Research article

Rainwater Harvesting as a Mean for Water Conservation in Ovche Pole Region, Macedonia

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Abstract Ovche Pole is an area in Macedonia located in the central part of the country. The region is the second largest grain producing area and agriculture is the main economic activity for most of the people there. From an agro-ecological perspective, larger part of the region is part of the sub-humid agricultural zone; however, there is an area that is identified as semiarid agricultural zone, too. In both agro-ecological zones, main problem and constraint for agricultural production are the dryness and low precipitation in the growing period. This problem is especially emphasized on the agricultural land without irrigation system. Therefore, this study analyzes rainwater harvesting approach as a mean for water conservation and improvement of agriculture productivity in the research area. The first objective of this study is to determine the runoff potential in the research area and the second is to identify suitable areas and measures for water harvesting. Remote sensing and geographic information system techniques were used to obtain, prepare and analyze input data. Because of simplicity and lack of hydrological data in the research area, SCS-Curve Number method was used for rainfall-runoff modelling. Hydrologic Soil Group (HSG) map was build using data obtained from the Macedonian Soil Information System (MASIS). Land use/land cover was prepared by combining supervised classification of Sentinel-2 satellite image and visual interpretation and editing to improve the classification. Slope map was generated from a 20-meter resolution DEM data obtained from the Agency for Real Estate Cadaster. Data of the annual average precipitation for the period between 1981 and 2010 was obtained from the National Hydrometeorological Service. Set of rainwater harvesting measures were selected as appropriate for the context of the research area. The site suitability for each rainwater harvesting intervention was determined by considering different varying parameters like runoff potential, slope, soil texture, land use, stream order of proximity to users. The results indicate that rainwater harvesting can be considered as a strategy for water conservation in the research area.

Keywords water conservation, rainwater harvesting, surface runoff, SCS-SN method, suitable site selection

INTRODUCTION

Having in mind the United Nation Convention for Combating Desertification (UNCCD) definition, approximately 40% of the global land can be considered as a type of dryland (WRI, 2012). Although there are many challenges, in these areas water is the key limiting constraint for agricultural and biological productivity. Irrigated areas to some extent can avoid this constraint, however rainfed agricultural land is dependent on water that comes as precipitation. To unlock the potential of smallscale rained agriculture, investments in better water management need to be emphasized. In dry area water harvesting coupled with in situ water management as well as improved soil, nutrient and crop management have great potential. In humid areas, in situ water management technologies such as conservation agriculture based on no-till, mulching and crop rotation are generally more suitable and appropriate. Mekdaschi and Liniger (2013) define water harvesting (WH) as "The collection and management of flood water or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance". Although there are multiple benefits, there are some considerations that must be taken before water harvesting systems can be successful implemented. Therefore, objectives of this study is to determine the runoff potential in the research area and to identify suitable areas and measures for water harvesting. In this line different methodologies and criteria for WH site and method selection were developed, however two main groups are defined-biophysical and socio-economic (Ammar et al., 2016). In his study Ammar (2016) identified three commonly most followed set of criteria for selection of suitable WH. Those are the sets proposed by: Integrated Mission for Sustainable Development (IMSD) in 1995, Dr. Theib Y. Owesi in 1998 and Food and Agriculture Organization of the United Nations (FAO) proposed in 2003. Since field surveying can be resource consuming, nowadays the assessment and selection of suitable WH sites and measures is assisted by remote sensing and geographical information systems, because when coupled they are cost-efficient and provide reasonably good possibility for analyzation of spatial data (Wani et al., 2009)

METHODOLOGY

Description of the Study Area

Ovche Pole is a plain located in central part of Macedonia that takes an area of 649 km^2. It lies between latitude 41 59 30 N and 41 38 43 N and longitude 21 48 13 E and 22 01 28 E (Fig. 1). Agriculture is dominant economic activity in the region. Agricultural land takes 40,183 ha (62% of the study area), however much of the arable land is not irrigated. Forests cover 14,619 ha (22.5%) of which 2/3 are degraded, whereas 9,134 ha (14%) are pastures (CORINE LC/LU, 2012). The climate is modified warm continental with Mediterranean influence (Zikov, 1995; Filipovski et al., 1996). Considering the data between 1981 and 2010 the annual average precipitation in the region is 455 mm. From an agro-ecological perspective, larger area of the region is part of the sub-humid agricultural zone; however, there is an area that is identified as semiarid agricultural zone, too. In both agro-ecological zones, main problem and constraint for agriculture production are the dryness and low precipitation in the growing period (Aksoy et al, 2020).

