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Participatory Land Suitability Analysis to Identify the Optimum Land Use for a Mountainous Watershed in Jordan

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ABSTRACT: Land suitability analysis provides decision support information to select and put in practice optimum land use options. The sustainability of land resources and their potential to meet food security target is crucial in fragile mountainous and marginal areas, especially with the future expectations of population growth, harshness of land degradation and climate change. The quality of the land suitability results and consequently the competence to support the farmers' and land users' decisions depend on the criteria used to assess the land suitability. The results of this study emphasized the value of stakeholders' participation in fine-tuning the suitability results and generating realistic decision support tool. The analyses indicated an acceptable match between current and potential land use when the local knowledge was integrated in the suitability analysis. The results revealed the potential for implementing promising land use options based on adapting an acceptable and affordable sustainable land and water management practices. The analyses also revealed unsustainable land uses that are currently practiced in the study area. Implementing the results of these analyses is expected to enhance the sustainability of land use, lessen land degradation and improve food security and livelihoods. The analyses could be implemented in other countries/watersheds to generate comparable benefits.
Keywords: Land use; Soil survey; Land suitability criteria, GIS, Participatory approach

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I. INTRODUCTION

More than half of the world's population depends directly on water from mountain watersheds to grow food. Over the last three decades, these upland watersheds have come under increasing pressure. Degraded watersheds are a threat to the environment and to the livelihoods of rural communities, both upstream and downstream. Watershed degradation is a clear symptom of unsustainable development. The link between poverty and the environment is very pronounced in the fragile mountain ecosystems, where people and communities frequently overuse natural resources in their struggle for survival [1].

Rainfall in these areas is highly erratic both in space and time. Agricultural development is also constrained by numerous other factors (small landholdings, obsolete farming methods, lack of infrastructure and institutional support), but the key limiting factor is water: erratic supplies during the cropping season, and shortage of irrigation water during the dry season. Improved land and water management practices will help sustain these fragile systems and enable communities to achieve self-resilience [2].

Jordan is generally dominated by dry, hot summers and mild wet winters with extreme variability in rainfall which is generally insufficient for crop production [3]. As rainfall is poorly distributed over the growing season and often comes in intense bursts, it usually cannot support economically viable farming. In addition, land resources are limited and the miss management of land will leads to desertification. Therefore, information on land resources and possibilities for their sustained use is essential for the selection, planning and implementation of land uses to meet the increasing demands for basic human needs on sustainable bases [4]. Adaptation of land use to the potentials and constraints of the agro-ecosystem is a key principle of sustainable land management (5,6). The utilization of mountainous areas needs proper, updated management policies in order to avoid further deterioration of land resources. Land should be classified according to its potential suitability for different kinds of use. The proper utilization of these areas requires adopting proper evaluation of land in order to maximize and sustain production and to reduce land degradation (4).

Land evaluation, the process of estimating the potential of land for alternative kinds of use (7), contributes to the understanding of the relationship between the conditions of a land and the uses to which it is put (2). This process typically requires large sets of data as inputs (7,8). The FAO framework (9) is an approach for land suitability evaluation, which classifies land in terms of suitability ratings from highly suitable to not suitable based on soil, climate and terrain properties (10,11). This framework is based on basic concepts, principles, and procedures for land evaluation that are "universally valid, applicable in any part of the world at any level, from global to single farm" (10).

The output of suitability analyses provided not only the type of land use for which the land is suitable, but also information about the type of limitation (s) facing the utilization of land (12,13).

GIS and remote sensing are commonly used in the process; as they offer the speed, flexibility, and power to synthesize large quantities of data (14-17). The use of soil survey data integrated with remotely sensed and other GIS layers is beneficial for this purpose (18). Research indicated the contemporary roles of GIS capabilities and their roles in such land evaluation studies (12).

One of the most important steps in the land suitability evaluation is the selection of the limiting values (criteria) for suitability classification. Usually determined by scientists according to previous studies and experience (13). One feature of the framework is the comparison of present or future land conditions with the most preferred conditions for any given landuse through an iterative adjustment process called "matching" (19).

The FAO framework for land evaluation has been applied in previous projects in many countries including Jordan: particularly the National Soil Map and Land Use Project (NSMP) and the Jordan Arid Zone Productivity project (JAZPP). The land suitability evaluation was undertaken for many land utilization types using the FAO criteria of both projects (4), and indicated that shortage of water and soil constraints are the major limiting factors for agricultural development. Furthermore, the differences between existing and potential land use was obvious with variations among the different LUT's. These variations were mainly attributed to climatic factors, land characteristics and management practices (12).

The objectives of this study are to evaluate the potential land suitability of the watershed, to recommend an optimum land use alternatives taking into consideration the criteria modified by stakeholders that reflect their knowledge and experience in addition to compare the current land use with potential land suitability.

II. MATERIALS AND METHODS

2.1 Study site

The pilot area (Erak Village) is located 30 km south of Al-Karak, 10 km west of Mu'ta town (Figure 1). The area of the watershed within which the village is located is 30 km^2. The parent material is primarily colluviums derived from limestone, moderately deep stony to shallow, very common stones and boulders with > 20% rock outcrop. The topography is dominated by an undulating to rolling dissected plateau with slope of 0 to more than 50%. The watershed is characterized by Thermic temperature regime and Xeric moisture regime with annual rainfall ranges between 280 to 350mm whereas altitude ranges between 100-1260 m above sea level.

The land use consists of rangelands with some rainfed arable and tree crops with some irrigated areas. The hill slopes are generally suitable for tree crops and the gently sloping colluvial foot slope for cereals with appropriate conservation measures. The broad valley bottoms are suitable for cereals and summer crops. Tree crops are also successfully growing in the valley, as are horticultural crops with ground water irrigation.

