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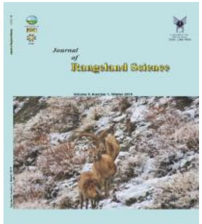

Research and Full Length Article:

Annual Water Yield Estimation for Different Land Uses by GIS-Based InVEST Model (Case Study: Mish-khas Catchment, Ilam Province, Iran)

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Abstract. Fresh water supply and its security encounter a high level of fluctuating variability under global climate changes. To address these concerns in catchment water management, a good understanding of land use/cover impacts on the hydrological cycle affecting water supply is crucial. The objective of this study is to define a model to investigate the impact of existing land use/cover on water yielding in Mish-khas catchment of Zagros region, Ilam province, Iran. In this research, a water yield model of Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) was employed to estimate annual water yield in the catchments as a basic foundation for policy and decision making. The input data set included land use/cover layers of the region produced in 2016, average annual precipitation and potential evapotranspiration from 1986-2016, soil depth, plant available water content and land use/cover bio-physical database. Based on the results, total annual water yield was estimated 30.2 million m^3 for the whole Mish-khas catchment. The annual water yield percent for rangeland, forest, farmland and orchards land uses was 57%, 31%, 8.6% and 3.4% of the total water yield of the catchment, respectively. In addition, the results showed that the farmland had the highest water yield (2449 m^3/ha) followed by forests (2269 m^3/ha), orchards (2254 m^3/ha) and rangeland (2196 m^3/ha) land uses. In terms of water distribution, the northern regions with a volume of 2315 m^3/ha had higher water yield than the southern regions (2210 m^3/ha). The results also indicate that a GIS-based InVEST model is a useful instrument to identify more suitable areas for water-table recharge.

Key words: Evapotranspiration, Soil Depth, Plant Available Water Content, Bio-physical Database.

Introduction

Almost 97.5% of all water on Earth is salty leaving only 2.5% as fresh water. Fresh water is one of the basic necessities for life sustenance, human consumption, habitat support and maintaining the quality base flow of rivers. Nearly 70% of fresh water is frozen in the icecaps of Antarctica and Greenland and only 1% of world fresh water (~0.007% of all water on earth) is accessible for direct human uses. This is the water found in lakes, rivers, reservoirs and those underground sources that are shallow enough to be tapped at an affordable cost (Ebrahimi *et al*., 2011; Alizadeh, 2008). Among enormous ecosystem services, water supply contributes to the welfare of society, ensuring the development of irrigation agriculture, increased population, improved living standards, industry and tourism activities (Cudennec *et al*., 2007). Water yield assessment and mapping are of great importance for water resources management and planning for optimized land use management. By recent development in geographical information system technology, some physical hydrological models have been established and employed to simulate hydrological processes and responses to disturbance such as Soil and Water Assessment Tool (SWAT) (Arnold, 1998) and Precipitation Runoff Modeling System (PRMS) (Leavesley, 1983).

Rangeland and forest ecosystems provide multiple benefits to human society in general and the economic sub-system in particular (Reyes *et al*., 2002; Vedeld *et al*., 2007) besides producing timber, seeds, fodder and a few other marketable non-wood products. However, ecosystem services are not fully recognized by human societies. The ecosystem services have become one of the most significant and fastest evolving research areas in environmental and ecological economics (Mashayekhi *et al*., 2010; Guo *et al*., 2001). Zagros ecosystems of Iranian mountains are a major source of tangible and intangible benefits to the local community in particular according to goods and services production. Recent outbreak of twig-borer beetle and crown defoliation in Zagros Persian oak forests has highlighted the forest degradation issues caused by ecosystem fragmentation, loss of biodiversity, soil erosion, reduction of goods and services, etc (Mashayekhi *et al*., 2010). Major role of ecosystems in water supply, yielding and regulating water resources has been recently discussed (Reyes *et al*., 2002; Guo and Gan, 2002; Guo *et al*., 2001). It is also a crucial issue in Zagros and for the governance of its forest ecosystems. Zagros ecosystems provide 40% of the total water resources of the country and flow into the Persian Gulf (Sagheb-Talebi *et al*., 2014). The provision of fresh water is Zagros ecosystem service that contributes to the welfare of society, ensuring the development of irrigation agriculture, increased population, improved living standards, industry and tourism activities (Cudennec *et al*., 2007).

