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Land suitability mapping for rainfed olive tree plantation in the West Bank, Palestine

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ABSTRACT

In many developing countries, with a Mediterranean climate, the olive sector forms an important source of income. Thus, the assessment of land and identification of the highly suitable areas for olive is a very important step toward sustainable olive cultivation. A land suitability assessment for olive tree plantation in the West Bank, Palestine, was conducted and an olive land suitability (OLS) map was developed. GIS-based multi-criteria decision analysis (MCDA) was applied to assess the OLS based on identifying the most influential criteria that include ground surface elevations, aspects, slope, average annual maximum and minimum temperatures, average annual rainfall, land use, soil texture, and agricultural rainwater harvesting suitability. The analytic hierarchy process (AHP) was used to assign proper weights for the different criteria. Results of this study show that 47% of the West Bank area is high to very high suitable for olive plantation. Additionally, 30% and 23% of the West Bank area are under low to very low and medium suitability classes, respectively. However, 100% of Tulkarm, Qalqiliya, and Salfit areas are highly suitable, whereas Jericho and Tubas governorates are not suitable for olive tree plantation. Overlaying the OLS map and the A, B, and C areas of the Oslo accord (Palestinian-Israel peace process agreement) indicates that about 52% of the total highly OLS areas are located in areas A and B. Thus, investment in olive tree expansion in these areas is feasible as these areas are under Palestinian administrative control. Further, juxtaposing the OLS map and the existing rough grazing areas indicates that the highly suitable OLS areas are located in the rough grazing areas in the northwest governorates. Thus, encroachment of olive trees in rough grazing areas, where possible, is a viable option for potential future olive expansion in these governorates. Finally, the outputs of this study are of high value to help stakeholders and decision-makers to select the most suitable sites for olive tree plantation and as such enhance olive production in Palestine.

Keywords: Olive tree plantation; Geographic information system (GIS); Analytic hierarchy process (AHP); Multi-criteria decision analysis (MCDA); Suitability mapping; West Bank

1. Introduction

Olive is the oldest well-known planted tree in the world [1]. It is believed that the Mediterranean region is the origin of this tree, where the availability of olive trees therein dated back to 4800 B.C. [2]. Most often, olive trees are being planted in areas where the topographic, climatic and soil conditions are suitable [3]. Accordingly, the plantation of olives in such areas can enhance economic, social, and ecological conditions [4].

Temperature and rainfall are the most important climatic factors for the plantation of olive trees. The

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Mediterranean climate is highly suitable for the plantation of olives [5,6]. The optimal average monthly temperatures for olive tree plantation in the Mediterranean region vary between 7°C (in January) to 25°C (in July) [7]. Moreover, the olive tree cannot withstand a temperature of less than 8°C for more than one week [8]. Due to their extended rooting system, olive trees are tolerant to drought conditions and can still be grown with annual rainfall between 200 to 300 mm [9,10].

Worldwide, the olive cultivation area is nearly 10 million hectares with a total olive production of 20 million tons [11]. However, 90% of these areas are located in the Mediterranean region, mostly in Spain (25%), Tunisia (13%), Italy (11%), Morocco (10%), and Greece (9%) [11].

Globally, the expected population growth by 2050, the food demand will be increased by 70% [12]. Under uncertain agricultural land availability, satisfying food security for the increasing population will not be possible [13]. Thus, sustainable agriculture entails the need to plant each crop in its highly suitable areas to enhance crop productivity and accordingly availability of food [14]. This, in turn, directs the need to carry out agricultural land suitability assessment as an early step to achieve optimal crop production in trying to bridge the increasing food supply-demand gap [15]. Based on the land assessment, the spatial extent of suitable areas for the potential expansion of certain crops (e.g., olive trees) could be utilized to enhance food security [16].

Land suitability assessment is a process for the selection of suitable areas for specific land use [17,18]. In other words, land suitability assessment is a technique to estimate the suitability (also known as the "quality") level of certain land for a certain use [19–21]. Different influential criteria are used in land suitability assessment; these criteria could include biophysical (i.e., soil, land use, slope, altitude, rainfall, and climatic conditions), economic, and socio-cultural conditions [22]. According to [23], the climate factors (temperature and rainfall) are the most important factors in the assessment of olive land suitability (OLS). Additionally, [24,25] showed in their studies that slope and elevation are also highly important in the OLS assessment.