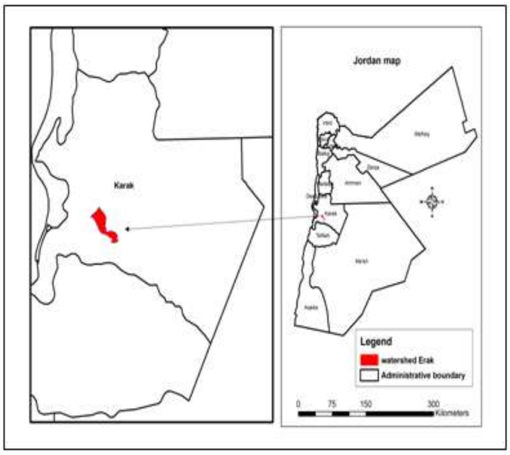

Figure 1. Location of Erak watershed in Al-Karak, Jordan

2.2 Land suitability evaluation

Land evaluation is an interpretation of land properties in terms of suitability of the land for different land use types or crop types. A qualitative approach to land Evaluation was adopted in this study following principles and guidelines of FAO (20,21). An important factor to consider in land evaluation is the land use type. The suitability of a given type of land can be identified only by satisfying the question "suitability for what?" .

Two sets of information are required for such an evaluation: multidisciplinary data for land mapping units and the requirements and limitations of possible kinds of land use. These two sets of data are compared by the process of matching. The requirements of each land utilization type are compared (matched) with land attributes derived from each land mapping, resulting in the land suitability classifications for each use.

In the FAO framework, combinations of land characteristics relevant to specified uses are used as assessment factors reflecting limitations to land suitability and are called land qualities (Table 1).Within each land quality, a number of constituent, single or compound, land characteristics would have to be distinguished for rating each land quality.

Table 1. Land qualities and relevant land characteristics.

Land quality	Land characteristics	Unit
Climate	Annual rainfall	mm
	Winter Growth Potential	degree-days
Soil	Rooting depth	Cm
Erosion	Type	class
	Hazard	class
Topography	Slope	%
Rockiness/ stoniness	Rock outcrop	%
	Stone at surface	%
	Stone in surface horizon	%

The relationship between specific crop needs (qualities) and directly measurable parameters (characteristics) is presented in criteria table (Tables 2, 3 and 4). These crop's growth requirements or qualities are not always directly measured in the field and may need to be derived from other observations. On the other hand, land characteristics refer mainly to measurable climatic and soil-related parameters, and landform data.

The first step for land suitability is defining the land use types to be evaluated in the study area. Therefore, ten land use types were defined based on the current land use pattern and potential for introducing new alternatives inferred from the biophysical factors and consultations with local experts and the community: 1) rainfed annual crops; 2) rainfed perennials ; 3) rangeland; 4) drip irrigation/vegetables; 5) drip irrigation/trees; 6) surface irrigation; 7) runoff collection area for WH; 8) improved rangeland/contour ridges; 9) small runoff basin for trees; and 10) forestry/reforestation. The second step required is developing land suitability criteria for the ten land use types considered for evaluation. The criteria developed for Jordan with participation of stakeholders are shown in Tables 2, 3 and 4.

Suitability maps for the ten LUT were presented to the local experts working in land management program. The experts indicated many discrepancies in the maps according to their knowledge and experience in the area. Accordingly the suitability criteria were modified following a thorough discussion. A new set of suitability maps were generated and compared with current land use.

Table 2. Land use requirements for five land utilization types using research suggested criteria and modified criteria according to stakeholder's consultation.

		Rainfed annual (field crops)				Rainfed perennials				Rangeland				Drip irrigation vegetables				Drip irrigated trees			
Land characteristic		S1[2]	S2	S3	NS	S1	S2	S3	NS	S1	S2	S3	NS	S1	S2	S3	NS	S1	S2	S3	NS
Rainfall	Research	>250	200-250	150-200	<150	>400	300-400	250-30C	<250	>100	75-100	50-75	<50								
	Modified	not modified				not modified				>150	100-150	75-100	<75								
WGPT (3)	Research	>250				>250				>400	250-400			>400	250-400			>250			
	Modified	not modified				not modified				not modified				not modified				not modified			
AWHC (4)	Research	>150	110-150	75-110	>75	>150	110-150	75-110	>75	>90	60-90	30-60	<30	>110	75-110	50-75	<50	>110	75-110	50-75	<50
	Modified	not modified				not modified				not modified				>75	50-75	30-50	<30	>75	60-75	40-60	<40
Soil depth	Research	>90	60-90	30-60	<30	>150	100-150	50-100	<50	>50	35-50	10-35	<10	>10	50-100	25-50	<25	>150	100-15C	10-50	<50
	Modified	not modified				not modified				not modified				>60	40-60	25-40	<25	>100	75-100	60-75	<60
Erosion (5)See table (4)																					
slope	Research	<4	4-8	8-16	>16	<10	10-20	20-30	>30	<20	20-40	40-80	>80	<2	2-5	5-10	>10	<4	4-8	8-16	>16
	Modified	<5	5-8	8-15	>15	<6	6-10	10-20	>20	<15	15-30	30-50	>50	<8	8-15	15-25	>25	<10	10-15	15-20	>20
Rockiness	Research	<5	5-10	10-20	>20	<10	10-20	20-35	>35	<20	20-50	50-100		<5	5-10	10-20	>20	<2	2-5	5-10	>10
	Modified	not modified				not modified				not modified				<10	10-20	20-30	>30	not modified			
stone at the surfac	Research	<20	20-40	40-60	>60	<20	20-40	40-60	>60	<30	30-60	60-100		<5	5-10	10-20	>20	<5	5-10	10-20	>20
	Modified	not modified				not modified				not modified				<10	10-20	20-30	>30	<8	8-12	12-20	>20
stone content	Research	<10	10-20	20-30	>30	<15	15-35	35-50	>50	<20	20-50	50-100		<5	5-10	10-20	>20	<5	5-10	10-20	>20
	Modified	not modified				not modified				not modified				not modified				<8	8-12	12-20	>20
Ec (6)	Research	0-2	2-4	4-8	>8	0-2	2-4	4-8	>8	0-2	2-8	8-30	>30	<1	1-4	4-8	>8	<4	4-8	8-12	>16
	Modified	not modified				not modified				not modified				not modified				not modified			
Esp (7)	Research	0-15	15-25	25-35	>35	<25	25-30	30-45	>45	<35	35-50			0-15	15-25	25-35	>35	0-15	15-25	25-35	>35
	Modified	not modified				not modified				not modified				not modified				not modified			
IR (8)	Research													>16	8-16	4-8	<4	>16	8-16	4-8	<4
	Modified													not modified				>12	8-12	4-8	<4