Land use/cover impacts on hydrological cycle of catchments are less investigated. Water yield assessment and mapping are of great importance to planning, the management of water resources and hydropower station construction. However, surface runoff is a complex process influenced by precipitation intensity, soil permeability, slope steepness and land cover.

Describing the overall water yield condition is difficult due to the spatial variability of multiple contaminants and wide range of indicators that could be measured. Geographical Information System (GIS) can be an effective and powerful tool for mapping, monitoring, modeling and assessing water yield, detecting environmental changes, determining water availability, preventing from floods and managing water resources on a local or regional scale (Ebrahimi *et al*., 2011). GIS can be utilized in various water assessments for assessing the water resource hazard (Masoudi *et al*., 2009).

generating the groundwater contamination risk map (Ducci 1997) prepared the spatial variation map of water quality (Anbazhagan and Nair 2004) relating the water yield variations to spatial variation of some environmental variables as land cover, topography, geology and climate (Hong and Chon, 1999).

To address these concerns in yield water management, understanding impacts of different land uses on the catchment hydrological cycle is needed. The objective of this study is to model and understand the impact of existing land uses on water yield in the Mish-khas catchment. The ultimate objectives of this research are to provide management options for policy-makers by establishing a GIS-based decision support system (Invest model) for water yielding estimation.

Material and Methods

Study area

The study area (Mish-khas basin) about 13468 ha is located in Ilam province in the western part of Iran within 33°30'12" to 33°38'46" N Latitude and 45°29'12" to 46°38'23" E Longitude (Fig. 2). It includes a vast variety of land uses/covers, relief, slope in addition to population and few small rural residences. The climate is mostly characterized by Mediterranean arid and semi-arid regions with annual average temperature between 10.8 to16.7°C. Annual mean precipitation is 633 mm, and over 70% of rainfall occurs in the flood season (Nov. to Apr.). Altitude ranges from 1217 m to 2603 m. The main species of the forests of area which are part of the Zagros open forests consisted of *Quercus brantii*, *Quercus libani* and *Pistacia atlantica*. The dominant species is *Q. brantii*. Livelihood of local community highly depends on forest ecosystem services (Fattahi, 2003).

