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Article

Using Landscape Metrics Analysis and Analytic Hierarchy Process to Assess Water Harvesting Potential Sites in Jordan

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Abstract: Jordan is characterized as a "water scarce" country. Therefore, conserving ecosystem services such as water regulation and soil retention is challenging. In Jordan, rainwater harvesting has been adapted to meet those challenges. However, the spatial composition and configuration features of a target landscape are rarely considered when selecting a rainwater-harvesting site. This study aimed to introduce landscape spatial features into the schemes for selecting a proper water-harvesting site. Landscape metrics analysis was used to quantify 10 metrics for three potential landscapes (*i.e.*, Watershed 104 (WS 104), Watershed 59 (WS 59), and Watershed 108 (WS 108)) located in the Jordanian Badia region. Results of the metrics analysis showed that the three non–vegetative land cover types in the three landscapes were highly suitable for serving as rainwater harvesting sites. Furthermore, Analytic Hierarchy Process (AHP) was used to prioritize the fitness of the three target sites by comparing their landscape metrics. Results of AHP indicate that the non-vegetative land cover in the WS 104 landscape was the most suitable site for rainwater harvesting intervention, based on its dominance, connectivity, shape, and low degree of fragmentation. Our study advances the water harvesting network design by considering its landscape spatial pattern.

Keywords: landscape metrics; rainwater harvesting; analytic hierarchy process

1. Introduction

Water scarcity is one of the biggest challenges that Jordan currently faces. The current per capita share of water is estimated at 140 m^3 per year, which is well below the 1000 m^3 threshold [1]. Increasing temperatures, coupled with changing precipitation patterns, are expected to increase water scarcity there [2]. By the year of 2025, although water resources are limited and the population in Jordan is expected to rise, the per-capita water supply is expected to fall to less than 91 m^3 per year [2]. A large proportion of Jordanian agriculture is based on dry land farming systems, where production depends on low and extremely variable rainfall. Under these conditions, there is a great need to manage water in special ways [3]. Rainwater harvesting has emerged as a crucial means for water management and conservation in water scarce environments [4]. Rainwater harvesting is the process of concentrating precipitation through runoff; instead of leaving unharvested runoff, which causes erosion, it is harvested and utilized for beneficial uses [5]. The objectives of rainwater harvesting include improving water availability for plants, improving soil structure, decreasing soil erosion rates, reducing the impact of drought, reducing surface runoff, maintaining soil organic matter, and improving the capacity of the soil to hold water [6]. Therefore, rainwater harvesting is a directly productive form of soil and water conservation. Both yields and production reliability can be significantly improved with this method [4,5]. Consequently, human intervention through use of water harvesting can advance the ecosystem functions in water scarce areas [7].

Rainwater harvesting systems are typically classified into three categories that are based on the size of the runoff producing area: on-farm systems, *in situ*, micro-catchment systems, and macro-catchment systems [8]. *In situ* systems capture rainfall where it falls and ensures that crops make the most effective use of scarce water, for example through deep tillage, dry seeding, mixed cropping, ridges and borders, terraces, and trash lines [8]. Micro-catchment systems create a distinct division between a runoff generating catchment area and a cultivated basin where the runoff is concentrated, stored, and productively used by plants. The catchment area and cultivated basin are adjacent to one another [9], such as pitting, strip catchment tillage, contour bunds, and semi-circular bunds. Macro-catchment rainwater harvesting is characterized by large catchment areas, where the catchment area for this system is located outside the cropped area. These systems include intermediate components for collecting, transferring, and storing runoff. Macro-catchment systems are difficult to differentiate from conventional irrigation systems [9], but are considered rainwater harvesting systems as long as the harvested water is not available beyond the rainy season [8].

Many previous researchers have developed criteria and procedures for rainwater harvesting site selection; most of the criteria are based on soil, topographic suitability, land cover and land use, and surface runoff, and most procedures use hydrologic modeling, remote sensing, and/or a geographical information system (GIS) approach [1,3,4,6,10,11]. The implementation of rainwater harvesting will lead to subsequent changes to the ecosystem functions at a landscape level [7]; however, little consideration has been given to landscape spatial features when selecting rainwater harvesting sites. Spatial composition and configuration of a landscape play a critical role in determining hydrological processes, energy flows, nutrient cycles, and natural habitats [12–14]. Many studies have explored the impact of water provision, regulation, and purification from landscape changes on ecosystem services [13,14]. These studies have suggested that spatial configuration factors that should be considered include the extent, distribution, intensity, and frequency of human land use [13,14]. Therefore, further research is needed to develop methodologies that explicitly identify and prioritize regions that show potential for water harvesting [15]. Moreover, spatially explicit assessment of rainwater harvesting sites at a watershed scale can be used to develop landscape management strategies, not only for water regulation but also for the other ecosystem services such as soil retention and biodiversity conservation.

2. State of the Art of the Methodologies Applied

Landscape spatial structure has two components: composition (e.g., the number and amount of different land use types) and configuration (*i.e.*, the spatial arrangement of those types) [16]. These days, many spatial landscape properties can be quantified through a set of metrics [17] that are aggregate measurements derived from digital analysis of thematic categorical maps that show spatial heterogeneity at a specified scale and resolution [18]. This methodology has been effectively used to capture landscape dynamics that describe ecological functions and services [19]. Software such as Fragstats and APACK is available to researchers worldwide to quantify the areal extent and spatial configuration of a landscape [20]. In this study, we quantified the landscape special structure and then used the Analytic Hierarchy Process (AHP) to prioritize the site suitability for water harvesting.