This research aims to develop a land suitability map for rainfed olive tree plantation in the West Bank. The development of an OLS map is of high value to guide stakeholders in the planning of the expansion of olive tree plantation in the highly suitable areas to enhance olive production in the West Bank, Palestine.

2. Materials and methods

2.1. Study area

The study area is the West Bank, Palestine, with a total area of 5,658 km^2 [26]. The total population in the West Bank is nearly 2.88 million, spread over 11 governorates. These are Jerusalem, Salfit, Jenin, Tubas, Nablus, Jericho, Hebron, Tulkarm, Qalqiliya, Bethlehem, and Ramallah [27] (Fig. 1). Based on the available topographic map [26], the West Bank elevations are in the range of 1,022 m above mean sea level (msl) to 410 m below (msl) in the Dead Sea. Additionally, the surface slope (in degrees) is ranged between 0 to 82 degrees with an average value of 7.7 degrees.

The prevailing climate in the West Bank is of the Mediterranean type (hot-dry in summer and wet-cold in winter) [28]. The average monthly temperature ranges between 20.8°C and 30°C in summer and between 8.7°C and 14°C in winter [29]. Additionally, most of the rainfall (80%) occurs during the winter and the rainy season usually extends from October to May [30,31]. However, long-term annual average rainfall for the entire West Bank is 420 mm [32].

Soils in the West Bank are divided into four categories based on soil texture (clay, clay loam, loamy and sandy loamy). 47% of the West Bank soil is clay and 31% is clay loam [33]. The land use in the West Bank is classified into eight categories: rough grazing/subsistence farming (53.9%), arable land (13%), irrigated farming (2.5%), permanent crops (grapes, citrus, etc.) (9%), olive groves (14.8%), built-up areas (4.8%), woodland/forest (0.6%), and Israeli settlements (1.4%) [26]. The area of cultivated and arable land is nearly 1,862 km^2. According to [26], the West Bank area is classified into three classes based on the agricultural land value, high (9.4%), moderate (27.2%), low (62.3%), and others (1.1%).

Olive areas occupied about 15% of the total West Bank area (836 km^2) (Fig. 1). Fig. 2 presents the distribution of olive areas in the different governorates. Most olive areas (93%) are located in the northwest governorates (Jenin, Nablus, Ramallah, Salfit, Tulkarm, and Qalqiliya) [33].

According to [34], 100,000 families in Palestine (14% of the total population) are depending on the olive sector for their income (direct and indirect). The olive represents nearly 56% of the total agricultural area and contributes nearly 85% of the total number of cultivated trees in Palestine. The amount of olives that were pressed in the olive presses in Palestine has increased from 102,162 metric tons (in 2010) to 177,611 metric tons (in 2019) and offer 1,859 seasonal employees work (1,300 in the West Bank and 559 in Gaza) [35].

2.2. Methodology

A geographic information system (GIS) is widely used in land suitability mapping [36]. Recently, the multi-criterion decision analysis (MCDA) approach in combination with GIS has been widely adopted in the land suitability mapping for different crops [18]. The GIS-based MCDA can be utilized to develop land suitability maps that help decision-makers to plan and manage land use for sustainable plantation of certain crops [37]. Different MCDA approaches could be used in the GIS environment. For instance: analytical hierarchy process (AHP), Boolean overlays, weighted linear combinations, ordered weighted averaging, and multiple-objective land allocation [38]. However, the AHP is the most commonly used MCDA approach in land suitability mapping [39–43]. The AHP-based GIS is widely used in suitability mapping due to its ability to combine a large number of different inputs even if their weight is not equal [44].

In this study, OLS map was developed based on the application of the GIS-based MCDA approach, where

