado	88	88	85	82	42	40	31	30	10
	Distance to water (D): Change of areas close to surface waters (irrespective of their current land use)									
D-1	… toward Cerrado	89	89	88	85	53	51	28	28	14
D-2	… toward forests (afforestation)	89	89	87	84	49	47	28	28	14
D-3	… toward pasture	89	89	86	82	47	45	30	30	14
D-4	… toward arable land (general, no-till)	86	86	86	82	43	41	35	35	14
	Change of degraded Cerrado and Cerrado (DCC)									
DCC-1	… toward arable land (general, no-till)	85	85	85	81	40	38	39	38	17
DCC-2	… toward arable land (corn, no-till)	82	82	85	81	40	38	43	42	17
DCC-3	… toward pasture	88	88	84	81	45	43	33	33	17
DCC-4	… irrigated land	77	77	82	78	40	38	47	46	17
	Change of pastureland (Pa)									
Pa-1	… toward Cerrado	88	88	89	87	57	55	27	27	21
Pa-2	… toward grass Savanna (Campo)	88	88	89	87	57	55	27	27	21
Pa-3	… toward forests (afforestation)	88	88	89	85	51	49	27	27	21
Pa-4	… toward natural forest (Mata)	88	88	90	87	57	55	27	27	21
Pa-5	… arable land (general, no-till)	84	84	87	83	41	39	38	37	21
Pa-6	… toward arable land (corn, no-till)	81	81	88	84	41	39	43	42	21
	Combined (C): Change of areas with low potential for nitrogen retention, runoff retention, sediment retention, and production potential									
C-1	… toward Cerrado	90	90	89	86	56	54	27	27	23
	Change of arable land (general) (Ar)									
Ar-1	… toward arable land (soy, till)	95	95	76	73	40	39	33	32	47
Ar-2	… toward arable land (wheat)	94	94	81	78	48	46	24	23	47
Ar-3	… toward arable land (corn, no-till)	81	81	88	85	48	46	42	42	47
Ar-4	… toward Cerrado	97	97	92	90	82	81	7	7	47

(Scenarios were tabulated according to the affected area).

this. This is not true for sediment retention, water retention, and food and fodder provision where the values were reduced by 3, 2, and 1 point(s), respectively, for BAU (Table 3b).

The results of LULCC scenarios are depicted in Table 3b. Compared to BAU, LULCC impact on water purification ranged from 0 to 18 value points for both the land use-based assessment and the combined assessment. Values of food and fodder provision showed a range of 23 value points throughout all scenarios and therefore had themost pronounced response to LULCC. In general, in comparison to BAU, effects grew more distinct with increasing number of altered cells. In fact, according to water purification, the assessment of the nitrogen retention potential had no effect at all compared to the spatial inexplicit land use-based assessment. As for sediment retention and water retention, the combined assessment led to reductions of 3.4 and 1.9 value points on average, respectively, compared to the land use-based assessment. For food and fodder provision, the impact of the yield potential map was also negligible with 0.4 points average reduction.

In order to go into detail we will focus on results of scenarios NRP-1, D-1, DCC-4, and C-1 (Figure 5a–d), to display the impact of more intensive and less intensive land use on the provision of ES. Referring to the combined assessment (Table 3, LU + EP), water purification was not influenced in scenario NRP-1. The change of areas close to surface waters (D-1) and the combined change of areas with a low potential to provide hydrological ES (C-1) led to a slight increase (+1 and +2 points). The change from Cerrado and degraded Cerrado into irrigated agriculture (DCC-4) led to a strong negative impact (−11). The response of sediment retention was negligible with respect to NRP-1 (+/− 0). The increased surface area share of irrigated land in DCC-4 negatively affected sediment retention (−5) while through the change of areas near to surface waters (D-1) and through the change of low potential areas into Cerrado (C-1), an increase of 2 and 3 points, respectively, could be achieved. The performance of water retention could be increased in NRP-1, NRP-4, and C-1 by +1, +5, and +8 points, respectively. A reduction was again caused by DCC-4 (−8 points). Food and fodder provision remained the same for NRP-1. An increase of 16 points could be observed through extension of irrigated land (DCC-4). Conversely, fostering hydrological ES in scenarios D-1 and C-1 through extension of less intensive land uses reduced food and fodder provision by 2 and 3 points, respectively.