AHP is a multi-criteria decision making approach in which factors are arranged in a hierarchic structure [21]. AHP is a theory of measurement that uses pairwise comparisons, and it relies on the judgments of experts to derive priority scales [22]. Judgments in AHP may be inconsistent, therefore, obtaining better consistency is a concern of the AHP that is addressed through measuring the inconsistency and improving the judgments [22]. AHP has become a mathematical science today [23] and one of the most widely used multi-criteria decision support system tools [24]. AHP has the flexibility to be integrated with different techniques so as to extract benefits from the combined methods [24]. Many outstanding AHP-based approaches have been used in various fields, and it allows users to allocate and optimize resources to select the best alternative [24]. In environmental studies, AHP has served as a useful decision aid [25–27], in particular for identifying potential rainwater harvesting sites [11] and for handling certain watershed management and related issues such as reservoir system management, irrigation scheduling, and risk management [28].

The objective of this study is to introduce the landscape spatial composition and configuration features into the schemes for selecting appropriate rainwater harvesting sites, through use of a combined landscape metrics and AHP analysis. Three Jordanian landscapes (*i.e.*, Watershed (WS) 104, WS 59, and WS 108) were studied; ten different landscape metrics were identified for each landscape. These metrics were then used as input data in an AHP model, in order to prioritize the suitability of each landscape for water harvesting.

3. Methodology

3.1. Study Area

The study area includes the three Jordanian landscapes WS 104, WS 59, and WS 108 as shown in Figure 1. A description of the studied landscapes is provided in Table 1. These landscapes are located in the Badia region of Jordan, which falls within an arid and semi-arid climatic zone. The Badia region covers approximately 72,600 km^2 and constitutes 81% of the total area of the country [6]. The study area is characterized by low annual rainfall that varies from 250 mm in WS 108, 220 mm in WS 59, to 150 mm in the eastern parts of WS 104, and an erratic distribution throughout the rainy season. These study areas were selected based on the following criteria: existence of a well-identified watershed, representative of the Badia area, presence of fulfilling facilities (*i.e.*, size, boundary conditions, and data availability), and designation by Jordanian agricultural policy as potential rainwater harvesting locations.

Table 1. The studied landscapes.

Landscape Name	Area Name	Surface Area (m^2)
WS 104	Mohareb	9356
WS 59	Mansheyat Bani Hasan	6060
WS 108	Urainbeh Al-gharbieh	6149

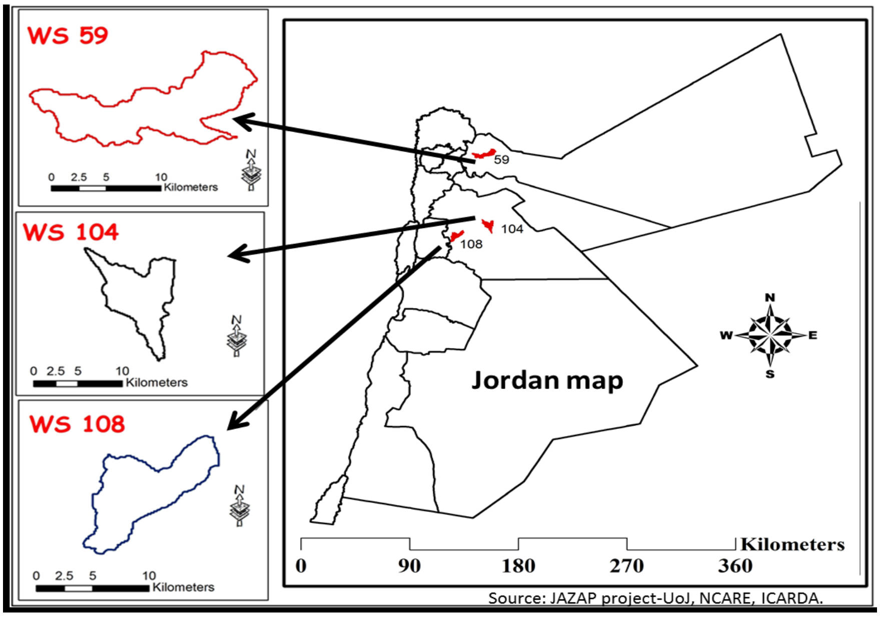


Figure 1. Landscapes location.

3.2. Procedure for Using Combined Landscape Metrics and Analytic Hierarchy Process Analysis

This study integrates landscape metrics analysis and AHP for selecting a proper rainwater harvesting site. The methodology is detailed below.

- **Compile Land Cover/Use Data**

To incorporate considerations of landscape structure into the site selection process, the first step was to collect and compile land cover/use data. Land use maps for the three landscapes were prepared by the Jordanian National Center for Agricultural Research and Extension for the purposes of conducting a rapid environmental impact assessment (unpublished report). We used these maps in this study. These maps show that there are five different land cover types that exist in the WS 59 and WS 108 landscapes (Figure 2), which are barley, non-vegetative land, mixed agricultural area, quarries, and urban. In contrast, WS 104 only has two dominant land cover types, barley and non-vegetative. The urban land cover type (LCT) includes residential, built-up, industrial, and commercial areas. The non-vegetative land is composed of bare rocks, bare soil, shrub, and herbaceous rangelands. Mixed agricultural areas include horticulture, field crops, and orchards. The barley LCT includes rain-fed areas planted with barley (*Hordeum vulgare* L.). Quarries are rocks and sand mining areas.