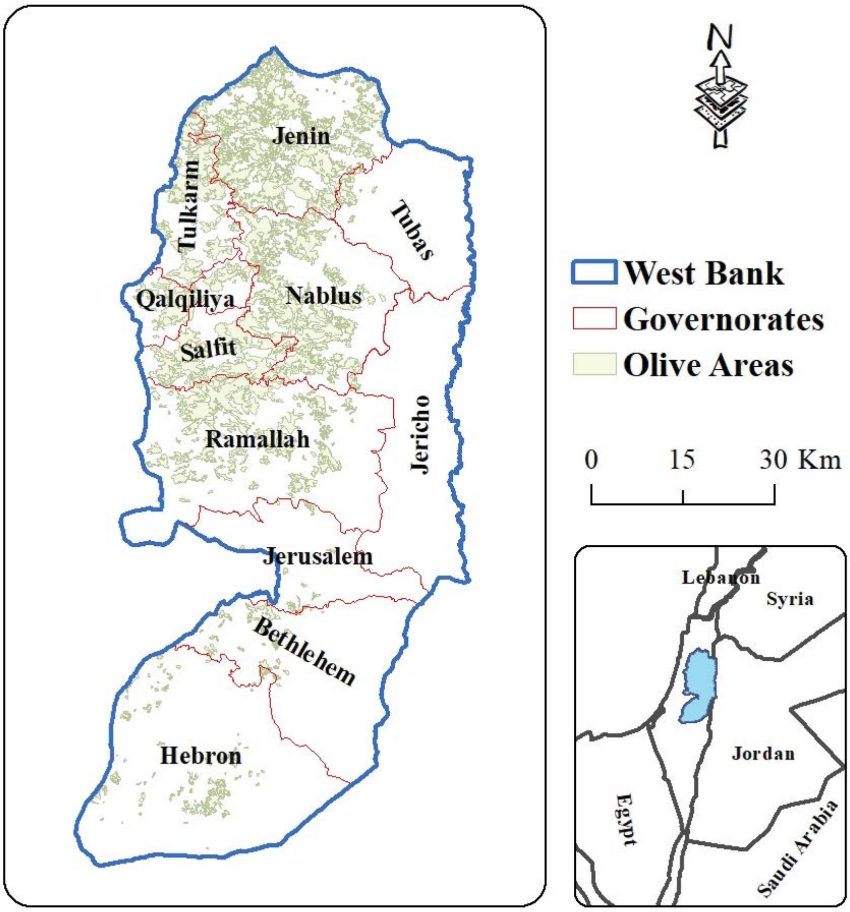

Fig. 1. Location map of governorates and current olive growing areas in the West Bank, Palestine.

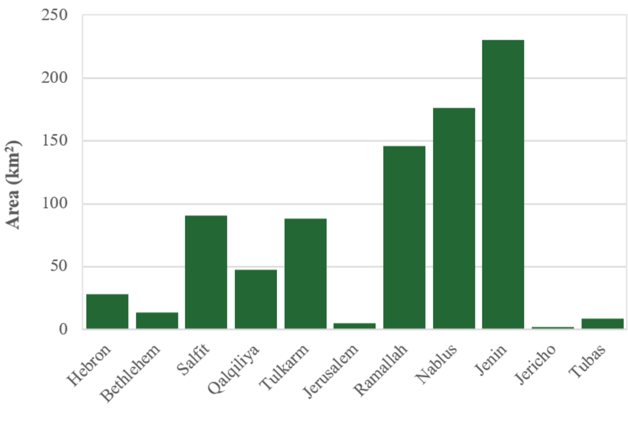

Fig. 2. Olive areas in the different West Bank governorates.

9 influential criteria were identified and used (Table 1). The influential criteria were selected from the data of topography, temperature, land use, soil texture, and rainwater harvesting suitability.

The selected criteria include ground surface elevation (E), aspect (A), slope (S), average annual maximum temperature (Tx), average annual minimum temperature (Tn), average annual rainfall depth (R), land use (L), soil texture (St), and agricultural rainwater harvesting suitability (ARWHS). Based on several inputs, the ARWHS map was developed for the entire West Bank [45]. The OLS criteria were identified based on their suitability to increase olive plantation in rainfed areas on the West Bank.

The general methodological framework for developing the OLS map is shown in Fig. 3.

To give proper weights for the selected OLS criteria, the AHP pairwise comparison matrix approach [47] was used (Table 2). Consequently, the reliability of the defined weights was verified based on the consistency ratio (CR) as follows [47]:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad (1)$$

$$\mathrm{CI} = \frac{\lambda - n}{n - 1} \quad (2)$$

where CI is the consistency index, RI is a random consistency index that depends on the number of criteria, λ is the maximum eigenvector of the matrix, and n is the number of criteria.

The maximum allowable value of CR is 0.1 [48]. In this research, an estimated value of 0.09 was obtained for the CR. This indicates that the OLS criteria matrix is consistent.