Table 3. Land use requirements for five land utilization types using research suggested criteria and modified criteria according to stakeholder's consultation.

		Surface irrigation				Runoff				WH(1) for Trees				WH for Range				Forestry			
Land characteristic		S1(2)	S2	S3	NS	S1	S2	S3	NS	S1	S2	S3	NS	S1	S2	S3	NS	S1	S2	S3	NS
Rainfall	Research									>200	150-200	100-150	<100	>200	150-200	100-150	<100	>350	>250-350	>200-250	<200
	Modified									**not modified**				**not modified**							
WGPT (3)	Research									>250				>400	250-400			>100			
	Modified									**not modified**				**not modified**				**not modified**			
AWHC (4)	Research	>160	90-160	50-90	>50					>220	150-220	100-150	<100	>110	75-110	50-75	<50	>110	75-110	40-75	<40
	Modified	**not modified**								**not modified**				**>75**	**60-75**	**50-60**	**<50**	**not modified**			
Soil depth	Research	>150	100-150	50-100	<50	>65	65-120			>150	100-150	50-100	<50	>100	70-100	40-70	<40				
	Modified	**not modified**				**not modified**				**>100**	**75-100**	**50-75**	**<50**	**>80**	**60-80**	**40-60**	**<40**				
Erosion (5)See table (4)																					
slope	Research	<2	2-4	4-6	>6	<6	3-6	1-3	<1	1-3	3-5	5-7	>7	<7	7-12	12-20	>20	<30	30-40	>40	
	Modified	**not modified**				**>5**	**3-5**	**1-3**	**<1**	**1-5**	**5-10**	**10-12**	**>12**	**not modified**				**not modified**			
Rockiness	Research	<15	15-40	40-75	>75					<10	10-20	20-35	>35	<10	10-20	20-35	>35	<35	30-60		
	Modified	**not modified**								**not modified**				**not modified**				**not modified**			
stone at the surface	Research	<15	15-40	40-75	>75					<20	20-40	40-60	>60	<20	20-40	40-60	>60	<50			
	Modified	**not modified**								**not modified**				**not modified**				**not modified**			
stone content	Research	<3	3-15	15-40	>40	0-25	25-35	35-70	>70	<10	10-20	20-30	>35	<10	10-20	20-30	>35	<20	20-35	30-60	>60
	Modified	**not modified**				**0-35**	**35-50**	**50-70**	**>70**	**not modified**				**not modified**				**not modified**			
Ec (6)	Research	0-8	8-15	15-30	>30					<4	4-8	8-12	>12	<4	4-8	8-16	>16				
	Modified	**not modified**								**not modified**				**not modified**							
Esp (7)	Research	8-35	35-70	70-100	>100					0-15	15-25	25-35	>35	<35	35-50						
	Modified	**not modified**								**not modified**				**not modified**							
IR (8)	Research					<4	4-6	6-8	>8	<4	4-6	6-8	>8	<4	4-6	>8					
	Modified					**<6**	**6-10**	**10-12**	**>12**	**<6**	**6-8**	**8-10**	**>10**	**<6**	**6-8**	**>8**					

(1)Water harvesting. (2) Suitability class: S1, highly suitable; S2, moderately suitable; S3, marginally suitable; NS, not suitable. (3) Winter growth potential (degree.day).(4) Available water-holding capacity (mm/100cm).(5) Erosion see table (4). (6) Electrical conductivity (ds/m). (7) Exchangeable sodium percentage (%). (8) Infiltration rate (mm/hr).

Table 4. Erosion suitability criteria (erosion type and severity class) for ten land utilization types.