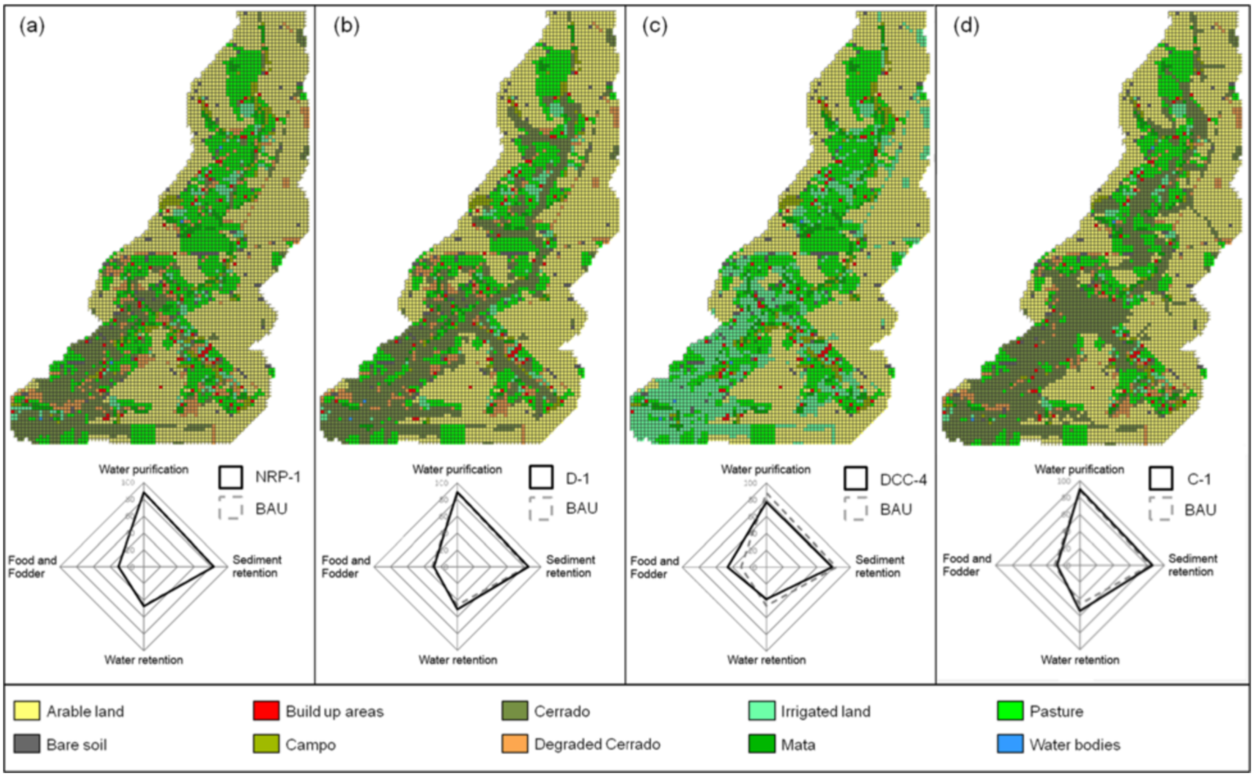

Figure 5 Land use patterns and assessment results for selected scenarios. (a) NRP-1, change of areas with low nitrogen retention potential toward Cerrado; **(b)** D-1, change of areas close to surface waters (irrespective of their current land use) toward Cerrado; **(c)** DCC-4, change of degraded Cerrado and Cerrado to arable land (general, no-till) toward irrigated land; **(d)** C-1, change of areas with low potential for nitrogen retention, runoff retention, sediment retention, and production potential. Resulting spider charts display scenario results (black line) and results of the initial pattern (BAU, dotted line). The different colors in the maps represent the individual land use classes (see legend below). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article).

Discussion

Assessment approach

The underlying evaluation matrix of land uses (step i; Lorz et al. 2012b) and the procedure to produce EP maps (step ii) are subject to uncertainty and depend heavily on data quality, data availability, and resolution. In order to prevent false precision, we kept the 200 m resolution used in the setup of the system for this Brazilian case study. LULCC might have unforeseen (nonlinear) and ambiguous effects and land use-related indicator values might show widely varying ranges (Koschke et al. 2013). It is also difficult to establish a quantitative link between ES properties and potentials and ES provision (e.g., how much the nitrogen retention under arable land increases/decreases at sites with low nitrogen retention potential). Thus, the combination of the results of step i and step ii (in step iii) is based on subjective percentage reductions of value points (Table 2), but can be easily adapted, for instance, through stakeholder or expert knowledge.