Table 1
Identified criteria for the development of OLS map

Criteria	Description	Data source
E	Ground surface elevation (m)	
A	Aspect (°)	[26]
S	Surface slope (°)	
Tx	Average annual maximum temperature (°C)	
Tn	Average annual minimum temperature (°C)	[46]
R	Average annual rainfall depth (mm)	
L	Land use	[26]
St	Soil texture	
ARWHS	Agricultural rainwater harvesting suitability	[45]

Table 2
AHP pairwise comparison matrix for the OLS mapping in the West Bank

Criteria	E	A	S	Tx	Tn	R	L	St	ARWHS	Weight
E	1.0	3.0	0.5	2.0	2.0	0.2	3.0	0.5	2.0	0.11
A	0.3	1.0	0.5	2.0	2.0	0.2	0.5	0.3	2.0	0.07
S	2.0	2.0	1.0	2.0	2.0	0.2	2.0	2.0	2.0	0.12
Tx	0.5	0.5	0.5	1.0	1.0	0.2	2.0	2.0	2.0	0.07
Tn	0.5	0.5	0.5	1.0	1.0	0.2	2.0	2.0	2.0	0.07
R	6.0	6.0	6.0	6.0	6.0	1.0	6.0	6.0	6.0	0.38
L	0.3	2.0	0.5	0.5	0.5	0.2	1.0	2.0	2.0	0.07
St	2.0	3.0	0.5	0.5	0.5	0.2	0.5	1.0	2.0	0.08
ARWHS	0.5	0.5	0.5	0.5	0.5	0.2	0.5	0.5	1.0	0.04

Each criterion used in the development of the OLS map was categorized into several scores, and each of them was assigned a value from 1 (low suitability) to 9 (high suitability) (Table 3) [47]. The approach of [49] was utilized in the suitability scoring for some criteria. The selected criteria were rasterized and reclassified using different GIS (ArcMap 10.1) tools (Fig. 4).

In a GIS environment and using the weighted overlay summation process, the OLS index was estimated [48] for the different selected criteria by combining the weighted cell values. Each input raster was multiplied by its weight and the results are combined as:

$$\mathrm{OLS}_i = \sum_{i=1}^{n} W_i \times S_{ij} \tag{3}$$

where OLS_i is the total cell index, W_i is a standardized weight ($\sum W_i = 1$), S_{ij} is the suitability value of the ith cell for the jth raster, and n is the number of cells in each jth raster. The total OLS_i indices were reclassified through the use of natural breaks (Jenks) in GIS to develop the final OLS map for the entire West Bank. Furthermore, the developed OLS map was validated based on the existing olive area at different governorates. Finally, combined mapping between (1) OLS map and rough grazing areas (2) OLS map and Oslo areas was conducted to identify potential sites for future olive expansion in the West Bank, Palestine.

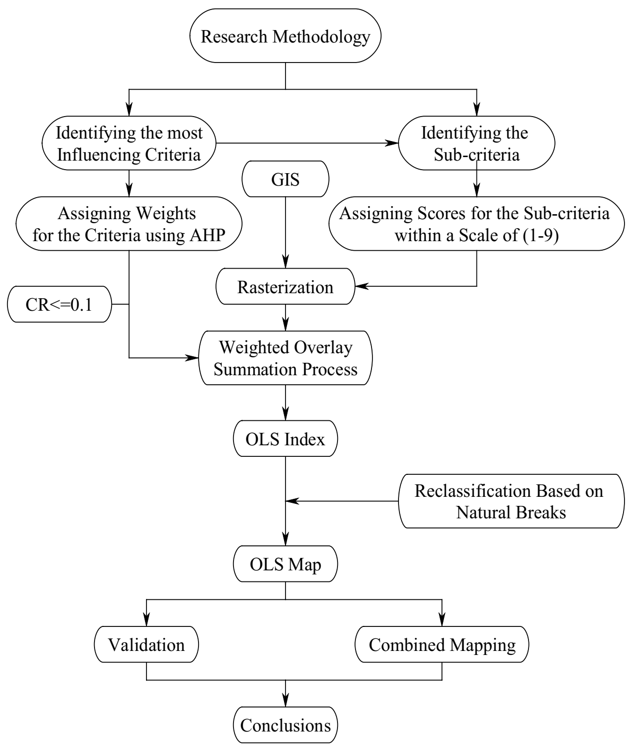

Fig. 3. General methodological framework.