	Land Quality /Land Characteristics (grouping) Erosion (E)	**Unit**	S1	S2	S3	NS
Rainfed annual	ErosionHazard 2=Rill or 3=Gully	class	(nil-no erosion)	Rill -(slight)	Gully-moderate	4(severe)
	1=sheet 4=wind 5=undifferentiated	class	sheet-slight	Sheet-moderate, gully-slight, undiffer-slight)	Undiffer-moderate, Rill-moderate	All-severe
Rainfed perennials	2=Rill or 3=Gully	class	(nil-no erosion)	Rill -(slight)	Gully-moderate	4(severe)
	1=sheet 4=wind 5=undifferentiated	class	sheet-slight	Sheet-moderate, gully-slight, undiffer-slight)	Undiffer-moderate, Rill-moderate	All-severe
Rangeland	2=Rill or 3=Gully	class	(nil)-no erosion, rill-slight,	Gully-mod, undiffer-mod		All-(severe)

			sheet-mod, gully-slight			
	1=sheet 4=wind 5=undifferentiated	class	Undiffer-slight, sheet-slight	Rill-moderate		
Drip irrigated vegetable	2=Rill or 3=Gully	class	(nil-no erosion)	Rill -(slight)	Gully-moderate	4(severe)
	1=sheet 4=wind 5=undifferentiated	class	sheet-slight	Sheet-moderate, gully-slight, undiffer-slight)	Undiffer-moderate, Rill-moderate	All-severe
Drip irrigated trees	2=Rill or 3=Gully	class	(nil-no erosion)	Rill -(slight)	Gully-moderate	4(severe)
	1=sheet 4=wind 5=undifferentiated	class	sheet-slight	Sheet-moderate, gully-slight, undiffer-slight)	Undiffer-moderate, Rill-moderate	All-severe
WH(1) for trees	2=Rill or 3=Gully	class	(nil-no erosion)	Rill -(slight)	Gully-moderate	4(severe)
	1=sheet 4=wind 5=undifferentiated	class	sheet-slight	Sheet-moderate, gully-slight, undiffer-slight)	Undiffer-moderate, Rill-moderate	All-severe
WH(1) for Range	2=Rill or 3=Gully	class	(nil)-no erosion, rill-slight, sheet-mod, gully-slight	Gully-mod, undiffer-mod		All-(severe)
	1=sheet 4=wind 5=undifferentiated	class	undifferentiated -slight, sheet-slight	Rill-moderate		
Re-forestation	2=Rill or 3=Gully	class	(nil-noerosion), slight(sheet ,rill)	Gully(MODERATE)	All-severe	Gully-severe
	1=sheet 4=wind 5=undifferentiated	class	sheet,Rill, Gully	NL	All-severe	

2.3 Suitability analysis based on consultation with Stakeholders

2.3.1 Modified criteria

Land suitability criteria for eight land use types were modified and fine-tuned according to stakeholders of the Erak watershed through a meeting between the researchers from NCARE and from the ARMP II development program, who are working in the area since many years. The stakeholders suggested some modification on the criteria of evaluation to reflect their knowledge and experience. The criteria developed are shown in Tables 2, 3 and 4. The modified criteria are shown in **bold** color. The criteria for surface irrigation were left without modifications because preferences were given first to seek more water saving irrigation methods. No changes were made to the suitability criteria for forestry as it was considered satisfactory.

An interesting part of the meeting between researchers and development program is to reach a consensus on the concept of land suitability. This is by reaching an agreement that it is not necessary that the current land use is the best one and therefore we should not deploy suitability criteria based on the current land use. The team suggested together the most appropriate criteria rating based on the potential of land to produce on sustainable basis. If the current land use does not match with the potential land suitability then there are two options. First, the farmers are adopting sustainable land management options that overcome the current constraints and therefore the researchers should consider these and include them in the recommended management practices. The other option is that the farmers are overexploiting the land by adopting the wrong land use (or exceed the land potential) and therefore efforts should be exerted to change the land use to those which match the sustainably suitable use.

The modifications to fine tune the criteria according to the stakeholders experiences are explained in Table 5. The rational for these modifications is also explained. In general, these modifications are considering the possibility of reducing the land use requirement of some land use types, which is compensated by some locally known management practices. However, in some cases, criteria were changed to more stringent values to reflect the need for protecting the land by sustaining the production, especially under the expected climate change predictions.

Table 5. Shows the criteria modified for eight land use types with justification.

Landuse type	Criteria modified	Suitability class	S1	S2	S3	NS	Justification
Rainfed annual (field crops)	Slope	Research	<4	4-8	8-16	>16	Changed to be in harmony with the limits for ARMP II activities to implement soil and water conservation
		Modified	**<5**	**5-8**	**8-15**	**>15**	
Rainfed perennials	Slope	Research	<10	10-20	20-30	>30	Low slope to avoid accelerated erosion as the future climate change scenarios expecting frequent intensive rainfall events
		Modified	**<6**	**6-10**	**10-20**	**>20**	
Range	Climate (C)	Research	>100	75-100	50-75	50	Mean annual rainfall increase the limit of rainfall to 150 to ensure enough rain in low-rainfall years
		Modified	**>150**	**100-150**	**75-100**	**<75**	
	Slope	Research	<20	20-40	40-80	>80	Low slope to avoid accelerated erosion as the future climate change scenarios expecting frequent intensive rainfall events
		Modified	**<15**	**15-30**	**30-50**	**>50**	
Drip -	Total available water holding capacity (AWHC) and						Irrigation

irrigation vegetables	Soil depth						
	AWHC	Suitability class	S1	S2	S3	NS	management and scheduling is assumed to tackle challenges of low AWHC and soil depth, therefore soil depth and AWHC were reduced.
		Research	>110	75-110	50-75	<50	
		Modified	**>75**	**50-75**	**30-50**	**<30**	
	Soil depth	Suitability class	S1	S2	S3	NS	
		Research	>10	50-100	25-50	<25	
		Modified	**>60**	**40-60**	**25-40**	**<25**	Irrigation at higher slopes is possible with good management practices, given water is available
	Slope	Suitability class	S1	S2	S3	NS	
		Research	<2	2-5	5-10	>10	
		Modified	**<8**	**8-15**	**15-25**	**>25**	relaxed rating of rock and stone because farmers tend to invest in preparing the land whenever water is available
	Rockiness (R)	Suitability class	S1	S2	S3	NS	
		Research	<5	5-10	10-20	>20	
		Modified	<5	5-8	8-12	>12	
	Stone at surface	Suitability class	S1	S2	S3	NS	
		Research	<5	5-10	10-20	>20	
		Modified	**<10**	**10-20**	**20-30**	**>30**	
	salinity (Ec)	Suitability class	S1	S2	S3	NS	
		Research	<1	1-4	4-8	>8	
		Modified	**<2**	**2-4**	**4-8**	**>8**	Tolerating higher salinity levels under irrigation