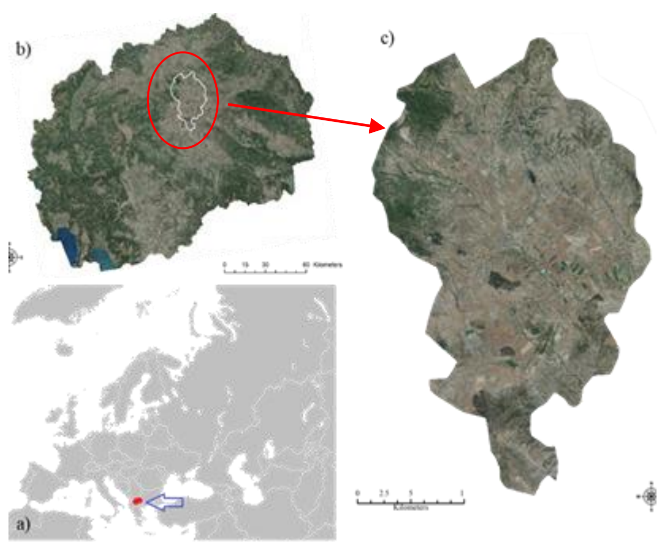

Fig. 1 Geographical position of the research area

Materials

Different data such as land use/cover data, Sentinel-2 satellite images, elevation model (DEM), climate data and soil data were used in this study analysis. Land cover/land use (LCLU) analysis was done by using CORINE Land Cover (CLC2018) data set from 2018, program coordinated by European Environmental Agency (EEA) and Sentinel-2 satellite image. Soil data were obtained from The Macedonian Soil Information System (MASIS). Watershed delineation, stream network, slope, topographic maps were generated using 20-meter resolution DEM obtained from the Agency for Real Estate Cadaster. Average year precipitation of 455 mm. was derived from climatic data for the period between 1981 and 2010 provided by the National Hydrometeorological Service (NHS).

Methods

Assessment of the water harvesting potential and identification of suitable water harvesting sites was done by evaluation of parameters such as: surface runoff, land use/cover, slope, soil infiltration characteristics, stream order and proximity to users. The complete quantitative and qualitative data analysis in this research was done by remote sensing and Geographical Information System (GIS) techniques. To compute hydrological elements more accurately generation of Land Cover/Land Use map is required (Rana and Suryanarayana. 2020). In this study CORINE Land Cover 2018(CLC2018) dataset for Macedonia together with Sentinel-2 satellite image were combined to create the LCLU map for the research area. The Sentinel-2 image captured on 20 August 2019 was used as a background information for additional interpretation and editing of existing CLC2018 vector layer. We only used the bands with 10-meter resolution (blue B2:490 nm, green B3:560 nm, red B4:665 nm, NIR B8:842 nm). As a result of this hybrid process, a new more precise and detailed land cover map was created. For the Hydrological Soil Group (HSG) analysis and map generation three raster files on sand, silt and clay content in soil were used. Each pixel is specified with a 100 meters resolution and a value that represents the content of specific soil fraction expressed in unit percent. Using raster calculator and reclassification function in ArcGIS Pro, the three layers were used to create new raster layer. In this raster each pixel was assigned a value that represented some soil texture class, following the USDA textural soil classification. Considering the infiltration rate of various soil texture each pixel was reclassified into A, B, C or D hydrologic soil group. Accordingly, the hydrologic soil group (HSG) map was prepared for the entire research area. The DEM data was used to generate the slope map and stream network map for the research area. Surface runoff is the primary component of every water harvesting system. In this study Conservation Service Curve Number (SCS-CN) methodology was used to calculate the runoff depth and generate run-off potential map for the research area. The SCS run-off equation is widely used in estimating direct run-off because of its simplicity, flexibility and versatility (Kumar and Jharya. 2016) and often used by researcher for watersheds that are ungauged, as it is the study area in this research. Although the method is designed for a single storm, it can be scaled to calculate the annual values for run-off of an area. Basically, the SCS-CN method depends on the relationship between the rainfall parameter (P) and the run-off depth (Q), simplified into the CN concept. The CN is a dimensionless run-off index determined based on Hydrological Soil Group (HSG), land use/land cover and Antecedent Moisture Conditions (AMC). The CN method can also reflect the effect of changes in land use on run-off. The CN values range between 1 and 100. Higher values of CN indicate higher run-off. In this study the runoff derived by SCS-CN method was expressed as runoff coefficient which represent the ratio between the runoff and rainfall. Based on the runoff coefficient a runoff-potential map was created in which the run-off coefficient is reclassified in four classes: low run-off potential, moderate run-off potential, high run-off potential and very high run-off potential.