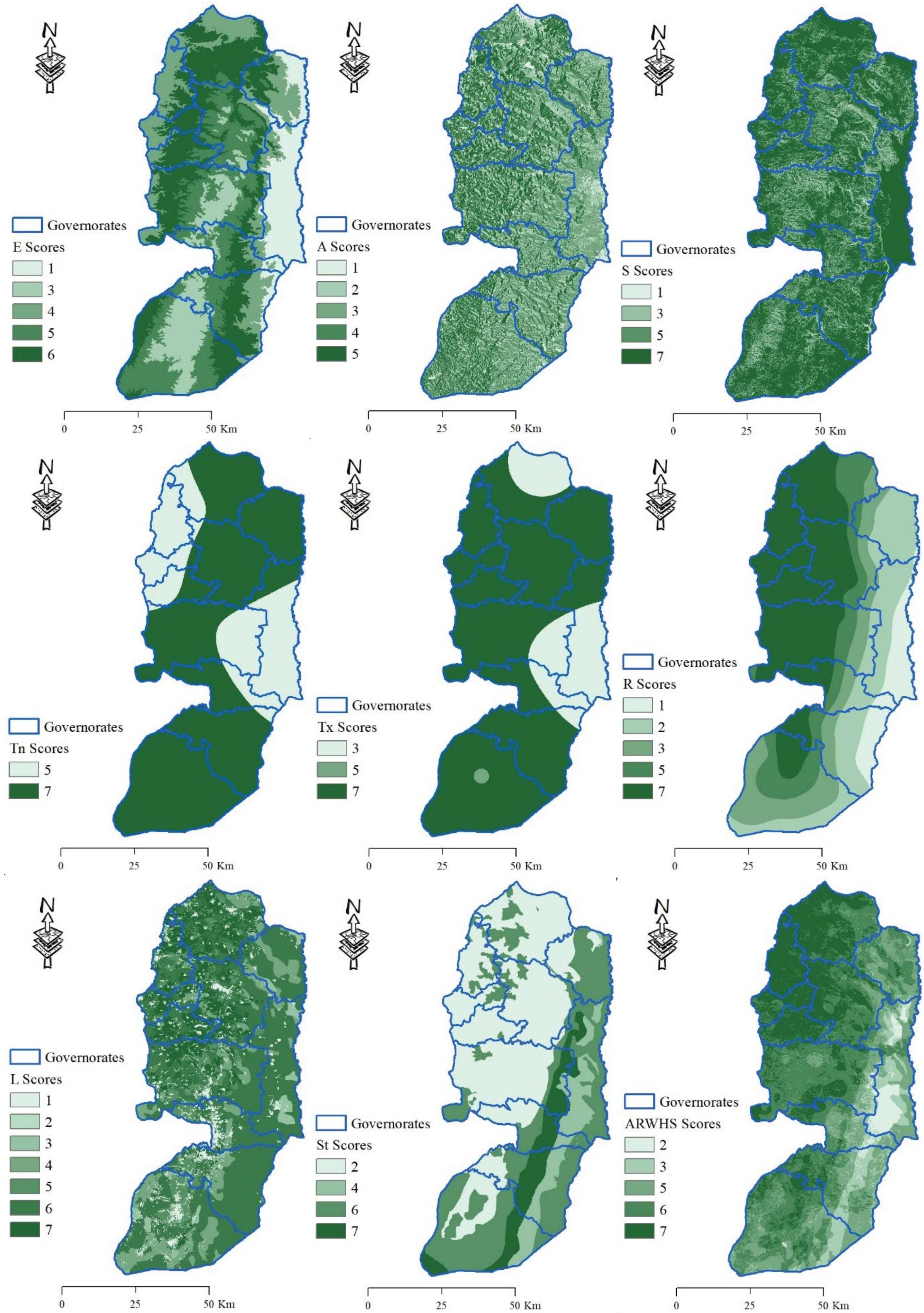

Fig. 4. Scored input-data rasters of the 9 criteria for OLS mapping.