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Total available water holding capacity (AWHC) and soil depth
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<td>Runoff</td>
<td>
Stone content of the surface horizons
<table>
<tr><td>Suitability class</td><td>S1</td><td>S2</td><td>S3</td><td>NS</td></tr>
<tr><td>Research</td><td>0-25</td><td>25-35</td><td>35-70</td><td>>70</td></tr>
<tr><td>Modified</td><td>0-35</td><td>35-50</td><td>50-70</td><td>>70</td></tr>
</table>
</td>
<td>Higher stone content was suggested to avoid excluding potential areas</td>
</tr>
<tr>
<td></td>
<td>
Slope
<table>
<tr><td>Suitability class</td><td>S1</td><td>S2</td><td>S3</td><td>NS</td></tr>
<tr><td>Research</td><td>>6</td><td>3-6</td><td>1-3</td><td><1</td></tr>
<tr><td>Modified</td><td>>5</td><td>3-5</td><td>1-3</td><td><1</td></tr>
</table>
Infiltration Rate(Terminal IR)
</td>
<td>Lower slope is accepted in areas with low infiltration rate</td>
</tr>
</table>

<table>
<tr>
<td></td>
<td>
<table>
<tr><td>Suitability class</td><td>S1</td><td>S2</td><td>S3</td><td>NS</td></tr>
<tr><td>Research</td><td><4</td><td>4-6</td><td>6-8</td><td>>8</td></tr>
<tr><td>Modified</td><td><6</td><td>6-10</td><td>10-12</td><td>>12</td></tr>
</table>
</td>
<td>Higher infiltration rate suggested to allow for including more areas</td>
</tr>
<tr>
<td>Water harvesting for trees</td>
<td>
Soil depth
<table>
<tr><td>Suitability class</td><td>S1</td><td>S2</td><td>S3</td><td>NS</td></tr>
<tr><td>Research</td><td>>150</td><td>100-150</td><td>500-100</td><td><50</td></tr>
<tr><td>Modified</td><td>>100</td><td>75-100</td><td>50-75</td><td><50</td></tr>
</table>
Slope
<table>
<tr><td>Suitability class</td><td>S1</td><td>S2</td><td>S3</td><td>NS</td></tr>
<tr><td>Research</td><td>1-3</td><td>3-5</td><td>5-7</td><td>>7</td></tr>
<tr><td>Modified</td><td>1-5</td><td>5-10</td><td>10-12</td><td>>12</td></tr>
</table>
Infiltration Rate (Terminal IR)
<table>
<tr><td>Suitability class</td><td>S1</td><td>S2</td><td>S3</td><td>NS</td></tr>
<tr><td>Research</td><td><4</td><td>4-6</td><td>6-8</td><td>>8</td></tr>
<tr><td>Modified</td><td><6</td><td>6-8</td><td>8-10</td><td>>10</td></tr>
</table>
</td>
<td>Successful implementation of runoff basin was reported in field with lower soil depth in the area

Areas with 5% slope are used for successful implementation in the area

Higher infiltration was suggested to allow infiltration in the collection area and increase runoff from the collection area</td>
</tr>
<tr>
<td>Water harvesting for range</td>
<td>
Total available water holding capacity (AWHC)
<table>
<tr><td>Suitability class</td><td>S1</td><td>S2</td><td>S3</td><td>NS</td></tr>
<tr><td>Research</td><td>>110</td><td>75-110</td><td>50-75</td><td><50</td></tr>
<tr><td>Modified</td><td>>75</td><td>60-75</td><td>50-60</td><td><50</td></tr>
</table>
Soil depth
<table>
<tr><td>Suitability class</td><td>S1</td><td>S2</td><td>S3</td><td>NS</td></tr>
<tr><td>Research</td><td>>100</td><td>70-100</td><td>40-70</td><td><40</td></tr>
<tr><td>Modified</td><td>>80</td><td>60-80</td><td>40-60</td><td><40</td></tr>
</table>
Infiltration Rate (Terminal IR)
<table>
<tr><td>Suitability class</td><td>S1</td><td>S2</td><td>S3</td><td>NS</td></tr>
<tr><td>Research</td><td><4</td><td>4-6</td><td>>8</td><td>-</td></tr>
<tr><td>Modified</td><td><6</td><td>6-8</td><td>>8</td><td>-</td></tr>
</table>
</td>
<td>There are many example of successful implementation of water harvesting in relatively shallow soils. Also, within a shallow soil field, there are pockets of deeper soils

Allow for higher infiltration rate to allow including more potential areas</td>
</tr>
</table>

2.3.2Data collection and processing

The applied approach was elaborated through field data collection and analysis. To determine the optimum utilization alternatives for Erak watershed, data on different aspects of land attributes were collected and thoroughly assessed, then, suitability maps were generated.