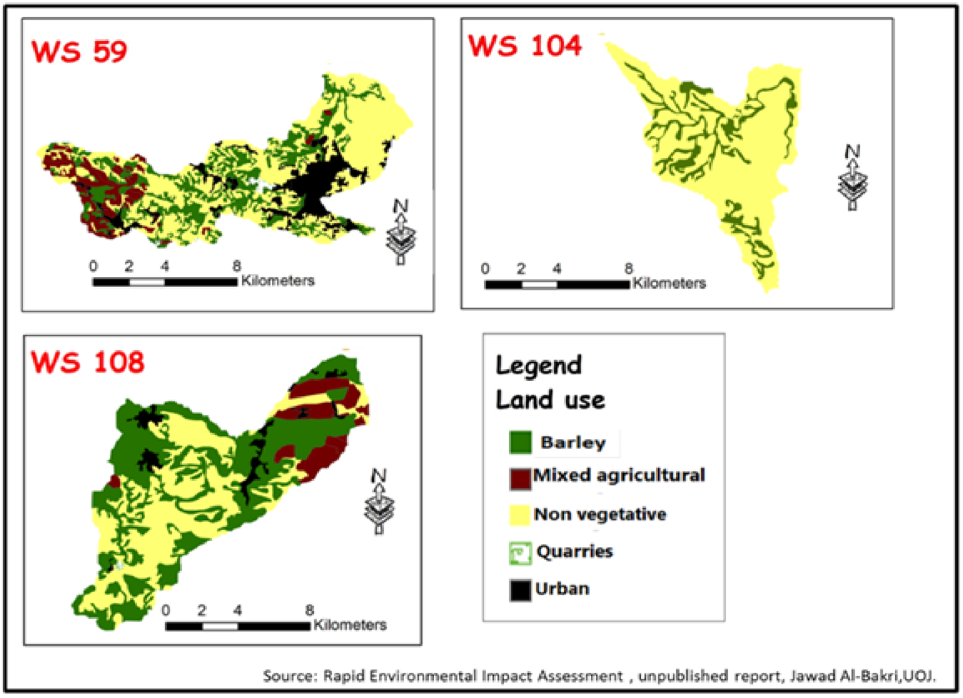


Figure 2. Land use satellite imagery for WS 59, WS 104 and WS 108.

- **Determine Landscape Metrics for Analysis**

Landscapes metrics can quantitatively represent the spatial composition and configuration of a landscape. They are used to analyze the importance of both composition and configuration in rainwater harvesting site selection. Previous research studies indicate that different ecosystem functions would be maintained under conditions of less fragmentation, a large core area [14,29–31], high connectivity [32], and less complex patches [33]. Therefore, we decided that the metrics that represent dominance, connectivity, shape, and fragmentation should be included in the analysis. In this study, 10 metrics associated with the presence and abundance of LCTs were selected: Class Area (CA), Class Area Proportion (CAP), Mean Patch Size (MPS), Radius of Gyration (GYRATE), Proximity Index (PROX), Number of Patches (PN), Total Edge (TE), Edge Contrast (ECON), Shape Index (SHAPE), and Euclidean Nearest Neighbor

Distance (ENN) [16] (For a detailed definition of each metric, please see appendix Supplementary Table S1). The CA, CAP, MPS, and PN were selected to represent the landscape composition (*i.e.*, measure landscape characteristics such as dominance and fragmentation) [12,34]. The ENN, SHAPE, ECON, GYRATE, TE, and PROX metrics were selected to represent the landscape configuration (*i.e.*, measure landscape characteristics such as connectivity, shape, and fragmentation) [8,34–38].

- **Analyze the Landscape Metrics and Find Inferior Solutions**

Landscape spatial features shape various ecosystem functions and interactions. We sought to find the spatial features that provide better rainwater harvesting network benefits such as improving the water availability for plants and decreasing soil erosion rates (*i.e.*, ecosystem services). Two assumptions were built up that were based on the perspectives of conserving ecosystem services through landscape structure management. The first assumption is that the suitability of rainwater harvesting site increases as its dominancy and connectivity increases (*i.e.*, CA, CAP, MPS, GYRATE, and PROX; Table 2). The second assumption is that the suitability of rainwater harvesting site decreases as its fragmentation and shape complexity increases (*i.e.*, PN, TE, ECON, SHAPE, and ENN; Table 2). These assumptions were developed in focus group discussions; the focus group was composed of three rainwater harvesting specialists and two landscape metrics specialists. In this study, the 10 landscape metrics for each potential rainwater harvesting site were calculated using Fragstats software version 3.3 [18]. Calculation of these landscape metrics enabled us to compare each potential site along these 10 dimensions in order to choose three candidate sites that possess the most optimal combination of these desired characteristics (recognizing, of course, that there might be a tradeoff in the benefits provided between locations).

- **Use the Analytic Hierarchy Process Model to Prioritize the Candidate Sites**

To find the most suitable location within the candidate sites, an AHP model was built up using Supper Decision 2.2.6 software (www.superdecisions.com). We built an AHP model to rate each potential site according to the 10 landscape metrics, with the goal of identifying three candidate sites that best maximized these metrics. Therefore, our AHP model was set up with three major components: alternatives, criteria, and goals. The alternatives were the candidate rainwater harvesting sites (*i.e.*, the three sites identified from landscape metrics analysis). The criteria were the landscape metric associated with each alternative. The goal was to prioritize the candidate sites' suitability for rainwater harvesting as shown in Figure 3.

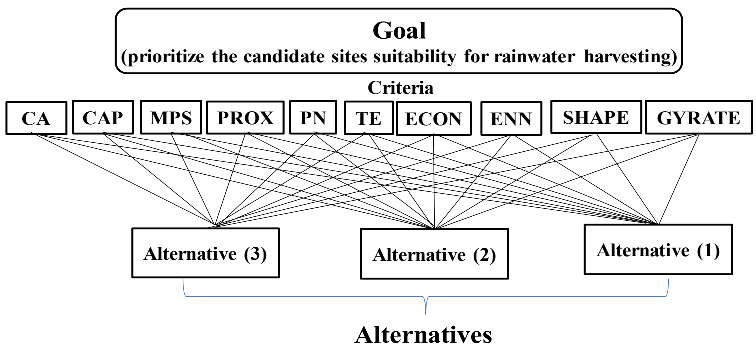


Figure 3. The AHP model.