Table 3
Olive scores assigned for the value classes for the West Bank

#	Criteria	Sub-criteria	Suitability value
1	Elevation (m)	–375–0	1
		0–250	4
		250–500	6
		500–750	5
		>750	3
2	Aspect (°)	–1 (flat)	1
		0–67.5 (north, northeast)	2
		67.5–157.5 (east, southeast)	3
		157.5–247.5 (south, southwest)	4
		247.5–360 (west, northwest, north)	5
3	Slope (°)	0–8	7
		8–16	5
		16–30	3
		>30	1
4	T_{max} (°C)	16–20	5
		20–26	7
		26–30	3
5	T_{min} (°C)	10–14	7
		14–16	5
6	Rainfall (mm/y)	<150	1
		150–300	2
		300–400	3
		400–500	5
		>500	7
7	Land use	Built-up areas/Israeli settlements	1
		Woodland/forest	2
		Rough grazing/subsistence farming	6
		Irrigated farming (supporting vegetables)	3
		Permanent crops (grapes, citrus, etc.)	5
		Olive groves	7
		Arable land (supporting grains)	4
8	Soil texture	Clay	2
		Clay loam	6
		Loamy	7
		Sandy loam	4
9	ARWHS	Very low	2
		Low	3
		Medium	5
		High	6
		Very high	7

3. Results and discussion

Based on the previous approach and depending on the identified OLS criteria, the OLS map for the West Bank was developed. The developed OLS map was classified into five suitability classes; very low, low, moderate, high, and very high (Fig. 5).

The obtained OLS map denotes that areas of high to very high suitability are mostly available in the north-western part of the West Bank. While very low to low suitable areas for olive plantation are prevailing in the eastern part. This can be attributed to the general rainfall spatial distribution (increases northwest and decreases southeast) in the West Bank that highly influenced (weight = 0.38) the developed OLS map. The area percentages of the different OLS classes in the West Bank are shown in Table 4.

From Table 4, it is obvious that about 47% of the total West Bank area is high to very high suitable for growing olive trees. Very low to low suitability areas occupied 30% of the total area, whereas, 23% of the area is under

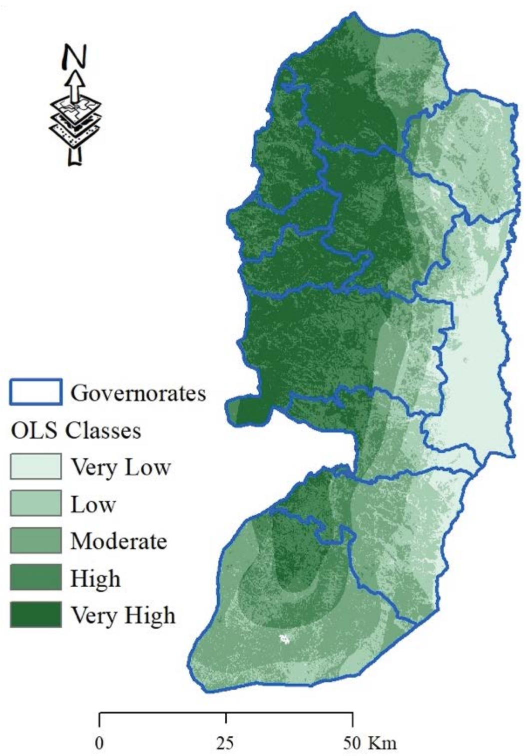

Fig. 5. Developed olive land suitability (OLS) map for the West Bank.

the moderate suitability class. In these areas, any type of common agricultural rainwater harvesting (RWH) techniques (e.g., eyebrow terraces, contour ridges, bench terraces, etc.) are potentially possible to enhance soil moisture content and accordingly olive productivity. Moreover, the area percentages of the different OLS categories in the different governorates are shown in Fig. 6.

From Fig. 6, the high to very high OLS areas totally (100%) occupied 3 out of 11 governorates (Tulkarm, Qalqiliya, and Salfit). Additionally, more than 70% of the total areas in Ramallah, Nablus, and Jenin governorates are under high to very high OLS classes. This indicates the high potential expansion of olive tree plantation in these governorates to increase rainfed olive production in the West Bank, Palestine. However, Jericho and Tubas are the two least suitable governorates for olive plantation, where the very low to low suitable areas occupied 96% and 76%, respectively, of the total governorate area.