Data required for suitability analysis were collected through field survey (214 locations were selected and sampled), as shown in Figure 2. For field survey purpose, recent detailed satellite image - world view (with resolution 50 cm) was used for interpretation and identification of the proposed locations for sampling and site description. Global Positing system (GPS) was used to identify the coordinates of the surveyed sites. The main criteria used for field survey were land cover, land use, slope, stones-rock percentage on the surface of the soil. Therefore, the soil samples were taken accordingly for 3 depths using Augers. The collected samples were analyzed at the soil lab at National Center for Agricultural Research and Extension (NCARE) and data for all sites were verified and registered.

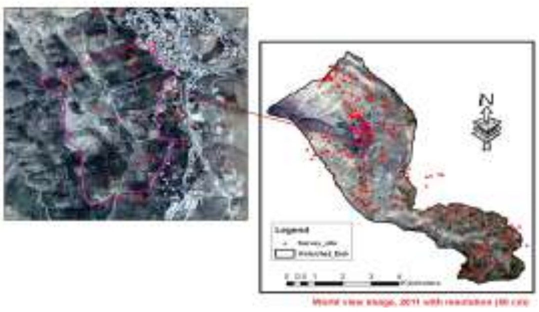

Figure 2. Distribution of the field observations in Erak watershed.

The source of information used for suitability analysis was based on field description, derived data and lab analysis. Available water holding capacity (AWHC) was estimated for 36 sites using pedo-transfer function according to texture and stone content in all horizons. Also, stones in the surface horizon was measured and estimated for 36 sites.

In order to run the suitability mapping, surfaces (rasters) from soil survey data (numeric data) were created using interpolation process using Inverse Distance Weighted (IDW) method in ArcGIS. These surfaces represent: Infiltration rate, $CaCO_3$ %, EC, Soil depth, Rockiness %, Stone in the horizon % (36 sites), Stone at surface %, AWHC mm/m (36 sites), and ESP %. An example of the interpolated surface for stone content at surface (214 sites) is shown in Figure 3. Theissen polygons were created for some data (Figure 4) which have (non-numeric) classes using 214 surveyed sites to interpolate erosion status, erosion hazard, and drainage classes.

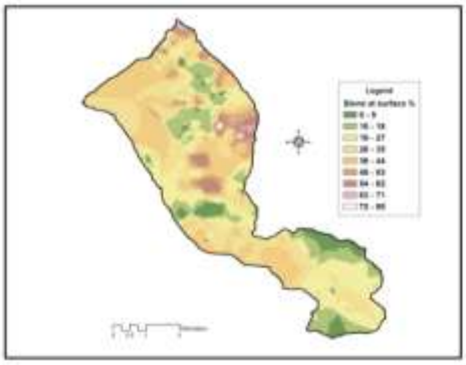

Figure 3. Interpolated surface for stone content.

Figure 4. Theissen polygons map produced for non-numeric data (erosion status, erosion hazard, and drainage classes).

The basic unit for suitability analysis was “slope FID” created in the slope map. Therefore, average values were calculated for numerical data using summarize option in the GIS while mode data were estimated for text-type data (erosion status and type, drainage class) using SPSS software. Join process was carried out between (mode and average values) table and the “intersect” map according to “id slope” in the GIS resulting in a map with data required for suitability analysis.

2.3.3 Suitability ratings and maps

Suitability ratings are sets of values which indicate how well each land use requirement is satisfied by particular conditions of the corresponding land quality; in other words, the suitability of the land for the specific land use (21,22).

According to the FAO framework, four suitability categories are distinguished:

Land suitability orders reflecting kinds of suitability S= suitable, N= Not suitable.

Land suitability classes reflecting degrees of suitability within orders (S_1, S_2, S_3, NS).
Land suitability subclasses reflecting kinds of limitation, or main kinds of improvement measures required, within classes and they are indicated in the symbol using lower case letters with numeric significance.
Factor ratings are made in terms of four classes (11):
S1: Highly suitable: Land having no significant limitations to the sustained application of the defined use.
S2: Moderately suitable: Land having limitations which will reduce production levels and / or increase costs, but which is physically and economically suitable for the defined use.
S3: Marginally suitable: Land having limitations which will reduce production levels and / or costs such that it is economically marginal for the defined use.
Ns: Not suitable

An assessment of the qualities of the different land units was carried out to see how well they meet the Land use requirements through a process called matching. Using GIS commands and functions to select attributes that represent the criteria (Tables2 and 3) and rate them to suitability classes (S1,S2, S3, NS). The approach of limiting condition (Leibig's law) or simple limitation method has been adopted to conduct the overall suitability in which the least favorable quality is taken as limiting. The final suitability ratings are referred to in terms of severity (worst) of climatic constraints as well as soil, erosion hazard, rockiness/stoniness, and salinity/alkalinity constraints (1).

III. RESULTS AND DISCUSSION

3.1. Land suitability mapping
The suitability maps using the criteria modified according to the stakeholders' contribution are shown in Figure 5 classified into highly, moderately, marginally and not suitable for ten different land use types.

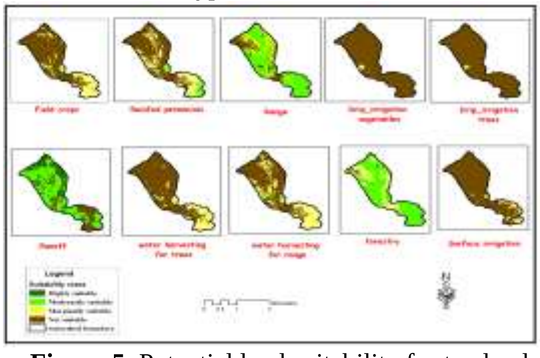

Figure 5. Potential land suitability for ten land utilization types applying stakeholders' modified criteria.

The suitability classes were analyzed for each LUT in terms of Area percentage as shown in Table 6.