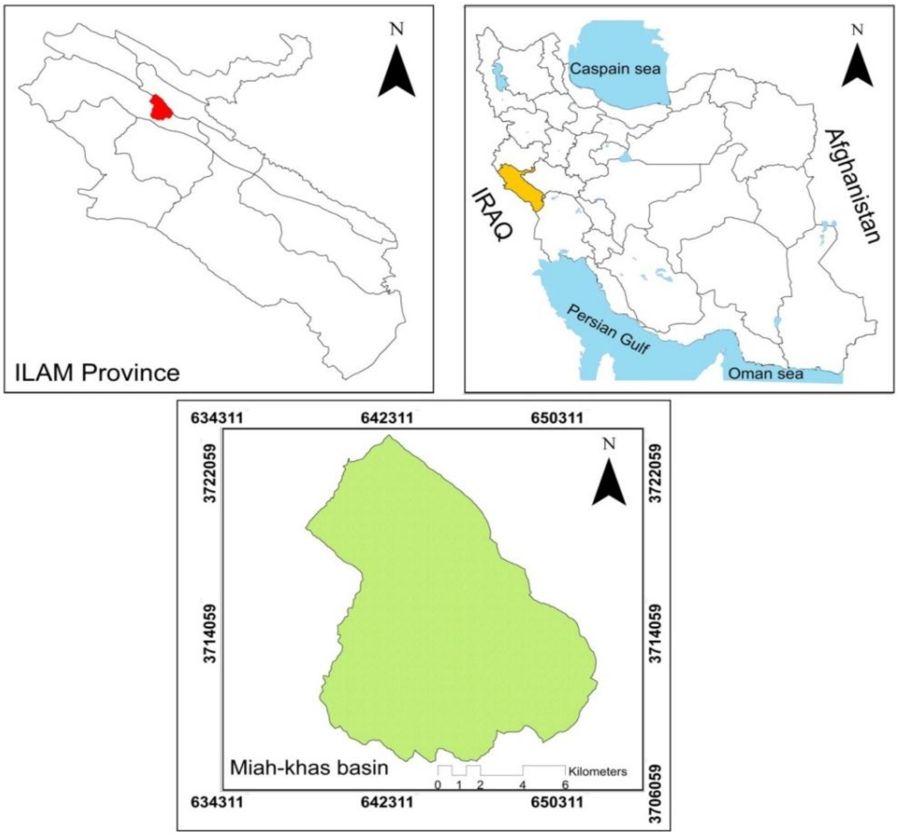

Fig. 1. Location of the study area in Ilam province of Iran

Methods

In this study, an Ecosystem Service Modeler (ESM) has been used to calculate annual water yield. The ESM is closely based on the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) toolkit developed by the Natural Capital Project (Eastman, 2015). The InVEST Water Yield model required 8 input datasets including six spatial map data and two ones derived by coefficients (Sharp *et al*., 2015). The InVEST set of tools has been developed to enable the managers to recognize synergies and trade-offs among ecosystem services and to compare scenarios of change such as land uses (Redhead *et al*., 2016).

The water yield model measures the average annual runoff, i.e., water yield in millimeters at the watershed, sub-watershed, and pixel levels (Fig. 1). The model estimates the total annual water yield (Y) for each grid square (x) of the study basin as total catchment annual precipitation. (P) is total catchment annual actual evapotranspiration (AET) (Eq. 1). The model assumes that on an annual time step, all water falling as rainfall over a catchment that is evapo-transpired leaves the catchment (Redhead *et al*., 2016).

$$Y(x) = \left(1 - \frac{AET_x}{P_x}\right) . P_x \quad (1)$$

The InVEST approach relates AET to potential evapotranspiration (PET), which is easier to model using the methodology developed by Budyko (1974) and later adapted by Fu (1981) and Zhang *et al*. (2008) (Eq. 2) where ω is an empirical parameter which defines the shape of the curve relating potential to actual evapotranspiration (Redhead *et al*, 2016).

$$\frac{AET_x}{P_x} = 1 + \frac{PET_x}{P_x} - \left[\left(\frac{PET_x}{P_x}\right)^{\omega}\right]^{1/\omega} \quad (2)$$

PET is estimated as the product of the reference evapotranspiration and the crop coefficient for each grid square (Redhead *et al*, 2016). ω is related to the Plant Available Water Content (PAWC), precipitation and the constant Z which captures the local precipitation pattern and additional hydrogeological characteristics (Eq. 3) (Sharp *et al*., 2015).

$$\omega = Z \frac{AWC_x}{P_x} + 1.25 \quad (3)$$

In this study, the temperature-based method Hargreaves equation was employed as it generates superior results than the Pennman-Montieth given limited long term data (Hargreaves and Samani, 1985). The Hargreaves equation is given as (Zhang *et al*., 2012):

$$ET_0 = 0.0023 \times Ra \times [(T_{max} + T_{min})/2 + 17.8] \times (T_{max} - T_{min})^{0.5}$$
(4)

Where Ra is extraterrestrial radiation (in mm day-1); T_{max} is meant maximum temperature in 0C; T_{min} is mean minimum temperature in 0C. The radiation is far more expensive to measure directly but can be reliably estimated as follows (Zhang *et al*., 2012):

$$Ra = \frac{24 \times 60}{\pi} G_{sc} d_r [\omega_s \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\sin(\omega_s)] \quad (5)$$

Where G_{sc} is solar constant = 0.0820 MJ m-2 min-1, d_r is inverse relative distance Earth-Sun, ω_s is sunset hour angle, φ is latitude, and solar decimation is given by δ. These parameters were calculated following Allen (1998).

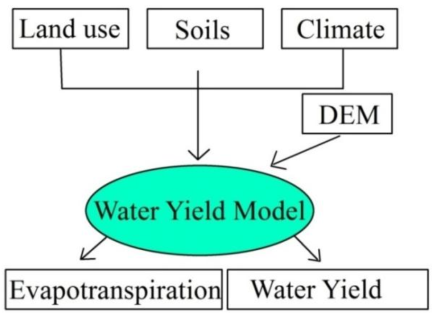

Fig. 2. A view of water yield model (InVEST)

Model input parameters

The current model requires geo-referenced raster layers with 1:25000 scales as major input data. Here, the input layers are: catchment and sub-catchments boundaries, land use/cover map, precipitation (in mm), average annual potential evapotranspiration (in mm), soil depth (in mm), and PAWC, in percent in addition to the attributes of land use/cover collected in a spreadsheet database.