Table 2. Rainwater harvesting benefits according to various landscape metrics values.

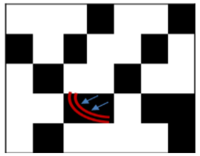
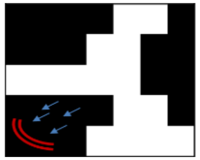
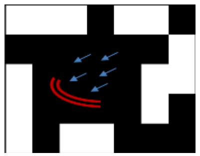
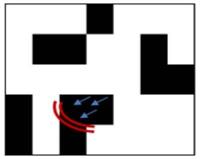
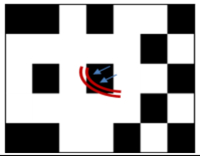
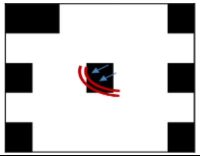
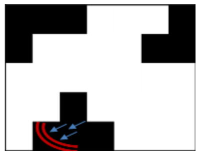
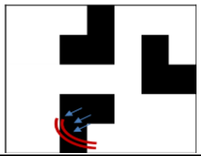
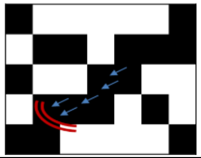
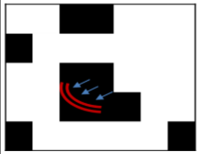
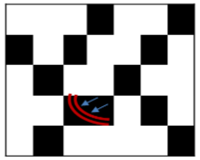
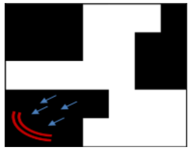
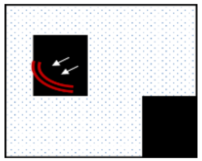
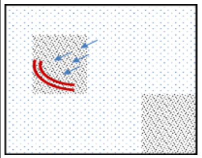
Implement Rainwater Harvesting under Different Landscape Metrics Values		Metrics Comparisons	Benefits from rainwater harvesting								Suitability of Rainwater Harvesting (S)
			Amount of Water Collected	Decrease the Soil Erosion Rates	Improve the Soil Water Holding Capacity	Improve the Water Availability for Plants	Improve the Soil Structure	Reduce the Surface Runoff	Maintain Soil Organic Matter	Reducing the Impact of Drought	
A 	B 	MPS(B) > MPS(A) PN(A) > PN(B)	B > A	B > A	B > A	B > A	B > A	B > A	B > A	B > A	S(B) > S(A)
C 	D 	CA(C) > CA(D) CAP(C) > CAP(D)	C > D	C > D	C > D	C > D	C > D	C > D	C > D	C > D	S(C) > S(D)
E 	F 	PROX(E) > PROX(F)	E > F	E > F	E > F	E > F	E > F	E > F	E > F	E > F	S(E) > S(F)
G 	H 	ENN(H) > ENN(G)	H > G	H > G	H > G	H > G	H > G	H > G	H > G	H > G	S(H) > S(G)

Table 2. *Cont.*

Implement rainwater harvesting under different landscape metrics values	Metrics comparisons	Benefits from rainwater harvesting								Suitability of rainwater harvesting (S)
		Amount of water collected	Decrease the soil erosion rates	Improve the soil water holding capacity	Improve the water availability for plants	Improve the soil structure	Reduce the surface runoff	maintain soil organic matter	reducing the impact of drought	
I  J 	GYRATE(I) > GYRATE(J)	I > J	I > J	I > J	I > J	I > J	I > J	I > J	I > J	S(I) > S(J)
K  L 	SHAPE (K) > SHAPE(L) TE(K) > TE(L)	L > K	L > K	L > K	L > K	L > K	L > K	L > K	L > K	S(L) > S(K)
M  N 	ECON(M) > ECON(N)	M > N	M > N	M > N	M > N	M>N	M>N	M>N	M>N	S(N) > S(M)

Rainwater harvesting construction;
Patch from a LCT;
Direction of collecting the rainwater.

Relative importance/preference matrices were formed and used for computing the priorities of the corresponding alternatives. Each alternative is compared against each other alternative with respect to one particular decision criterion at a time. The total number of matrices was 10 (*i.e.*, three square matrices of values (pairwise alternatives comparison] repeated 10 times (one pairwise comparison for each of the 10 criteria)). In these matrices, a scale from one to nine was used to express the strength of the preference or perceived importance of each criterion. The scale used for the purpose of this study is consistent with Satya's [27,39] one to nine numerical recommendations, where a verbal judgment preference of "equally preferred" is given a numerical rating of one and a verbal judgment preference of "extremely preferred" is given a numerical rating of nine. The importance/preference matrices were weighted by the same focus group mentioned above (*i.e.*, the experts who compared the rainwater harvesting benefits and different landscape metrics values). Since the importance/preferences of the matrices were weighted through a judgment process, we expected to see some inconsistency. Therefore, AHP was selected due to a small inconsistency in the decision-making process [24], and the AHP can create a better consistency through measuring the inconsistencies and improving the judgments [22].

AHP ratio scales are derived from principal Eigen vectors, and the consistency ratio is derived from the principal Eigen value; if the value of the consistency ratio is smaller than or equal to 10%, then the inconsistency is acceptable [24,40]. Results of the AHP model synthesized the priorities for the alternatives (*i.e.*, candidate rainwater harvesting sites) and were reported as a "Normal" column (*i.e.*, the results presented in the form of priorities), an "Ideals" column (*i.e.*, dividing the entries in the "Normal" column by the largest value in that column), and a "Raw" column (*i.e.*, obtained directly from the limit super matrix) [41].