In general, the approach of Orlikowski et al. (2011) to identify areas with a low, intermediate, and high nitrogen retention potential could be transferred, although some changes, for example as to the applied thresholds, were necessary. Areas that were identified as low yield potential areas in the GIS overlay match to a great extent areas that are currently covered by Cerrado, Campo, and Mata. Although, we had to assume soil related properties to be homogenous within the soil regions – which is very unlikely – the EP map seems to reflect site-specific conditions sufficiently. Although the suitability of land for crops differs widely (Elsheikh et al. 2013), differentiation of yield potential for specific crops and forest species is missing and should be the topic of future methodical refinement.

Referring to the first research question, the inclusion of environmental data constitutes a meaningful refinement of the assessment approach. The resulting EP layers could be used for two purposes: first, a spatially explicit evaluation of ES could be achieved. Second, the layers helped to identify areas that are likely to effectively improve ES provision in the case study area when managed appropriately and can be used for scenario simulations. The ES distribution maps can be displayed in GISCAME and show results from the combined assessment (Figure 4c). This can be used as a starting point for prioritization of areas in spatial planning and management (Egoh et al. 2008; Chan et al. 2006). In the context of the case study region, more specific data might be needed.

As to the second question raised in the introduction, although the effects of the combined assessment were marginal in many scenarios in the Pipiripau river basin, the introduction of the EP and the resulting layers enhanced the previous, spatial inexplicit assessment approach (Koschke et al. 2012, 2013) considerably. It is now possible to take site-specific conditions and ES-specific processes, such as erosion and nitrogen loss, into account. Interactive training of non-experts is facilitated, for instance, to discuss the importance and challenge of considering slope, distance to surface waters, soil properties, etc., for site-adapted land use to improve the regulating ES and to reduce trade-offs with provisioning services.

A number of decision support tools have been developed to assess spatially explicit ES and in quantitative terms, e.g. InVEST (Nelson et al. 2009), ARIES (Bagstad et al. 2013), and Polyscape (Jackson et al. 2013). Although the modeling approaches of these tools tend to be more sophisticated and reliable than those presented herein, they are also much more data intensive. To our knowledge, none of these tools is able to provide feedback in real-time to end-users upon LULCC scenario simulations. We are aware of the significant simplifications we based our analyses on. However, the parameterization of EPs was based on methods used in meso-scale assessments of landscapes and is therefore an appropriate and pragmatic approach in terms of the concerned scale and the spatial and thematic resolution of data. From discussion within the working group, we concluded that the areas identified in the course of the GIS procedures to estimate EPs for water purification, sediment retention, water retention, and provision of food and fodder are reasonable. In situations where data access/availability is restricted or resources to process or collect data are not obtainable, the presented approach of using proxies, e.g., for nitrogen export such as distance to rivers and soil texture, may serve to conduct a first, robust estimation of regional potentials and potential threats.

A comparison of outcomes from studies with comparable approaches and methods and/or comparison against results of process modeling are of great importance to study uncertainty and potential errors. Nevertheless, such comparisons are difficult and could up to now not be accomplished.

LULCC scenarios

Differences between scenarios and BAU were often marginal, especially with respect to water purification. This is because of the little area affected by LULCC in most scenarios and due to the fact that on areas with the lowest nitrogen retention potential, which are located in particular in the south-western part of the catchment area near to the drainage, often already favorable land uses such as Cerrado and degraded Cerrado are dominating (see NRP-1 to NRP-5). Thus, in the southern part, Cerrado vegetation coincides with very steep terrain. Otherwise, pasture can be found commonly on steep slopes. Arable land that extends all the way to the surface waters occurs relatively seldom. Along the river network Mata can still be found. Thus, the current land use pattern positively influences the assessment as the slope is an important factor for the considered hydrological ES. Considerable percentage reductions within the assessment procedure (Figure 4c) appear only if adverse land use coincides with areas of a low potential, e.g., areas with the prevalence of steep slopes. Since bothCerrado and pasture perform rather well in terms of water purification, and sediment- and water retention compared to arable land, the impact of EP maps in the combined assessment was often marginal as well. This was brought about by the small area with low nitrogen retention potential (4%) and the rather conservative reductions of value points we have assigned (Table 2). The impact of EP layers on the assessment in terms of sediment retention, water retention, and food and fodder provision was generally more distinct. This was due to a higher amount of adverse land uses in low-EP areas and a larger number of cells affected by percentage reductions, i.e., cells with a low and intermediate EP. Accordingly, the percentage reduction affected 16% of the area in the case of food and fodder provision, 33% as to water purification, 56% as to water retention, and 58% as to sediment retention. Consequently, the only ES affected by all four exemplary scenarios was water retention. Thus, the dependence of assessment results from basic, land use-related evaluation of LULCC was not alleviated as expected by introducing EP for water purification. This is due to the given environmental conditions, (favorable) current land use pattern, and the resulting already good performance of water purification and sediment retention.