The results show that the watershed is generally either marginally suitable 28% (especially the upper flat part) or not suitable 71.2% for rainfed annual (field) crops. This is mainly due to the low rainfall. However, some farmers are still using the land for rainfed annual crops hoping that in some years there will be enough rainfall to support good production. The results here show that unless this utilization is supported by additional moisture, by water harvesting for example, it is not a good choice for farmers.

There are some areas (6.8%) that are moderately suitable for rainfed perennials. These are distributed in the upper flat areas. Again, an additional source of moisture, such as water harvesting and soil conservation interventions, are needed to sustain and improve the production.

Table 6. Area analysis for suitability classes for 10 LUT's.

land utilization types	S1	S2	S3	NS
Field crops	0	0.8	28	71.2
Rain fed perennials	0	6.8	32.3	60.8
Range	1.5	62.3	18.8	17.4
Drip -irrigation vegetables	0	0	1.3	98.7
Drip irrigated trees	0	0	0.9	99.1
surface irrigation	0	0	9.5	90.5
runoff	22.3	53.9	1.5	22.3
WH for trees	0	0.2	23.2	76.6
WH for Range	0.3	1.85	37.75	60.1
Forestry	0.6	73.1	23.5	2.8

For rangeland, the analyses indicated that there are appreciable areas that are highly and moderately suitable (63.8 %) for rangeland. These areas are distributed all over the watershed. This provides a good option for the land users and if a proper water harvesting and soil conservation interventions are adopted together with proper grazing management strategies, the production could be improved and sustained. The majority of the watershed is not suitable (more than 99%) for drip irrigated vegetables or trees, while (90.5%) of the area is classified as not suitable for surface irrigation.

The stakeholders' recommended some changes in the criteria based on their experience and realizing the importance of these areas in generating additional water resources. The runoff-generating areas are distributed over the watershed and indicate a promising potential to implement water harvesting structures and to use the harvested water to improve the productivity of some crops as well as a source for domestic and livestock water demands. Examples of this model of water harvesting are available over the country and could be used to promote more adoption by farmers.

The suitability for water harvesting for trees (using micro-catchment water harvesting system) indicated a good potential for adopting this techniques. Farmers in the rainfed tree production system suffer from drought and therefore this provide additional source of moisture. The benefit of this technique, in addition to water conservation, is the contribution toward reducing soil erosion and land degradation.

The analysis indicated that, there are potential areas for improving the rangeland in the watershed (40%). Some of these areas are distributed around the village (at the center of the watershed) and therefore might provide additional feed for the livestock. Technical options for improving rangeland on these potential areas coupled with proper management of range resources, such as grazing management, will provide suitable improvement and sustainability of rangeland and livestock resources. Results show that the watershed has high potential for forestry (73%).

3.2. Mapping current land use

World View satellite image, with resolution 50 cm was used to map existing land use as shown in Figure 6. The image was classified into land use classes using digitizing in the GIS on the basis of Corine classification system following level 3 details. Based on the experience gained in the field survey of Erak study area, three classes have been added to Erak land use classes which are absent in the Corine classification system: bare soil, bare rock, and terraces. As a result, Figure 7 shows the current land use map.

Table 7 shows the land use classes with area percentages that exist in Erak watershed. Field crops and range lands dominated the land use, whereas bare rock and bare soil are also distributed in the study area.

Figure 6. World view satellite image for Erak watershed.

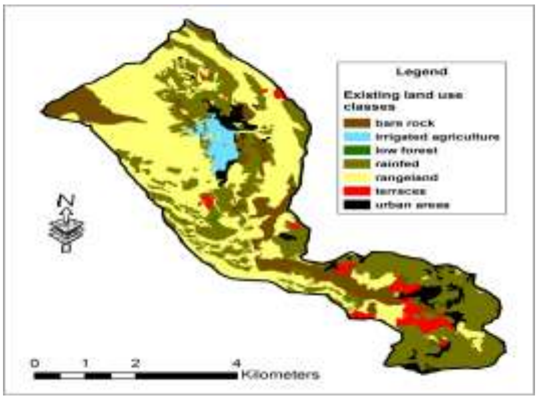

Figure 7. Current land use classes for Erak watershed (interpreted from world view image and ground survey).

Table 7. Area percentages of existing land use classes within Erak watershed.

Land use	Area (m²)	Area (%)	Land use	Area (m²)	Area (%)
Mining	8577.4	0.03	House at farm	302,588.0	1.01
Animal farm	33,845.0	0.11	Irrigated agriculture	734,522.0	2.44
Bare rock	3,567,290.0	11.87	Low forest	24,067.1	0.08
Bare soil	2,593,930.0	8.63	Olive trees	407,464.0	1.36
Continuous urban	603,337.0	2.01	Orchard	973,853.0	3.24
Discontinuous urban	467,475.0	1.56	Shrubs and range	10,204,200.0	33.94
Field crops	9,149,550.0	30.44	Terraces	990,358.0	3.29
Total (classes)	16,424,004	55		13,637,052	45
Total (watershed)				30,061,057	100

3.3. Formulation of the land use alternatives

In order to incorporate farmer's knowledge and experience in selecting particular land-use type, land use options with high land suitability classes (S1 and S2) were formulated by applying the stakeholders' criteria as shown in Figure 8. This analysis revealed that some land units are potentially suitable for more than one land use options while others are hardly suitable for one option.