4. Results

The results of landscape metrics analysis gained from the Fragstats software were as follows:

4.1. Landscape Spatial Patterns

The number of LCTs in a given landscape is usually measured by patch richness metrics [12]. The total number of patches, patch richness, and mean patch size were analyzed at the landscape level (Table 3). Results of these analyses clearly show that WS 59 is more fragmented than WS 108, while WS 104 is considered a non-fragmented landscape because WS 104 has a small patch number and large mean patch size, whereas WS 59 and WS 108 have a high number of patches and consequently, a small mean patch size.

Table 3. Landscape level analysis.

The studied landscapes	**Patch Richness**	**PN**	**MPS (m^2)**
WS 59	5	124	75
WS 104	2	6	1013
WS 108	5	40	154

4.2. Spatial Features of Land Cover Types

Results of the special feature of the LCTs were organized according to characteristics of dominancy, connectivity, shape, and fragmentation as follows:

4.2.1. Dominancy and Fragmentation

Both class area and class area proportions were used as measures of landscape composition [12]. In particular, class area and class area proportion are indicators of the dominant land use/cover type in a given landscape (Table 4). Results show that the non-vegetative LCT in WS 59 and WS 104 occupies an area of 4665 m^2 and 4908 m^2 (CAP_{non} of 50% and 81%, respectively). These results indicate that the non-vegetative LCT dominates both landscapes and might be identified as the landscape matrix (*i.e.*, background ecological system). Whereas in WS 108, barley is the dominant/matrix LCT since it occupies an area of 2893 m^2 with a CAP_{barley} of 47%.

The size, number, and shape of patches are all metrics that have been widely used to assess patch fragmentation at both small and large scales [34].The number of patches and mean patch size for each LCT were analyzed (Table 5). WS 59 has two major patches, non-vegetative (number of patches = 39) and barley (number of patches = 41). Of all the patches within WS 59, the non-vegetative patches in WS 59 have the largest mean patch size (mean patch size = 110 m^2). WS 104 has five barley patches and one non-vegetative patch (mean patch size = 4908 m^2); the non-vegetative patch is approximately 21 times larger than the mean size of the barley patches. WS 108 has two major patches, urban (number of patches = 11, mean patch size = 27 m^2) and non-vegetative (number of patches = 15, mean patch size = 157 m^2). The urban LCT in WS 108 appears to be highly scattered with small size patches, whereas the barley LCT is located in five main patches (mean patch size = 579 m^2).

Table 4. Class Area and Class Area Proportion of all land cover type (LCT).

LCTs	CA(m^2)			CAP (%)		
	WS 59	WS 104	WS 108	WS 59	WS 104	WS 108
Barley	2361	1171	2893	25	19	47
Urban	1350	-	297	14	-	5
Non-vegetative	4665	4908	2349	50	81	38
Quarries	75	-	11	0.8	-	0.2
Mixed Agriculture	904	-	597	10	-	10

Table 5. Number of patches and mean patch size for each LCT.

LCTs	Number of Patches			Mean Patch Size (m^2)		
	WS 59	WS 104	WS 108	WS 59	WS 104	WS 108
Barley	41	5	5	58	234	579
Urban	18	-	11	75	-	27
Non-vegetative	39	1	15	110	4908	157
Quarries	4	-	1	19	-	11
Mixed Agriculture	22	-	8	41	-	75

In addition, the degree of fragmentation of each LCT in each landscape is estimated by the total edge matrices. The results for the total length of the edges of each LCT show that the non-vegetative LCT in WS 59 has the longest total edge reach (approximately 471 km; Figure 4). Moreover, the non-vegetative LCT was fragmented in WS 59 and WS 108 but was not fragmented in WS 104. Even though the class area and class area proportion for non-vegetative LCT are larger in WS 104 than in WS 59, the total edge of non-vegetative LCT in WS 59 is still longer than it is in WS 104. This difference can be attributed to the fact that the total number of non-vegetative patches in WS 59 is 39, whereas there is only one patch in WS 104.

The proximity index is another measure of landscape fragmentation that relates to the distribution of distances between patches and patch sizes in a defined neighborhood [8]. Area-weighted mean proximity (PROX_AM) was calculated for all LCTs (Figure 4). Results show that the non-vegetative LCT has a higher proximity index in WS 108 and WS 59, as compared to WS 104 ($PROX\_AM_{non}$ = 922 and $PROX\_AM_{non}$ = 813 in WS 108 and WS 59, respectively). These results align with the other metrics, as WS 108 and WS 59 contain 15 and 39 non-vegetated patches, and their mean patch size is 157 m^2 and 110 m^2, respectively. In contrast, $PROX\_AM_{non}$ = 0 in the WS 104 because there is only one non-vegetative patch there.

4.2.2. Connectivity and Shape

The shape index is a measure of aggregation or clumpiness, so that if a patch comprises one single compact area, then the shape index will be small (*i.e.*, approaching 1.0), and if the landscape contains dispersed patches with complex and convoluted shapes, then the shape index will be large [35]. Figure 4 illustrates the results of the area-weighted mean shape (SHAPE–AM) index. As the SHAPE–AM index increases, the complexity of the patch increases. The complexities of the barley and non-vegetative patches in WS 104 are the highest among all of the LCTs, whereas the complexity drops dramatically in the quarries, mixed agriculture, and urban LCTs, where the patches have small class area proportions as compared to the barley and non-vegetative LCTs and they are human-made and thus likely to be near compact patches. Moreover, in spite of the fact that the CAP for mixed agriculture is nearly the same in WS 59 and WS 108, the SHAPE-AM for mixed agriculture is nearly twice as high in WS 59 as compared to WS 108, and this difference is because WS 59 has both a high CA and NP (CA_{mix} = 904 m^2, NP_{mix} = 22) as compared to WS 108 (CA_{mix} = 597 m^2, NP_{mix} = 8).