Based on a digital elevation model, DEM, catchment and sub-catchments boundaries were extracted and labeled by unique identifier in GIS environment. Finally, the catchment was partitioned into 23 sub-catchments based on the topography status and the streams network in the region.

Land use/cover maps were generated by visual interpretation of Landsat-8 OLI satellite remotely-sensed data (Maleknia *et al*., 2017). The map includes 4 thematic classes of Forest, Rangeland, Orchards and Farmland. Rangeland and Forest were the main landscapes, accounting for 58.1% and 30.4% of the surface area, respectively.

Annual precipitation data from 1986 to 2016 of 10 rain-gauge stations located in the watershed were collected from Annual Hydrological Report of Iran Meteorological Organization (IMO), center of IRAN (Fig. 3). The annual mean precipitation raster value in millimeters was generated using the Kriging interpolation method.

The daily mean, maximum and minimum temperature of 10 meteorological stations during 1986-2016 was collected from Iranian national data base of the Surface Meteorological Observation Report of IRAN. Annual potential evapotranspiration was obtained using the Hargreaves equation (Equation 5). Average annual potential evapotranspiration was produced by Kriging interpolation.

A raster layer of average soil depth was generated based on the hydrological studies of Mish-khas basin including soil types, particle composition, and soil depth. Soil depth values should be in millimeters (Watershed design consultant engineers, 2015).

PAWC is defined as the difference between the fraction of volumetric field capacity and permanent wilting point. It can be estimated based on physical and chemical properties of soil (Zhang *et al*., 2012; Yu *et al*., 2015). The physical and chemical properties of soil including the proportion of sand, silt, clay and the reference soil depth are acquired from the hydrological studies of Mish-khas basin and Harmonized World Soil Database (FAO, 2012). PAWC is generated by the Soil-Plant-Atmosphere-Water (SPAW) software and ArcGIS. In this study, we employ this method to estimate the PAWC.

In order to run the water yield model, a biophysical table is required presenting the attributions of each land use and land cover type (LULC) containing LULC labels, descriptive name of LULC, the maximum root depth for vegetated land use classes in millimeters (non-vegetated LULCs should be given a value of minimal root depth) and the plant evapotranspiration coefficient for each LULC class (Table 1). The root depth of main vegetation types was obtained following (Chen *et al*., 2008). Evapotranspiration coefficient of each land use/cover type has been determined based on (Allen *et al*., 1998) and the InVEST user guide. A Zhang constant should be chosen that characterizes the seasonality of precipitation where values close to 1 indicate that precipitation occurs predominantly during summer months or is evenly distributed through the year and values close to 10 indicate that more precipitation occurs during winter months.

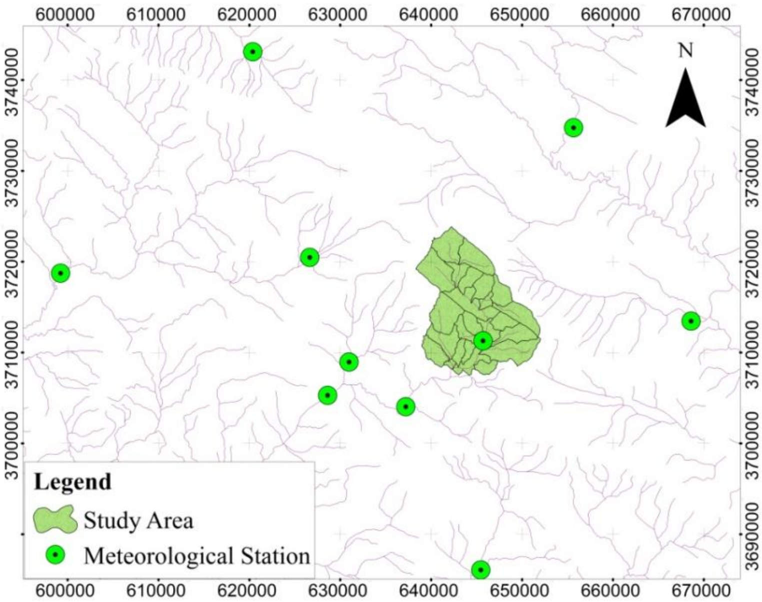

Fig. 3. Meteorological Stations in the study area

Table 1. Biophysical table for the study area

LULC code	Lulc_desc	Root_depth (mm)	Etk	Lulc_veg
1	Rangeland	300	100	1
2	Orchards	1500	300	1
3	Forest	2000	500	1
4	Farmland	200	100	1