To verify the applicability of the developed OLS map, the area of the existing olive tree plantation in the different West Bank governorates are compared with the highly (high to very high) OLS areas (Table 5). Results indicate that the existing olive trees are mostly prevailing in the governorates of Salfit, Jenin, Tulkarm, Nablus, Qalqiliya, and Ramallah, where the area of the existing olive trees ranges between 17% in Ramallah to 44% in Salfit. At the same time, these governorates were identified as highly suitable for growing olive trees, where the area classified as highly suitable for olive trees range between 70% to 100%. Generally, it can be concluded that the existing olive trees are prevailing in the governorates where further expansion of olive tree plantation is still possible to increase rainfed olive trees area in Palestine. Moreover, this good overall match between the existing olive and highly OLS areas indicates that the used approach (including the selection of different criteria) is valid to develop a rainfed OLS map in the West Bank, Palestine.

Table 4
Areas (%) of the different OLS classes in the West Bank

OLS class	Area (%)[a]
Very low	11.5
Low	18.7
Moderate	23.1
High	20.0
Very high	26.7

[a]Area of each OLS class to the total area of the West Bank.

Further analysis was carried out to assess the distribution of potential rainfed olive trees based on the political situation in the West Bank. As per the Palestinian-Israel peace process agreement (known as the Oslo accord), the West Bank has been divided into three areas: A, B, and C. The different areas were agreed to have a different status. Area A is fully controlled by the Palestinian National Authority (PNA); Area B is under the control of both the PNA and Israel; and Area C (which contains the Israeli settlements) is completely under Israel's control [26]. Areas A and B (where most Palestinians are living) form about 18% and 22%, respectively of the total West Bank area, whereas area C occupies the remaining 60%. Israel uses its unfair control over area C to defeat Palestinian planning and sustainable development in different sectors among which is the agricultural one. Therefore, this research tries to figure out the highly OLS areas that are located in areas A and B. In these areas, with the limited available resources, Palestinians are struggling to plan and develop the different sectors. Combined mapping between the developed OLS map, governorates, existing olive trees, and A, B, and C areas was accomplished. As a result, the potential for the expansion of olive trees plantation in the future in the highly OLS areas in the different West Bank governorates and A, B, and C zones are obtained (Table 6).

In the different governorates, it is clear that about 52% (1,361 out of 2,623 km^2) of the total highly OLS areas are located in areas A and B. However, the existing olive in areas A and B covers 63% (474 out of 752 km^2) of the total olive planted areas, it just accounts for 18% (474 out of 2,623 km^2) of the total highly OLS areas. Thus, the investment in olive expansion within areas A and B is feasible to enhance olive production in Palestine. On the other hand, the expansion of olive trees in area C is at risk, as it is under control by Israel.

This, in turn, will negatively impact the sustainable agriculture development therein. Further, the presented numbers in the table can help decision-makers to better plan for the investment in the future expansion of olive tree plantation in the A, B, and C areas at the different governorates.

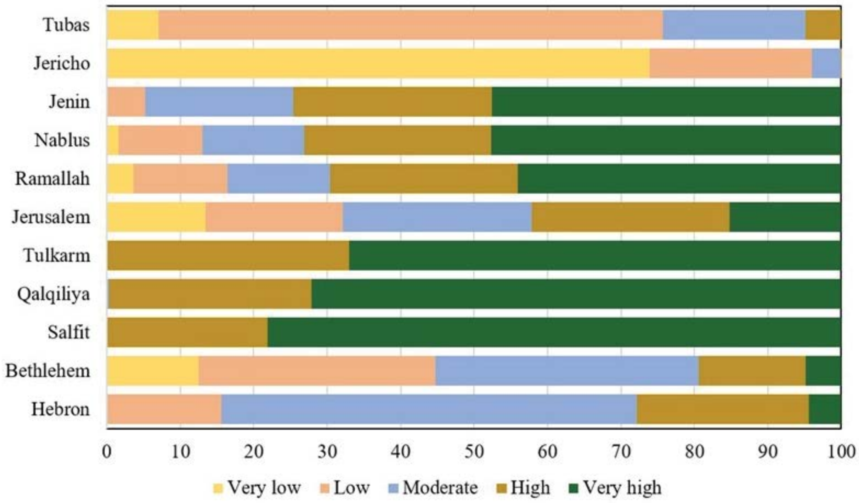

Fig. 6. Area percentages of the five OLS classes in the different West Bank governorates.