GYRATE is a measure of patch extent and connectivity, thus it is affected by both patch size and patch compactness [36]. Figure 4 illustrates the results of the area-weighted mean radius of gyration (GYRATE_AM). Results show that the non-vegetative patch in WS 104 is the most elongated patch within the three landscapes. The barley patches in the three landscapes are elongated as well (*i.e.*, $GYRATE\_AM_{barley}$ is 1470 m, 1956 m, and 2238 m in WS 59, WS 104, and WS 108, respectively). The quarries and urban patches in WS 108 are the least elongated patches (GYRATE_AM of 128 m and 408 m, respectively).

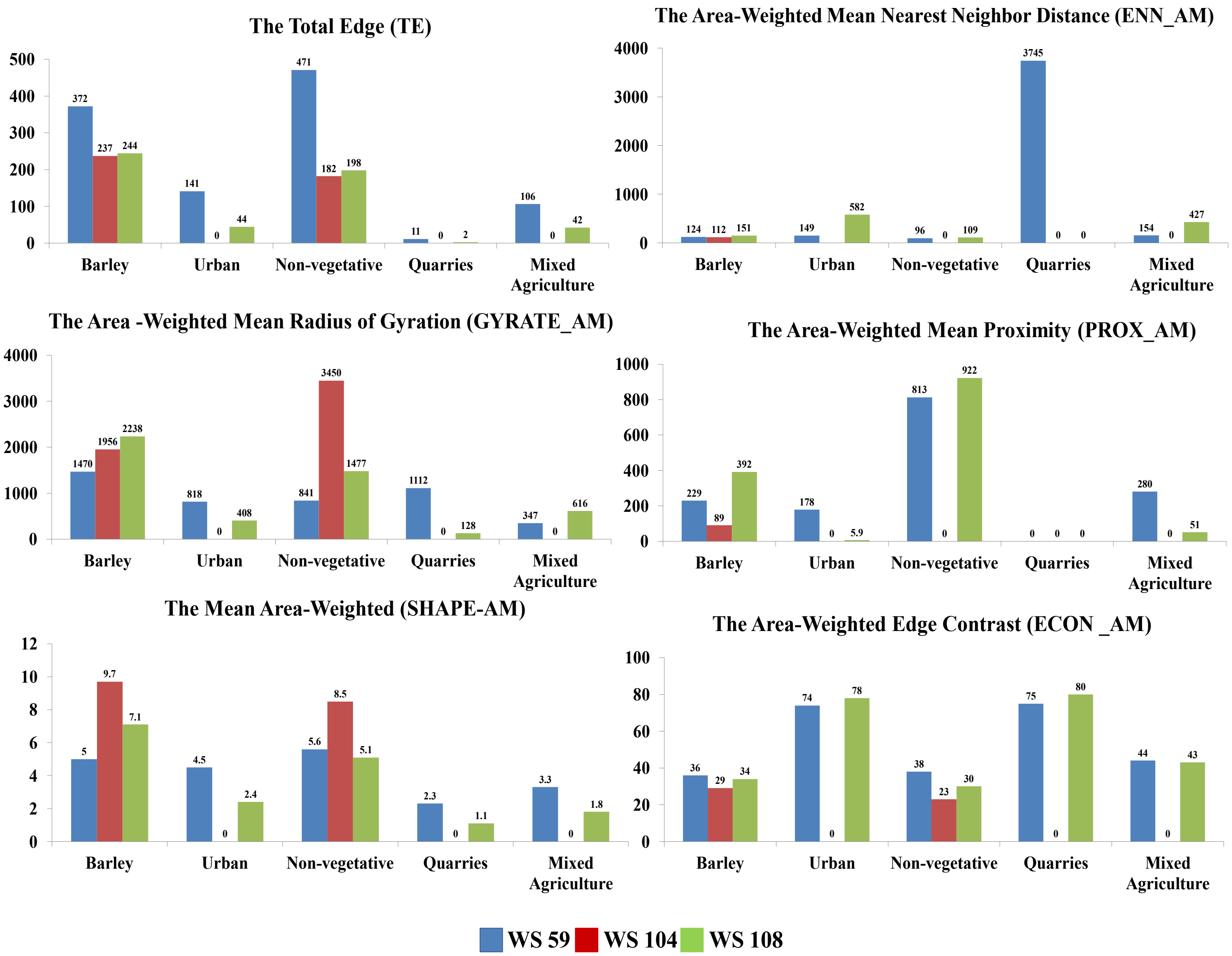


Figure 4. Landscape metrics analysis results.

The distribution of small, isolated patches from the complex cluster configuration of larger patches is measured by the Euclidean nearest neighbor distance metric [37]. The area-weighted mean of the Euclidean nearest neighbor distance (ENN_AM) indicates that the quarry patches in WS 59 have a high ENN_AM and are thus located far apart from one another (ENN_AM = 3745 m). Conversely, all other LCT patches are relatively close to one another and have a low ENN_AM (Figure 4). This is a reasonable result as the three landscapes all have relatively small total areas.

Edge contrast (ECON) metrics represent the magnitude of difference between classes in one or more attributes [38]. The results of area-weighted edge contrast (ECON_AM) show a general trend that the most extensive patches (*i.e.*, barley and non-vegetative) have the lowest edge contrast (Figure 4). Moreover, the least extensive patches (*i.e.*, quarries and urban) have the highest contrast, except for the quarries in WS 59; these quarries are both extensive and have high edge contrast (GYRATE_AM_{quar} = 1112 m, ECON_{quar} = 75).