The lucode and lulc_desc fields must correspond to the codes in the land cover map. Root depth is in mm. The etk field is FAO's Kc evapotranspiration coefficient * 1000 and is used to adjust the reference evapotranspiration image specific to the land cover type. The lulc_veg field indicates if the land cover type is vegetation

Results

In Fig. 4, watershed and sub-watersheds boundary, land use and land cover, precipitation (mm), average annual potential evapotranspiration (mm), soil depth (mm) and PAWC layers are presented. There are 11 watersheds and 17 sub-watersheds in the region. The main land use includes Range Land (1), Orchards (2), Forest (3) and Farm Land (4). The distribution of land use by area is given in Table 2. The results show that higher parts of the catchment are dominated by Rangeland (grazing natural vegetation). The annual precipitation of the study area is between 565 mm and 713 mm, and the average is 633 mm which is similar to the mean level of the entire region. While the annual evapotranspiration of sub-watershed units is between 90 mm and 224 mm, and the average is 151 mm (Fig. 4). Water yield is highly sensitive to changes in precipitation (Redhead *et al.*, 2016) with a 10% increase in precipitation resulting in an 11%–27% increase in water yield, and is somewhat less sensitive to variation in evapotranspiration (Redhead *et al.*, 2016).

The main soil depth of the region is between 250 mm and 700 mm, and the average is 450 mm and the PAWC value is between 0.01 to 0.02 (Fig. 2). Water yield model is relatively insensitive to soil depth and PAWC with 10% increase in either of these data sets resulting in a water yield decrease of 0%–3% (Redhead *et al.*, 2016).

There is a considerable variation of annual water yield with respect to type of land uses in the region. The distribution of water yield is shown in Fig. 4. Also, the results show that the farmland land use had higher water yield per ha (2449 m^3/h) than other land uses. The rangeland had the lowest water yield per ha in the study area (2196 m^3/h). In other words, each hectare of the forest and orchard can produce 2269 and 2254 m^3 water per ha (Table 2). The annual water yield was 2241 m^3/h and the total annual water yield was 30.2 m m^3 in Mish-khas basin. In terms of water distribution, the northern regions with a volume of 2315 m^3/h had more water yield than the southern regions (2210 m^3/h) (Fig. 5). Also, the annual water yields for rangeland, forest, farmland and orchards land uses were 17.2, 9.32, 2.61 and 1.04 m m^3, respectively. The results showed that the water yield was significantly higher in rangelands than forest, farmlands and orchards in Mish-khas basin (Fig. 6).

The water yield value of each hectare of Zagros ecosystems was economically assessed using Replacement Cost Method and estimated 0.5 US$/ m^3 annual water value (Mashayekhi *et al*., 2010). So, the water yield value of rangeland and forest land will be 8.61 m US$ and 4.66US$.

Table 2. Land use area in the study area (Mish-khas basin)

Land use	Area (ha)	Area (%)	Water yield (ha/m^3)	Water yield (%)
Rangeland	7842.6	58.0	2196	57
Forest	4107.7	30.5	2269	31
Farmland	1069.3	8.0	2449	8.6
Orchards	13484.5	3.5	2254	3.4