Rainwater Harvesting Measures Selection and Site Suitability Analysis

The rainfall, geology, physiographic, land use, climatic conditions and social set-up are the basic factors to be understood by the rainwater harvesters to choose the proper technique of rainwater management in a particular set-up identified by them. As first step in process, a set of RWH measures were identified and selected; in the second step, for each measure a set of site selection suitability criteria were compiled; and as last step, RWH site suitability analysis was performed. Selection of suitable RWH measures was done by revieing studies, manuals and other on-topic literature. We identified to groups of measures. First group are measures that can be implemented in valley formations such as impermanent water streams and gullies, such as: ponds, gabion checks, boulder checks and brushwood checks. Second group of measures are those that can be implemented on the ridge formations. Here we identified revegetation, contour ditches and contour bunds as possible appropriate measure. In the second step, we complied criteria for suitable site selection for each of the identified measure in the first step. The criteria for water harvesting site selection related to each water harvesting group of measure are presented in Table 1 and Table 2. According to the review study done by Ammar et al. (2016) on identification of suitable sites for water storage in arid and semi-arid regions, it was found out that the most common biophysical layers or criteria applied were slope followed by land use/land cover and soil type. In this study we selected runoff, land use/land cover, HSG, slope, stream network and distance to users play a critical role in rainwater harvesting site selection. These thematic layers were used as input data for a series of operations done in ArcGIS Pro that enabled identification of appropriate sites for each identified rainwater harvesting measure.

Table 1 Criteria for selection of on-ridge rainwater harvesting measures

	Water harvesting intervention	Runoff coefficient	Slope (%)	Land use	Hydrology Soil Group (HSG)
On-ridge interventions	Revegetation	>0.5	>25	Land principally occupied by agriculture with significant areas of natural vegetation; Pastures, Grasslands; Sparsely vegetated areas; Transitional woodland-shrubs	A, B, C, D
	Contour trenching	>0.5	10 - 25		A, B, C, D
	Contour bunds	>0.5	0-10		A, B, C, D

Table 2 Criteria for selection of on-stream rainwater harvesting measures

	Water harvesting intervention	Runoff coefficient	Slope (%)	Stream Order	Hydrology Soil Group (HSG)	Distance to users
On-stream interventions	Irrigation ponds	>0.5	0-5	1-2	C, D	< 250 meters from agricultural land
	Livestock ponds	>0.5	0-5	1-2	C, D	< 1000 meters from livestock barns
	Gabion checks	>0.5	0-5	1-2 (gullies)*	A, B, C, D	n/a
	Boulder Checks	>0.5	5 - 20	1-2	A, B, C, D	n/a
	Brushwood checks	>0.5	> 20	1-2	A, B, C, D	n/a