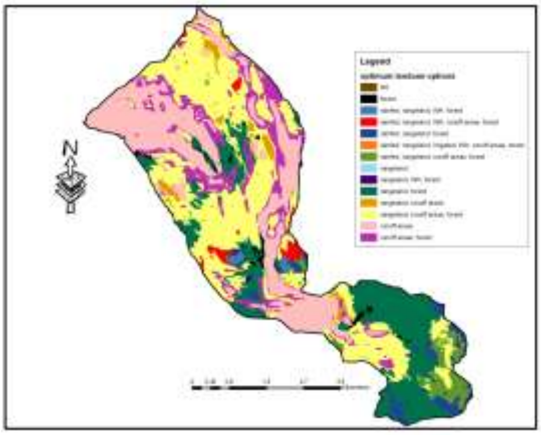

Figure 8. Optimum land use options after applying stakeholders' modified criteria for Erak watershed.

Area analysis was carried out to show the percentages of optimum proposed areas and percentages for different land uses with high suitability according to stakeholders' criteria (Table 8). The summation of areas with suitability classes S1 and S2 were used to identify the best land use alternatives for the study area. It is concluded that 35 % of the area could be used for range, forest and runoff. The results show that 24 % of the total area has high potential for runoff and water storage which will support the agricultural practices in some areas. The study area also has about 19 % of the total area potential to protect the land with either forest or rangeland.

In order to compare the main current land uses with the optimum suitability proposed for the watershed, data were analyzed using GIS and calculations to describe the agreement between existing land use and optimum options recommended with high suitability classes (S1 and S2) applying stakeholders criteria as shown in table 9 and figure 9.

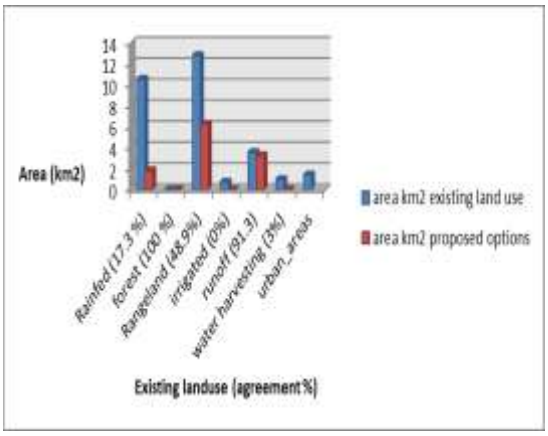

Figure 9. Comparison between areas of existing land use and the optimum land use for Erakwatershed.

The analysis show that there is 100 % agreement between area classified as potentially suitable (proposed options) for forestry and the existing land use area of forestry. This explains that the area planted by forest matches with the potential land use optimum options proposed for Erak watershed.

Areas classified as high potential for runoff, consists of 91.3% of the area that exists for bare rock. This result assures that some areas of the watershed should be utilized to collect runoff and store it for beneficial use by crops, livestock and domestic use. Also an agreement percentage of 48.9 % was found between rangeland existing in the area and the potential areas proposed for rangeland.

Low percentages of agreement was estimated between existing land use and the potential for that land use such as rainfed (17.29%), water harvesting (3%) for both trees and rangeland. This means that farmers practice rainfed cultivation more than land potential, also water harvesting should be applied in the watershed according to land potential.

In summary, the results indicated that the area is generally not suitable for field crops but farmers are still cultivating field crops, or the distribution of the current field crops area is not in the suitable areas. This might explain the low productivity of field crops (yield gap) and highlights the need to either cultivate the land with other, more productive, land use or to relocate the field crops in areas that are more suitable. Applying these options might improve the productivity with little inputs.

Irrigation practices in the area represent 2.4 % of the current land use areas and was not recommended as optimum land use. The areas used for irrigation is limited by the availability of irrigation water. Results showed that area recommended for rangeland was high, which also agrees with the current land use pattern.

Despite that areas suitable for runoff were 76 %, no area is currently used for collecting runoff from these potential areas for beneficial uses (irrigating crops fully or as supplemental irrigation, drinking or even for livestock). This highlights a great potential to collect large amounts of water to improve productivity and close the gap between water supply and demand, which would otherwise run-out of the watershed for unbeneficial uses. The analysis indicated appreciable areas that are potentially suitable for implementing soil conservation and water harvesting intervention (conservation terraces). However, the areas that are currently under conservation measures are low, 3.29 %. Therefore, there are promising areas within the watershed, which are not yet used for implementing soil conservation interventions to improve productivity and reduce degradation.

IV. CONCLUSIONS

The distribution of various potential land use options and the fact that some land units could be used for more than one land use provide a good basis to choose the most appropriate land use. Participation of farmers, land users and stakeholders from various development programs was very important to reflect their field experience. At field level, the farmers' participation is enough, however, at the level of the whole community or watershed, a collaboration of the whole community is needed. Based on modifying the suitability criteria by the stakeholders, it was concluded that 35 % of the area could be used for range, forest and runoff, 24 % of the total area has high potential for runoff and water storage which will support the agricultural practices in some areas, and about 19 % of the total area has the potential to protect the land with either forest or rangeland. Selection of the most suitable land uses for the whole watershed will help in optimizing the sustainable use of resources based on their potential and will also avoid conflicts and off-site impact.

The suitability analysis reported here is a good guide to locate the potential areas for different utilization that could be used to optimize the resources use in a sustainable manner. The comprehensive view offered by the suitability analysis, which scrutinize all options based on the biophysical potential provide a scientific bases for a participatory land use planning to optimize the use of resources, meet the growing demand on food and achieve sustainable agricultural production.

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Author Contributions

Safa Mazahreh and Doaa Abu Hamoor compiled and prepared the spatial and attribute data, performed the GIS analysis and produced the final results; Majed Bsoul designed and performed field survey and soil analyses; Safa Mazahreh and Feras Ziadat designed the study, compiled the results and wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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