4.3. Determination of Candidate Rainwater Harvesting Sites

All characteristics of candidate rainwater harvesting sites were summarized in Table 6. The candidate sites were determined using the value of the landscape metrics; as the location dominancy and connectivity of a candidate site increases (*i.e.*, CA, CAP, MPS, GYRATE, and PROX), its suitability for use as rainwater harvesting site increases. In contrast, as the fragmentation and shape complexity increases (*i.e.*, PN, TE, ECON, SHAPE, and ENN), the location suitability decreases. Quarries and urban LCTs were excluded from this comparison since they were not suitable to implement *in situ*, micro and macro rainwater harvesting. The results clearly show that the non-vegetative LCT in WS 59, WS 104, and WS 108 were the most promising candidate rainwater harvesting sites (Table 6). The barley LCT was the second most promising candidate rainwater harvesting site in WS 108.

Table 6. Features of candidate rainwater harvesting sites.

Landscape Metrics	WS 59			WS 104		WS 108		
	Non-Vegetative	Barley	Mixed Agriculture	Non-Vegetative	Barley	Non-Vegetative	Barley	Mixed Agriculture
PN				*	*		*	
MPS	*			*		*	*	
CA	*			*		*	*	
CAP	*			*		*	*	
TE			*	*				*
SHAPE	*	*				*		
GYRATE		*		*			*	
ENN	*				*	*		
PROX	*					*	*	
ECON	*			*	*	*		
Total number of *	7	2	1	7	3	7	6	1

* The LCT with the highest dominance and connectivity (*i.e.*, CA, CAP, MPS, GYRATE, and PROX) value or with the lowest fragmentation and shape complexity (*i.e.*, PN, TE, ECON, SHAPE, and ENN) value.

4.4. Analytic Hierarchy Process Results

The AHP results prioritize the fitness of the three candidate sites for harvesting rainwater. They show that the non-vegetative LCT in WS 104, WS 59, and WS 108 have a rainwater harvesting priority of 1.0, 0.61, and 0.49, respectively (Table 7). This means that the non-vegetative LCT in WS 104 would be the best location to implement a rainwater harvesting intervention, and that the non-vegetative LCT in WS 59 is only 61% as good for harvesting rainwater as the non-vegetative LCT in WS 104. Likewise, the non-vegetative LCT in WS 108 is only 50% as good for harvesting rainwater as the non-vegetative LCT in WS 104. Furthermore, the model consistency ratio was 9% (*i.e.*, within the acceptable consistency range of less than 10%).

Table 7. The overall synthesized priorities for the candidate rainwater harvesting sites.

Alternatives	Ideals	Normals	Raw
Non-vegetative LCT in WS 59	0.609923	0.289810	0.144905
Non-vegetative LCT in WS 104	1.000000	0.475159	0.237579
Non-vegetative LCT in WS 108	0.494637	0.235031	0.117516

5. Discussion

Rainwater harvesting is a useful measure of landscape management for conserving ecosystem functions in water scarce areas [7] (Figure 5). Therefore, the spatial pattern of rainwater harvesting sites should be considered in landscape planning. Previous rainwater harvesting site selection methods are dependent on many site-specific criteria, such as careful assessment of geographic locations, or the evaluation of surface and groundwater hydrology [1,3,4,6,7,10,11,15], without consideration of the spatial pattern of the selected sites. In this study, we focused on the use of landscape patterns in selecting appropriate rainwater harvesting sites. Our case study showed that our method can identify a rainwater network with good landscape structure under conditions of degraded landscape, lower vegetation, soil erosion, and with an annual rainfall of 100–250 mm [6]. Therefore, the proposed method is compatible with the general criteria of establishing a rainfall water harvesting network [6].

Figure 5. Before/after rainwater harvesting in a non-vegetative LCT. (**A**) Establishing rainwater harvesting in a barren non-vegetative LCT; (**B**) The growth of vegetation cover after implementing rainwater harvesting in a non-vegetative LCT. Source: The Jordanian National Centre for Agricultural Research and Extension.

Spatial features such as dominance, fragmentation, shape, and connectivity are important variables to consider when designing a rainfall water harvesting network, due to the need to maintain ecosystem functions in a large, aggregate area. In this study, the non-vegetative and barley LCTs dominate the three landscapes. The non-vegetative LCT is a nearly barren area without vegetation or any other land use. The amount and distribution of rainfall are the main controllers of barley productivity [42] and the main reasons behind the presence and size of barren non-vegetative LCTs. Many authors have demonstrated that both runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases, and this is true in a wide range of environments [42]. Therefore, our class area and class area proportion metrics (*i.e.*, dominancy feature) indicate that a large area of non-vegetative LCT might enhance the potential for runoff, erosion, and sediment loss in these landscapes. The barley LCT might have the same problems since barley is a rain-fed crop. However, both non-vegetative and barley LCTs offer a large catchment area. Our findings align with Hernandez's [43] findings that the highest contributors to sediment yield are areas with agricultural and desert scrub (*i.e.*, vegetative communities that are characterized by significant areas of barren ground devoid of perennial vegetation) [43]. Selecting the dominant non-vegetative LCT in WS 104 as a site for rainwater harvesting will conserve the ecosystem services in several ways: (1) rainwater harvesting will reduce the potential for runoff, erosion, and sediment loss in the non-vegetative LCT; (2) the large patch offers a large catchment area that can significantly increase plant production by concentrating rainfall/runoff in parts of the total area [44]; (3) the installation, management, and maintenance of a rainwater harvesting system will be easier to oversee if the system is located in one large patch; and (4) it will be easier to protect the rainwater harvesting system from overgrazing. Therefore, our assumption regarding the preference of patch dominancy in selecting rainwater harvesting site is true as long as the sites have nearly the same vegetation cover percentage.