RESULTS AND DISSCUSION

Runoff Potential

The run-off potential of the area affects the recharge and movement of surface water and is one of the important parameters for rainwater harvesting. (Kumar and Jhariya, 2016). The run-off potential map (Fig. 2) was built based the SCS-CN method by integrating average annual rainfall for the period between 1981 and 2010, land use/land cover information, and distribution hydraulic soil groups in the research area. The runoff derived by SCS-CN method is a function of runoff potential which can be expressed in as runoff coefficient - ratio between the runoff and rainfall. To perform RWH site suitability analysis the run-off potential was reclassified as very high run-off potential, high run-off potential, moderate run-off potential and low run-off potential. Category description and distribution in the research area is presented in Table 3. Results show that 26.8% of the total research area has very high runoff potential and 66.8% has high runoff potential.

Table 3 Runoff coefficient category description and distribution

Runoff coefficient	Description	Surface area (km^2)	Percent of total area (%)
≤ 0.5 (0.00 – 0.5)	Low runoff potential	23.25	3.6
≤ 0.6 (0.51 – 0.6)	Moderate runoff potential	3.3	0.5
≤ 0.7 (0.61 – 0.7)		14.6	2.3
≤ 0.8 (0.71 – 0.8)	High runoff potential	115.3	17.9
≤ 0.9 (0.81 – 0.9)		314.1	48.9
≤ 1.0 (0.91 – 1.0)	Very high runoff potential	172.2	26.8

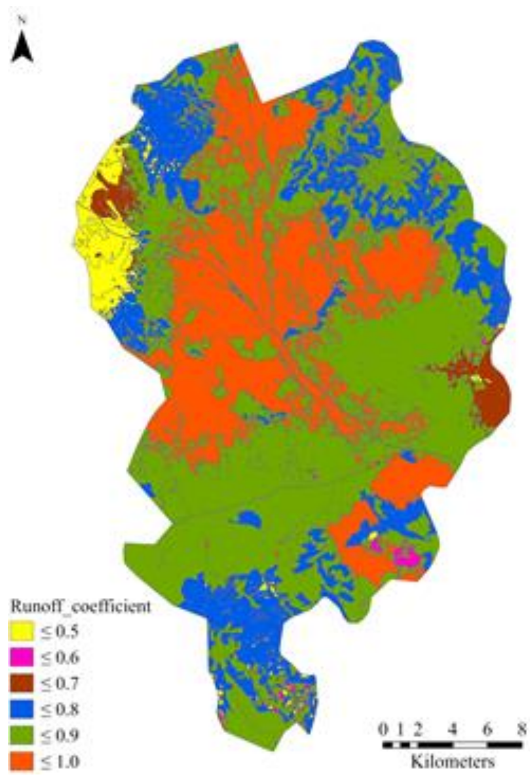

Fig. 2 Runoff coefficient map of the research area

Rainwater Harvesting Site Suitability Analysis

Rainwater harvesting site suitability analyses, based on the criteria given in Table 1 and Table 2 showed that identified measures can be applied on significant part of the research area. On-ridge measures can be implemented on 59% of the total area. Detailed information for each on-ridge measure is presented in Table 4, the distribution map is shown in Figure 4. Regarding the on-stream measures detailed analysis is presented in Table 5. and the distribution map in Figure 4. As an implementation unit for ponds and gabion checks is the number of pond-structures that can be build, whereas for brushwood and boulder check implementation unit is the length of stream sections appropriate for implementation.

Table 4 On-ridge measure distribution analysis

	On-ridge measures		
	Water harvesting intervention	Implementation area (km^2)	Percent of total area (%)
	Contour bunds	193	30
	Contour trenches	109	17
	Re-vegetation	77	12

