USING WATER YIELD ECOSYSTEM SERVICES TO ASSESS WATER SCARCITY IN A METROPOLITAN ARID ENVIRONMENT IN QAZVIN REGION (IRAN)

SUMARI

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Introduction

Ecosystem service management in metropolitan green infrastructures requires, on one hand, knowledge of dynamic patterns of information and of the status of current services (Darvishi et al., 2021a), and, on the other, an understanding of the tradeoff between different ecosystem services (Fisher et al, 2009; Nelson et al., 2009; Redhead et al 2013; Darvishi et al., 2021b). Green infrastructuress in both their natural and human-made forms provide ecosystem services that support sustainable development (Darvishi et al. 2020a). Water yield ecosystem services (WYES) are one of the most important of all natural resources and play an essential role in agriculture, industry, energy generation and social and ecological functioning (Troy & Wilson 2006).

WYES is a calculation of the relative precipitation of water produced by different components of the landscape and provides an insightinto how different ecological patterns affect water yield and its spatial distribution (Troy & Wilson 2006; Sharp et al., 2014). Water yield is defined as the total water discharge minus storage and evapotranspiration losses (Tallis et al., 2011; Leh et al., 2013). The quantity and quality of water availability plays a critical role in socio-economic development – including sustainable development in social and ecological systems – and is particularly importantin metropolitan areas having to face up to water shortages (Lang et al, 2017). Physical water scarcity is caused by a lack of natural water resources, while social water scarcity arises in the event of an unbalanced industrial, agricultural and residential distribution of this resource (Yuan et al 2019).

BroadBroad agreement exists regarding the significance of integrating the concept of scarcity into water management strategies and decision-making. The mapping of ecosystem services is essential if we are to understand how ecosystems participate in social well-being and as a support for policies that influence ecological structure and functioning (Darvishi et al., 2014). Several previous studies have focused on mapping WYES (Chacko et al., 2019; Fan et al, 2020; Redhead et al., 2016); likewise, the impact of Land Use Cover Change (LUCC) on water yield via a measure of dynamic changes in patterns in water yields over a period of time (Lang et al, 2017; Lian et al., 2019) has also been tackled in numerous works (Li et al., 2018; Scordo et al., 2018).

The Qazvin plain ((Iran)is home to an arid metropolitan landscape, typical of theMiddle East, where water resources are highly threatened due to non-optimal water management (Yousefi et al., 2021).Water scarcity is habitual (Darvishi et al. 2020a) and is a major problem in many arid and semi-arid countries (Yousefi et al. 2020). Hence,appropriate planning and management of irrigation and cropping patterns in this area are urgently required. Mapping WYES is a priority for this metropolitan region where water is so scarce, and must form part of any attempt to integrate the concept of ecosystem services into decision-making and to developgreen infrastructure strategies that will ensure future water supplies (Martínez-Harms & Balvanera 2012; Wade et al., 2010; Troy & Wilson 2006).

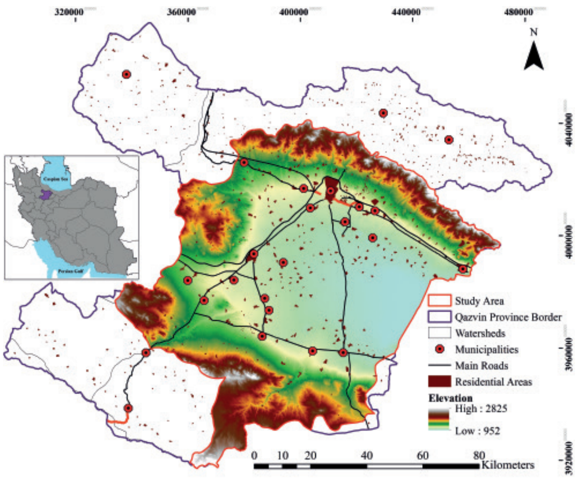
This paper quantifiesies and mapss WYES in the Qazvin metropolitan region, which consists of 19 urban areas and their surrounding territories, using an Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model to address water scarcity under two scenarios: the 'Continuing the Current Situation' (CCSS) and the ''Land-use Planning' (LPS) scenarios that incorporate LUCC under landscape ecological capability.