Fragmentation is a landscape-level process in which a specific ecosystem is progressively subdivided into smaller and more isolated patches [18,44]. In this study, analyses revealed that the fragmentation process was present in WS 59 and WS 108, whereas WS 104 consisted of non-fragmented landscapes. In addition, the fragmentation of each LCT in each landscape indicated that the non-vegetative LCT was fragmented in WS 59 and WS 108 but not in WS 104. Fragmentation of the natural ecosystem leads to large changes in water and nutrient cycles, radiation balance, and wind regimes [29], and can also be attributed to the complex interaction between policy, biophysical characteristics, and socioeconomic development pressures [30]. Fragmentation of patches can result in more conflicting edges, which creates greater opportunities for externalities that produce positive or negative effects on neighbors [31]. Avoiding fragmentation and its negative impact on an ecosystem would be in accordance with our assumption that fragmented areas are not suitable locations to implement rainwater harvesting techniques.

Patch shape influences the magnitude and nature of edge effects; as shape complexity increases, the proportional abundance of edge-influenced habitat increases as well. More complex or convoluted LCT shapes lead to more positive or negative interactions between each patch and its surroundings. Patch shape also influences a variety of cross-boundary ecological processes (*i.e.*, the movement of energy, materials, and organisms across patch boundaries) [33]. In this study, the complexity of the barley and non-vegetative patches in WS 104 was the highest among all other LCTs, and this complexity, in conjunction with the available climatic conditions, might facilitate LCTs to shift between barley and non-vegetative. On the other hand, landscape connectivity also represents the degree of physical linkage of native vegetation cover within a landscape [45]. For the most part, non-vegetative LCT is the dominate structural connectivity in the three landscapes, and it is also the spatial shape feature that will facilitate shifts in land use such that the sprawl of non-vegetative LCT will threaten other LCTs (particularly barley) and convert them to barren land. Moreover, this dominant structural connectivity may not be efficient for water retention or soil conservation at the regional level. Therefore, it is important to prevent such LCT conversion by adopting rainwater harvesting as a sustainable landscape management tool. Selecting patches with the highest connectivity and lowest complexity to serve as rainwater harvesting sites may advance the protection, retention, and rehabilitation of natural connections among habitats within ecosystems at the landscape level [32]. Figure 5 shows the effect of implementing rainwater harvesting systems in non-vegetative LCT in two different landscapes.

Due to the long edge, high shape index, low edge contrast, and high GYRATE of the barley LCT, it is expected that current trends will result in an increase in the rate of evapotranspiration along barley edges, exposure to sunlight, wind effect, and livestock overgrazing. Furthermore, subpopulation isolation of plants and animals will lead to decreased gene exchange [12]. All of these conditions, in addition to climate change, will threaten the barley LCTs. Establishing rainwater harvesting systems in the non-vegetative LCT, followed by good plant management, will offer additional landscapes for animals to forage in and thus indirectly protect the barley LCT; this strategy might be considered a climate change mitigation scenario in water scarce areas. However, the decreases in edge length, shape index, GYRATE, and high edge contrast of mixed agricultural LCTs will lead to decreases in the bird, insect, and wild plant species population inside of these patches, due to increased predatory pressures [12]. Mixed agricultural patches will intercept surface runoff and increase human movement along the landscape. Implementing rainwater harvesting systems in the non-vegetative LCTs will reduce surface runoff, decrease predatory pressures, and decrease human movement inside the mixed agriculture patches.

The AHP model results indicate that the non-vegetative LCT in WS 104 would be the best site to implement a rainwater harvesting intervention. The non-vegetative LCT in WS 59 is 61% as good as the non-vegetative LCT in WS 104, and the non-vegetative LCT in WS 108 is 50% as good as the non-vegetative LCT in WS 104. These location suitability rankings are reasonable since the CA, CAP, MPS, and GYRATE for the non-vegetative LCT in WS 104 are higher than the corresponding results in WS 59 and WS 108, whereas the PN, TE, ECON, and ENN for the non-vegetative LCT in WS 104 are lower than they are in WS 59 and WS 108.

Finally, our results suggest that landscape metrics analysis in combination with AHP is a useful tool for spatially assessing the suitability of rainwater harvesting sites. The ecosystem benefits of rainwater harvesting can be maximized by locating this technique within a large, non-fragmented, non-isolated, non-complex, and connective patch. Our tool might be integrated with previous rainwater harvesting site selection methods to build a new comprehensive method that considers all of the landscape criteria together.

6. Conclusions

This study provides a novel approach to the process of rainwater harvesting site selection. It extends prior rainwater harvesting site selection methods by quantifying the spatial composition and configuration of a target landscape. Our spatial analyses indicate that the non-vegetative LCT in WS

104 provides the most suitable spatial pattern to implement rainwater harvesting. The dominancy, connectivity, and decreased fragmentation features of the non–vegetative LCT are features that would increase the efficacy of rainwater harvesting systems. The ecosystem benefits of rainwater harvesting can be maximized by locating this technique within a large, non-fragmented, non-isolated, non-complex, and connective patch. Landscape metrics in combination with AHP can be a useful tool for assessing the suitability of a rainwater harvesting site to account for subsequent changes in landscape composition, configuration, and land use patterns. Our findings could be expanded into new viewpoints that simultaneously advance landscape ecosystem services and water management systems in the future.

Author Contributions

Main ideas: Abeer Albalawneh, Tsun-Kuo Chang, Chun-Wei Huang, Safa Mazahreh; Academic writing: Abeer Albalawneh, Tsun-Kuo Chang, Chun-Wei Huang; Data collection: Safa Mazahreh; metrics and AHP analysis: Abeer Albalawneh, Chun-Wei Huang; Wrote part of the first draft of the manuscript: Abeer Albalawneh; reviewed the paper: Tsun-Kuo Chang.

Conflicts of Interest

The authors declare no conflict of interest.

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