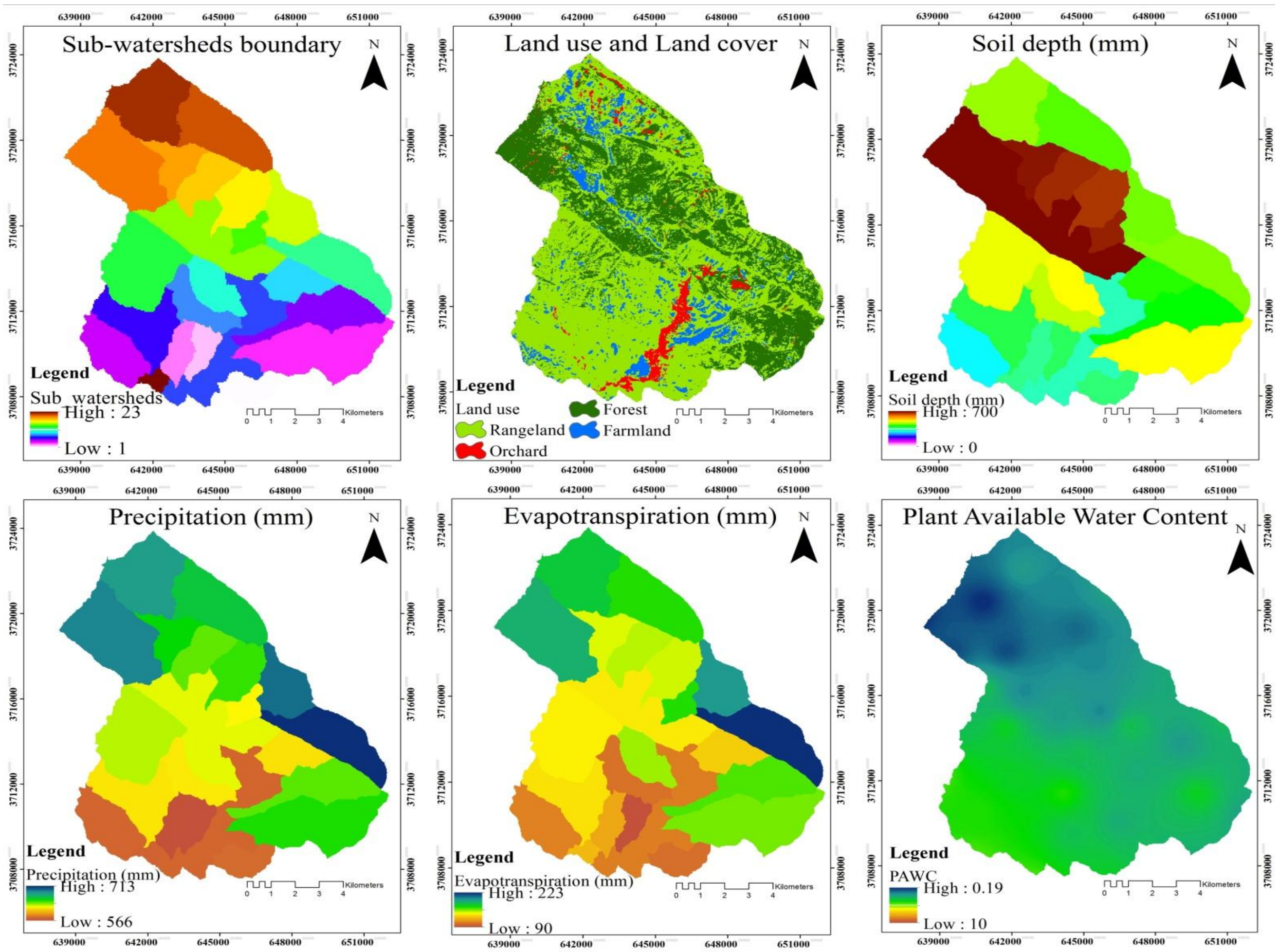

Fig.4. Layers obtained in data preparation. sub-watersheds; precipitation layer; reference evapotranspiration layer; soil depth layer; PAWC layer; land use layer