Positive effects of LULCC scenarios were found especially for sediment and water retention. In general, less intensive land use tended to cause increased provision of water purification, and sediment- and water retention while more intensive land use such as irrigated agriculture, pasture, and arable land (Table 3, e.g., Ca-2, Ca-3, Sl-5) had contrary effects. The response of hydrological ES can be evaluated as being unidirectional; water purification, sediment retention, and water retention are affected by similar biophysical processes. Through the utilization of similar parameters to identify areas of low, intermediate, and high potential to retain nitrogen, sediments, and runoff, synergetic effects of conducted LULCC scenarios could be observed for the hydrological ES included in this study. In general, an increase of hydrological ES led to decreased provision of food and fodder (e.g., Pa-4, C-1) and vice versa (e.g., DCC-4, Pa-5). D-1 and C-1 show the trade-offs with respect to provisioning services implied with a land use that focuses on improved water resources management. The extension of intensive agriculture on remaining Cerrado (DCC-4) would in turn impair the provision of hydrological services. The results are in agreement with findings that the regulation of ES responds simultaneously to drivers of change (Bennett et al. 2009; Kandziora et al. 2013; Kramer et al. 1997; Zedler 2003) and can therefore be assumed a meaningful result of our simplified assessment approach.

Assessment results, especially in terms of sediment retention, may not appropriately reflect the problems of degraded water resources that have been identified in other reports/studies (e.g. CAESB, Environmental Sanitation Company of the Federal District 2001; Felizola et al. 2001; Fortes et al. 2007; Goncalves et al. 2013; Lorz et al. 2012a,b). In the case study region, water resources might be threatened more by LULCC changes that cannot be detected by commonly available data sets because of their small spatial extent or temporal occurrence which makes their mapping challenging. Franz et al. (2014) showed that sediment input into the adjacent Lago Paranoá originates mainly from urban point sources, such as construction sites, and that agricultural sites contribute only with a small amount of sediments. Small scale erosion events and point sources of sediments, however, cannot be addressed given the available land use data and assessment approaches. Land use/management change would need to be included with higher temporal resolution, i.e., with respect to interannual changes.

The need for improved land use data is supported by scenario Ar-4, the change of all arable land into Cerrado, which resulted only in a small enhancement of regulating ES. Agricultural management (e.g., soil management, fertilizer input) can be very diverse and management measures can impact ES provision at the landscape scale heavily (Strauch et al. 2013). However, these measures cannot be accounted for in the land use data set which is the core of the assessment.

The Goncalves et al. (2013) pointed out that in the coming years, population growth and excessive use of pesticides and irrigation practices may (further) reduce the amount and quality of water resources of the case study region. With respect to question three, the scenario results can therefore play an important role in the IWRM to inform people on the effects of LULCC, to initiate discussion among land managers in participatory processes, and to find best-practice land use patterns with accepted trade-offs. However, the process of regulating ES is less tangible for people and therefore may not be acknowledged (Kandziora et al. 2013). For a trade-off analysis that is meaningful for a land manager, we have included provision of food and fodder. The inclusion of other provisioning services such as drinking water supply and their linking to Payments for

Environmental Services schemes would be important to communicate the benefits people obtain directly from ES (Rodriguez et al. 2006). Thus, the impact and practical relevance of applying the tool in IWRM and planning could be further enhanced.

Conclusions

In comparison to previous applications of the software platform GISCAME (Frank et al. 2012; Fürst et al. 2013; Koschke et al. 2012, 2013) a GIS-based spatial explicit assessment was developed for this case study. We used information on soil properties and topography to introduce EPs in the assessment approach. In this study we have demonstrated how, with a basic set of environmental data and an easy-to-use GIS approach, site-specific conditions can be accounted for in a qualitative ES assessment approach. Using the layers of areas with low EP for hydrological ES as a reference (e.g., areas with low nitrogen retention potential), LULCC scenarios were conducted in areas that bear the greatest potential for positive (and negative) LULCC impacts.