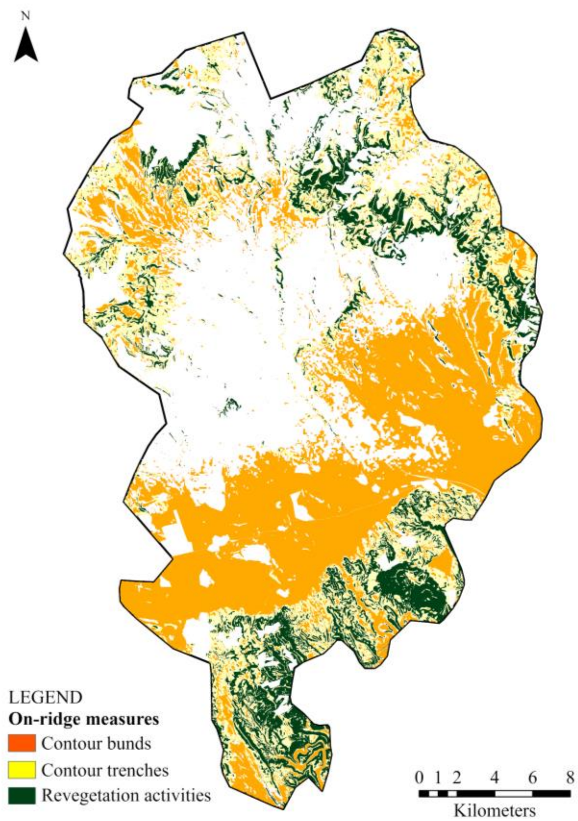

Fig. 3 On-ridge measures distribution map

Table 5 On-stream measure distribution analysis

On-stream measures	
Water harvesting intervention	Implementation units
Irrigation ponds	43 ponds
Livestock ponds	11 ponds
Gabion checks	183 checks
Brushwood checks	91 km (stream length)
Boulder checks	297 km (stream length)

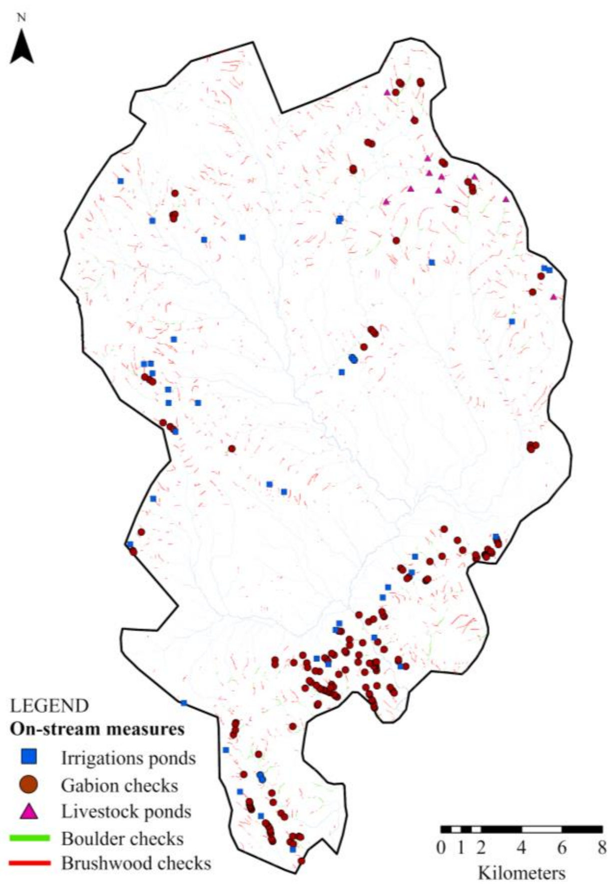

Fig. 4 On-stream measures distribution map

CONCLUTION

Ovche Pole region is part of the sub-humid and semiarid agricultural zone in Macedonia. Main constraint for agriculture production is dryness and low precipitation amounts during the growing season. This study explores the potential for implementation of rainwater harvesting measures as strategy for water conservation. The results show that 93.6% of the total area has potential to generate high and very high runoff. Rainwater harvesting site suitability analysis done in the study implies that

59% of the research area satisfy the criteria for implementation of the selected on-ridge RWH measures. Analysis shows there are significant number of potential sites suitable for implementation of on-stream RWH measures that can also significantly contribute to conservation of water resources in the research area.

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