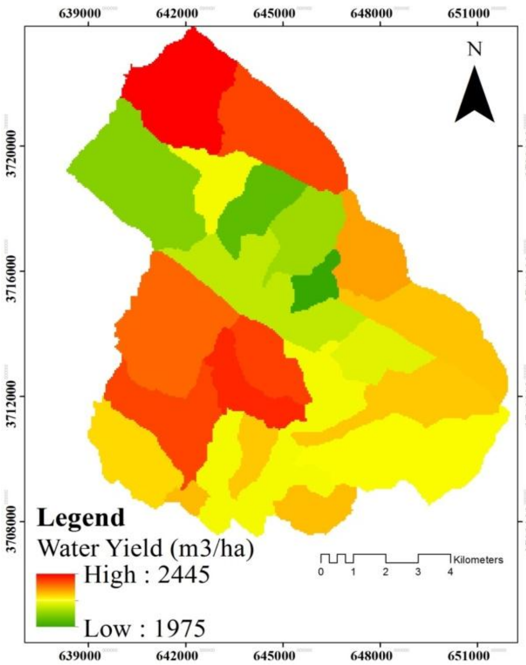

Fig.5. Water yield volume per hectare per sub-watershed

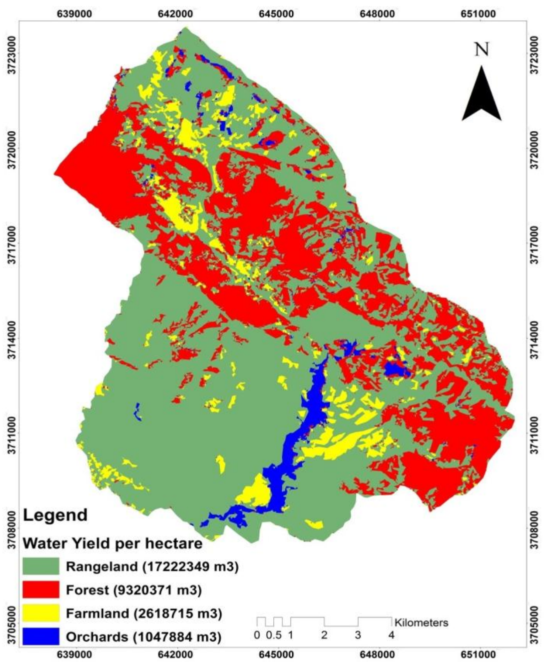

Fig.6. Water yield volume per hectare in different land uses

Discussion

Ecosystem service models such as InVEST have the potential to provide a crucial underpinning to decision and policy making in the local scale. The water yield simulated by InVEST represented natural stream flow; however, it is of great importance to note that the observed river flow at the watershed outlet or hydrological station was impacted by land use changes and human activities. Our results show that the InVEST water yield model can produce estimates of water yield in Mish-khas basin. However, this accuracy is dependent upon careful selection of appropriate model parameters and input data, especially precipitation and evapotranspiration to which the model is most sensitive. It is assumed that the water yield of each sub-watershed will vary with precipitation, temperature and other factors, but the relative capacity of water yield among sub-watersheds will not change in the absence of interference because the spatial structure of the geographical locations has had consistent strong stability over time. This assumption is consistent with (Yu *et al*., 2015) conclusion on the stability of spatial patterns for provision of water ecosystem services. Based on this assumption, the sub-watershed units are sorted from small to large ones according to the water yield in each period, which is used to describe the relative capacity of water yield.

Land use/cover change effects on watershed hydrology are neither spatially nor temporally uniform because of its coupling with climate variability (e.g. Li *et al*., 2007; Ma *et al*., 2008; Zhang *et al*., 2008). This is very important while making land and water management decisions to understand the seasonal and inter-annual water yield regime due to land use changes from a watershed given a specific climate condition.In this study, the results showed that there was a marked difference for the net water yield among the vegetation types and different land uses, which is consistent with the conclusion of (Xiao *et al*., 2015; Zhang *et al*., 2012; Liu *et al*., 2008) demonstrated that land use changes led to significant changes in ET, runoff, and water yield in most of China's river basins.

The total annual water yield was 30.2 m m^3 in Mish-khas catchment. In terms of water distribution, the northern regions with a volume of 2315 m^3/h had more water yield than the southern regions (2210 m^3/h). Also, the results show that the rangeland use had higher water yield than other land uses.

Zagros ecosystem produces high quality drinking water as well as essential environmental flows for revering systems. Adoption of sustainable management principles is a key to ensure these non-timber values delivered in perpetuity. Both water yield and quality can be adversely affected by high intensity wildfires or inappropriate forestry practices. However, Zagros management strategies can be used to maintain or enhance water quantity and quality in the study area. In the Zagros region, rangeland and forest land uses are the major sources of water yield (about 40% of Iran water provided from the Zagros forest (Fattahi, 2003). Both the quantity and quality of water in ecosystems are determined by soil type, cover land and catchment conditions. On the surface, it seems that the most important factor affecting water yield is still rainfall, which coincides with the results of (Yu *et al*., 2015; Cudennec *et al*., 2007). The water yield from rangeland and forest land uses can be affected by natural events and/or management actions.

Water yield from a catchment is strongly dependent on rainfall. Measurements in forests indicate where annual rainfall is less than 900 mm, little stream flow occurs but as rainfall approaches 2000 mm per annual, about 50% is returned as stream flow (Bari and Ruprecht, 2003). The results of this study show that the average yield in water supply catchment had been 30% of rainfall. Bari and Ruprecht (2003) stated that a permanent reduction in vegetation cover by clearing for agriculture has led to permanent increases of water yield of about 30% of annual rainfall. In this study, farmland had higher water yield than other land uses. Since the areas covered by the farmland are around 8% of the catchment, its impact on water yield is not as significant as natural forest vegetation. Fifty-eight percent of the catchment is covered byrangeland, which appears to have considerable impact on water yield than any other land use categories. Bosch and Hewlett (1982) further stated that water yield of forests is higher than grasslands.