Material and Methods

Study site

The Qazvin plain (877 050 ha) lies in the central plateau of Iran (Fig. 1) andhas a semi-arid climate with hot summers and relatively cold winters (Darvishi et al. 2020c). One of the most significant rivers in this province is the Taleghan river, dammed by the Taleghan reservoir. Thisis reservoir lies 135 km northwest of Tehran ((50 37'–51 5'N, N, 36 5'–36 25'E) and has a full capacity of 460 million m^{3}and a dead capacity of 210 million m^3. However, due to a severe loss of inflow, it has never stored more than 210 million m^3 of water (Mohammadrezapour et al. 2019). Overall, Qazvin province contains 24 different municipalities located in five main water basin. The water basin of the Qazvin plain was chosen due to the intensive agriculture and industrial activity found in the 19 different municipalities located in the plain. The main water sourcesin this plain are wells and inter-watershed transfer of water from the northern basin. The basin

Figure 1. Distribution of the municipalities and residential areas in the Qazvin plain water basin in Qazvin province.



lies at an altitude of 800—2500 m a.s.l. and is watered by many seasonal rivers.

Data collection

The InVEST model requires georeferenced rasterized biophysical parameters including (i) root restricting layer depth (mm), soil depth and plant available water content (AWC, as a proportion) calculated using data from the Soil Survey of Iran; (ii) the average annual precipitation (mm) taken from the Meteorological Organization of Iran; (iii) the average annual potential evapotranspiration (PET, mm) obtained using the Hargreaves equation (1985); and (iv) ariver and LULC map obtained from the Agricultural Organization of Iran. All the input data were resampled at a spatial resolution of 30 m and projected using the Universal Transverse Mercator (WGS_1984_UTM_Zone_39N).

Method

'Continuing the Current Situation' Scenario (CCSS)

The first scenario used a LUCC simulation. We applied the Land Change Modeler (LCM) built-in module with TerrSet Geospatial Monitoring and Modeling Software (https://clarklabs.org/terrset). LCM can be used for modelling LUCC based on a combination of social-economic-ecological criteria (Darvishi et al. 2015; Yousefi et al., 2018; Hewson et al 2019). Distances from major roads as a social driver of LUCC (Darvishi et al. 2016),as well as river, slope and climate change as ecological drivers of LUCC, were selected (Mertens and Lambin 1997). These variables were significant factors in the LUCC simulation (Dendoncker et al. 2007).

'Land-use Planning' Scenario (LPS)

The second scenario was selected according to the land capability of different land uses. The land capability evaluation characterizes and appraises land development units from a general point of view without taking into account the type of use (AbdelRahman et al, 2016). For this propose, a GIS-based Multi Criteria Decision-Making land capability analysis was performed employing several capability factors including a number of ecological (slope, fault, erosion, soil, elevation and river) and socioeconomic (distances from roads,s-residential areas, protected areas and airports, and land use) parameters (Salari et al. 2019; Fataei et al. 2015; Taibi and Atmani 2017). Then, all the criteria and indices were quantized and normalized using a fuzzy method (Menhaj 2007). An Analytical Hierarchical Process (AHP) ranked the various suitability factors and the resulting weights were used to construct the capability map layers. The derived weights were used for the final land capability maps for different land uses.

Mapping Water yield ecosystem services (WYES)

Water yield in InVEST is defined as the amount of water that runs off the landscape (precipitation minus storage and evapotranspiration losses) (Tallis et al., 2011; Darvishi et al., 2021c).This model uses average annual precipitation (Px), annual reference evapotranspiration, soil depth, plant available water content, plant root depth and land use characteristics to calculate the average annual water yield (Yxj) in each 300 m × 300 m grid cell as follows:

$$Y_{xj} = \left(1 - \frac{AET_{xi}}{P_{xi}}\right) P_x$$

where AET is the annual actual evapotranspiration and AETxj/Px is an approximation of the Budyko curve (Zhang et al., 2001) given as:

$$\frac{AWC_x}{P_x} = \left(\frac{1 + W_x R_{xi}}{1 + W_x R_{xi} + \left({}^{1}/_{R_{xi}}\right)}\right)$$

$$W_{xi} = \left(\frac{AWC_x}{P_x}\right) Z$$

where AWCx is the volumetric plant available water content and Z is a seasonal rainfall factor. The Budyko dryness index (Rxj) is given as

$$R_{xi} = \frac{ETO_x K_{xi}}{P_x}$$

where ETox is the reference evapotranspiration from pixel x and kxj is the evapotranspiration coefficient for LULC j. The average annual precipitation (1950–2000) for the West African region was downloaded from the WorldClim database (Hijmans et al., 2005), while the reference annual evapotranspiration was downloaded from the FAO GeoNetwork database (FAO, 2004). Soil-type data for the region was estimated using the FAO Harmonized World Soil Database (HWSD, version 1.2; FAO, 2009).

Result and discussion

Land Use Land Cover (LULC) modelling

The LULC surface area under the CCSS and LPS scenarios was obtained using, respectively, LUCC simulation and land capability evolution (Table 1). The main land cover types in the Qazvin plain are pastures and irrigated and dry farmland. Table 1 shows how pastureland coverss 32.3% of the total area of the case study, a figure that decreases to 30.2% under CCSS. However, the result for land capability reveals that this type of land cover will represent 31.1% of the study area under LPS. More pasture-

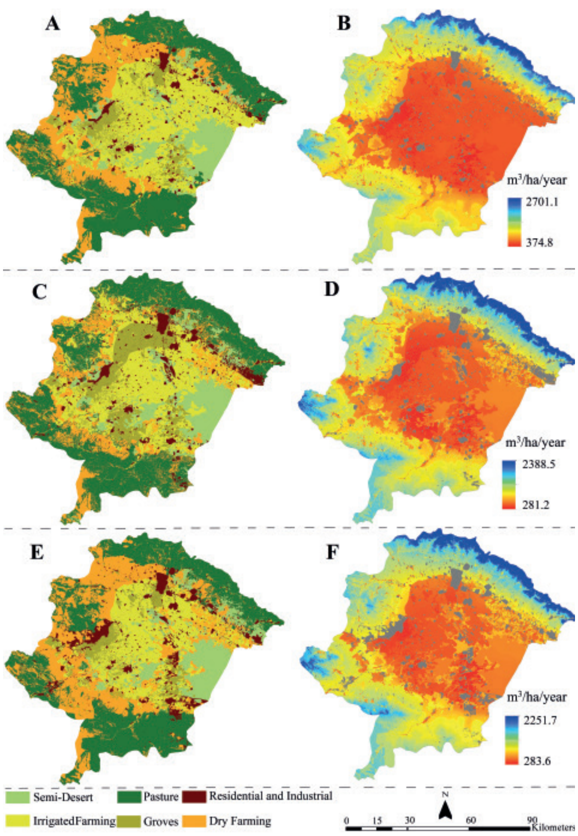
Table 1. Area (%) of LULC in different scenarios.

LULC	Current	CCSS	LPS
Pastures	32.3	30.2	31.1
Semi-desert	11.6	16.4	13
Irrigated Farmland	24	23.1	18.5
Dry Farmland	19.9	12.8	23.2
Groves	7.8	10.8	6.7
Residential and Industrial	4.1	6.3	7.3
Sum	100	100	100

land plandis present in the uplands to the north and south of the plain. Pastures decreasedeby 2% under CCSS due to the development of dry farmland and residential areas, as well as to the increase in semi-desert land cover (Fig 2).

The amount of semi-desert area was estimated at 11.6% of the study area and increases to 16.4% under CCSS. However, through management and LPS, this increase could remain at 13% in the study area. The rapid growth of semi-desert area under CCSS is due to water scarcity and, consequently, the destruction of agricultural areas.