With regards to scenario assessment results, we found that a considerable increase of water purification and sediment retention is difficult to achieve with reasonable, small scale land use changes as those did not affect the value points substantially. Given the current (2010) land use pattern, the Pipiripau case study area performed rather well in terms of water purification and sediment retention. There is much potential to increase water retention and provision of food and fodder which performed least well. Conservation and intensification scenarios did pinpoint the effects of efforts to restore natural systems and of further degrading land by adverse land uses, respectively. LULCC toward pastures, Campo, Cerrado, and forest in the areas with low EP to provide ES is recommended, and constitutes minimum measures to enhance water purification and sediment and water retention. More specifically, results showed that conservation measures in IWRM should be focused on arable land that is located at steep slopes. Thus, it is most likely to effectively increase hydrological ES by reducing provision services only marginally. Outcomes of the assessment indicated mono-directional, synergetic response of regulating ES to LULCC, which is in agreement with previous findings (Bennett et al. 2009; Kandziora et al. 2013). Our findings suggest that further degradation and loss of native Campo, Cerrado, and Mata must be avoided in order to safeguard water resources provision in the river basin.

In addition, the applied methods can be transferred/adapted easily for other regions and are not restricted to river basins. There is a risk to significantly over- or underestimate LULCC-related impacts due to small scale processes which cannot be adequately accounted for yet. Therefore, the methodical approach could be significantly improved by higher spatial resolution and easier availability of input data. Further, for validation of results and more appropriate inclusion of land management practices there is a need for more comprehensive monitoring (Strauch et al. 2013) of water related parameters (e.g., water quality, sediment generation), management (e.g., fertilizer application), and land use.

In spite of the existing uncertainties, the scenario results are useful for water resource managers to develop and advocate land use strategies aiming at water and soil protection in the Pipiripau river basin. The produced maps contribute to the negotiation and designation of priority areas with decision makers in (participatory) landscape planning processes to enhance water resources management and to promote resource-saving land use. Thus, in the context of IWRM, the cost-efficiency of less intensive land use to maintain and restore ES in comparison to technical solutions can be put more into focus (Maes et al. 2012). GISCAME is able to support such decision making processes as it is a powerful tool to visualize effects of LULCC and to make them more comprehensible for land managers (Fürst et al. 2013).

Abbreviations

ANA: National Water Agency of Brazil; BAU: Business as usual; DF: Distrito Federal; EMBRAPA: Empresa Brasileira de Pesquisa Agropecuária; ES: Ecosystem services; EP: Ecosystem potential; GISCAME, Geographic Information System: a Cellular Automaton, and a Multi-criteria Evaluation; IWRM: Integrated Water Resources Management; Ks: Saturated hydrological conductivity; LULCC: Land use/land cover change; RZAWC: Root zone available water capacity; USLE: Universal Soil Loss Equation.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

LK did write the main part of the manuscript and collected and processed data (in GIS) necessary for ES assessment. LK did implement and process previously prepared evaluation data and was responsible for setting up Letsmap and conducting land use change scenarios and analyses.
CL provided the idea and provided input with respect to the design, the scope of the study and methodical steps. He provided data, revised the first draft of the manuscript. CL also supported analyses and interpretation of results before drafting the final version. CF provided input to the conceptual and methodical approach and the linking between ES potentials and land use. She advised on the use of Letsmap. CF critically revised the manuscript before submission. TL processed data especially with respect to nitrogen retention. He adapted the assessment approach to the peculiarities of the general assessment approach and tested the applicability of different indicators and settings and the plausibility of data. Together with LK he discussed details and specific refinements of the methodical approach.
FM revised the first draft of the manuscript and made proposals to improve especially the structure and the focus of the investigation. FM helped to interpret the soil data and supported discussion of possible LULCC pathways, the impact of current land use activities and availability of land data.
All authors were discussing the thresholds for evaluation of environmental data considering individual value ranges. All authors participated in the discussion on the question of how much initial values have to or can be reduced in order to account for site specific potentials to provide ES.
All authors read and approved the final manuscript.

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Author details

[1]Department of Soil Science and Site Ecology, Dresden University of Technology, Pienner Str. 19, 01737 Tharandt, Germany. [2]Faculty for Woods and Forestry, Forest Pedology, Geology and Site Ecology, HochschuleWeihenstephan-Triesdorf, University of Applied Sciences, Freising, Germany. [3]Center for Development Research, Department of Ecology and Natural Resources Management, University of Bonn, Walter-Flex-Str. 3, 53113 Bonn, Germany.

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