The variation of water yield in relation to climatic factors and different types of land cover can be used to identify areas where water yield can be made through adopting better management practices in an integrated ground water and surface water management system.

Conclusions

Water yield calculation and its mapping are one of the most importance inputs for water resources planning and management. The method proposed in this research to assess water yield services provides some knowledge basis for the enrichment of water management in Iran. In this study, the water yield model in InVEST was employed to estimate annual water yield in the Mish-khas basin in Ilam province of Iran. InVEST model uses ecological production functions, basing on simplified hydrological processes, to quantify and map several ecosystem services. Input data included land use and land cover in 2016, average annual precipitation and potential evapotranspiration from 1986-2016, soil depth, PAWC and a biophysical table reflecting the attributes of each land useand land cover by running the model with relatively easy acquired and modified data. The annual water yield was estimated 30.2 m m^3. From the distribution of water yield, North area ofthe watershed had higher water yield volumes. Also, the results showed that the farmland and use had higher water yield (2449 m^3/ha) than other land uses. Increased potential evapotranspiration and reduction of precipitation will further aggravate the water yield reduction concerns in the region.

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برآورد تولید آب سالانه برای کاربری‌های مختلف حوزه میشخاص ایلام با استفاده از مدلInVEST مبتنی بر GIS

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چکیده. با افزایش تغییرات اقلیم جهانی، تأمین آب شیرین و امنیت آن نیز با تغییرات زیادی مواجه است. برای رسیدگی به این نگرانی‌ها در مدیریت حوزه آب، درک خوبی از تأثیرات کاربری اراضی/ پوشش اراضی بر چرخه هیدرولوژیکی تأثیرگذار بر تأمین آب ضروری است. هدف از این مطالعه تعریف مدل تأثیر کاربری اراضی و پوشش اراضی بر تولید آب در حوزه میشخاص در ناحیه رویشی زاگرس است. در این تحقیق، برای برآورد تولید آب سالانه در حوزه‌های آبخیز که یک پایه اساسی برای سیاست‌گذاری و تصمیم‌گیری محسوب می‌شود، یک مدل تولید آب به نام ارزش‌گذاری تلفیقی خدمات و تقابل‌های اکوسیستم (InVEST) مورد استفاده قرار گرفت. مجموعه داده‌های ورودی شامل لایه‌های کاربری اراضی (پوشش اراضی) مربوط به سال۱۳۹۵، میانگین بارش سالانه و پتانسیل تبخیر و تعرق طی سال‌های ۱۳۶۵تا ۱۳۹۵، عمق خاک، میزان آب در دسترس گیاه و پایگاه داده‌های زیستی- فیزیکی پوشش اراضی بودند. براساس نتایج به دست آمده، میزان تولید آب سالانه برای کل سطح کاربری‌های منطقه ۳۰/۲ میلیون مترمکعب برآورد گردید. میزان درصد تولید آب سالانه برای کاربری‌های مرتع، جنگل، زراعت و باغ به ترتیب ۵۷، ۳۱، ۸/۶ و ۳/۴ درصد از تولید آب کل حوزه به دست آمد. علاوه بر این، نتایج نشان داد که کاربری کشاورزی بیشترین میزان تولید آب در هکتار را به خود اختصاص داد (۲۴۴۹ مترمکعب در هکتار)، به دنبال آن کاربری‌های جنگل (۲۲۶۹ مترمکعب در هکتار) باغ (۲۲۵۴ مترمکعب در هکتار) و مرتع (۲۱۹۶ مترمکعب در هکتار). از نظر توزیع آب، مناطق شمالی با میزان ۲۳۱۵ متر مکعب در هکتار دارای تولید آب بیشتری نسبت به مناطق جنوبی حوزه با میزان ۲۲۱۰ متر مکعب در هکتار بودند. نتایج همچنین نشان می‌دهد که مدل InVEST مبتنی بر GIS ابزار مفید برای شناسایی مناطق مناسب‌تر برای ذخیره جدول آب است.

کلمات کلیدی: تبخیر و تعرق، عمق خاک، آب در دسترس گیاه، پایگاه داده بیوفیزیکی