Figure 2. Land Use/Cover maps and land Water Yield Ecosystem Services (WYES) under the current scenario (A & B), under the 'Continue the Current Situation' scenario (CCSS) (C&D), and under the 'Land-use Planning' scenario (LPS) (E&F)



Dry farmland occupied 19.9% of the total area and was predicted to decrease to 12.8% under CCSS, while under LPS this land use will increase to 23.2%. Given the seasonal nature of precipitation in the Qazvin metropolitan region, the model for land capability predicts a high potential in this area for dry farming. As a result, due to the non-dependence of dry farmland on surface and groundwater, this land use type has great potential for providing ecological capability management in the event of water scarcity (Fig 2).

The amount of irrigated farmland decreases from 24% to 23.1% in the study area under CCSS and to 18.5% under LPS. Due to the water scarcity, irrigated farmland needs to be morecarefully managed. This land use is only suitable for 18.5% of the study area. Although the continuation of current trends indicates that a decrease in this land use will occur, most of the decrease in irrigated farmland isisdue to the conversion to groves of tree crops and not tofarm abandonment.

The area occupied by groves will increase from 7.8% to 10.8% under CCSS as a consequence of thegreater economic efficiency of these groves. Due to the high demand for water in these groves, the model of land capability in this area predicts thatat groveswill decrease and occupy only 6.7% in order to overcome water scarcity.

LPSdemonstrates that the Qazvin metropolitan region has the capacity to host residential and industrial areas over 7.3% of its total surface area since these types of development consume far less water than irrigated agriculture and groves.

Water Yield Ecosystem Services (WYES) modelling

Figure 2 depicts the water yield and land use/cover map under different scenarios. Water yield increased or decreased with LUCC depending on the type of conversion (Lang, et al., 2017). The overall water yield was estimated at 752.02 million m^3 given the current situation. As can be seen from the spatial distribution, the distribution of the water yield has significant spatial heterogeneity since it decreases gradually from the north of Qazvin to the central part of the region, and then s again in the eastern areas along the edge of the water basin. It is clear that areas of low water yield are mainly concentrated in the area surrounding the plain and in areas of low elevation, which was consistent with what has been foundby Lian et al (2019) that showed the water yield is clearly greater in upland areas.

TheLUCC modeling shows a decreasing trend in water yields under CCSS, indicating that if this situation continues, the water yield will decrease to 575.32 million m^3. Due to the fall in precipitation and increasing evaporation (as predicted by climate change models), such a decline in the water yield in the study area was not unexpected.

In addition, this study showed that if planning could be established based on ecological capability, the amount of water yield in the region will increase to 602.74 million m^3,, 27.42 million m^3 more than under CCSS. The maximum value under CCSS is more than under LPS, which illustrates how the distribution of land use/covers is based on ecological capability. The range of changes in the water yield in the landscape under the LPS scenario is less than under CCSS.

Conclusion

Water yield assessment and its mapping are two of the key inputs required for accurate water resource planning when managing green infrastructures in metropolitan regions. The method used in this research to assess the Water Yield Ecosystem Service (WYES) provides a basis of knowledge for improving water management and highlights the areas prone to water scarcity in the Qazvin metropolitan region.

The InVEST model is easy to apply and performs well in the Qazvin basin. Although there tare still some uncertainties regarding this simulation, the outcomes provide a basis for decision-making as part of the scientific management of water resources in this social-ecological system. However, our study still has some limitations. InVEST represents bio-physical processes in a simplified manner and the model assumes that all the water yield from a pixel reaches a particular point. Consequently, the model does not distinguish between surface and ground water and water transferred between the basins located in the study area. However, its evaluation does provide valuable information regarding the constraints and opportunities for land management. This study can thus help guide decision-makers when developing strategies aimed at ensuringfuture water supplies.

The water yield calculation and modelling under two different scenarios is an effective input for spatial planning of green infrastructure in the Qazvin metropolitan area.The spatial-based and pixel-based water yield ecosystem service estimation in this study guarantees that planning will be accurate and meaningful on a spatial scale. As well,it can be useful for predicting natural ecosystem disservices such as floods in arid areas caused by seasonal rainfall. Green infrastructure policies are required to protect natural ecosystem services.

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