Table 5
Existing olive and highly OLS areas in the different West Bank governorates

Name	Area (km^2)			Area (%)	
	Governorate	Existing	Highly OLS	Existing	Highly OLS
Salfit	204.4	90.8	204.2	44	100
Tulkarm	248.0	88.2	247.6	36	100
Qalqiliya	163.4	47.4	162.9	29	100
Jenin	589.7	230.1	439.7	39	75
Nablus	563.8	175.9	414.4	31	74
Ramallah	859.5	146.1	598.1	17	70
Jerusalem	346.8	5.0	145.0	1	42
Hebron	1007.5	28.1	280.2	3	28
Bethlehem	636.3	13.7	122.8	2	19
Tubas	413.4	8.7	19.9	2	5
Jericho	619.1	1.9	0.3	0	0

A final analysis was conducted to assess the distribution of potential rainfed olive trees based on the rough grazing areas that account for 54% of the total West Bank area. It is being partially used for grazing, mainly in the eastern parts of the West Bank. However, this type of land cover is not optimally utilized. Therefore, this land-use type may be changed to olive groves in the future. The highly suitable areas of the developed OLS map intersected with this land type. Results are presented in Table 7.

Results show that the existing rough grazing areas are mostly available in the governorates of Jericho (79%) and Tubas (65%). However, these two governorates are not classified as highly suitable for rainfed olive trees. This indicates that the plantation of olive trees in these governorates is not very feasible. The rough grazing available areas in the governorates of Qalqiliya, Salfit, Tulkarm, Jenin, Nablus and Ramallah, on the other hand, contain highly suitable OLS areas ranging from 58% in Ramallah to 99% in Qalqiliya, Salfit, and Tulkarm. In other words there is a good potential for the expansion of olive tree plantation in the rough grazing available areas in these governorates to enhance rainfed olive production in Palestine.

4. Conclusions

In this study, the olive land suitability (OLS) map for the West Bank was developed. The GIS-based MCDA was used to assess the land suitability for the olive plantation. Nine influential criteria were selected; ground surface elevations, aspect, slope, average annual maximum and minimum temperatures, average annual rainfall, land use, soil texture, and agricultural rainwater harvesting suitability. AHP pairwise comparison matrix was adapted to assign weights for these criteria. The developed OLS map classifies the West Bank into five OLS classes; very low (11%), low (19%), moderate (23%), high (20%), and very high (27%). Among 11 governorates, Tulkarm, Qalqiliya, and Salfit are highly (high to

Table 6
Future potential olive trees plantation in the highly OLS areas in the different West Bank governorates and A, B, and C zones

Name	Highly OLS areas (km^2)			Existing olive in highly OLS areas (km^2)			Potential olive plantation in highly OLS areas (km^2)		
	A	B	C	A	B	C	A	B	C
Ramallah	93.9	166.6	334.1	37.5	47.1	44.1	56.4	119.5	290.1
Jenin	237.6	67.2	132.1	116.2	31.3	57.5	121.5	36.0	74.6
Nablus	107.8	176.5	129.5	36.8	81.6	45.9	71.0	94.9	83.5
Hebron	70.4	108.8	100.7	1.6	3.5	4.6	68.8	105.3	96.0
Tulkarm	54.5	96.0	94.5	21.2	36.5	30.6	33.2	59.5	63.9
Salfit	16.5	40.3	146.9	10.6	24.5	55.8	5.9	15.8	91.1
Qalqiliya	4.2	42.1	115.7	0.3	15.0	32.1	3.9	27.1	83.7
Jerusalem	0.0	17.3	125.8	0.0	0.1	1.4	0.0	17.2	124.4
Bethlehem	14.0	26.6	82.2	2.6	1.4	6.0	11.4	25.2	76.1
Tubas	19.7	0.2	0.0	5.8	0.0	0.0	13.9	0.2	0.0
Jericho	0.0	0.0	0.3	0.0	0.0	0.1	0.0	0.0	0.2
Sub-total	619	742	1,262	233	241	278	386	501	984
Total	2,623			752			1,871		

Table 7
Existing rough grazing and highly OLS areas in the different West Bank governorates

Name	Area (km^2)			Area (%)	
	Governorate	Rough grazing	Highly OLS	Rough grazing[a]	Highly OLS[b]
Qalqiliya	163.4	73.4	72.6	45	99
Salfit	204.4	79.0	78.4	39	99
Tulkarm	248.0	81.4	80.4	33	99
Jenin	589.7	195.1	149.2	33	77
Nablus	563.8	231.9	138.4	41	60
Ramallah	859.5	449.1	261.1	52	58
Jerusalem	346.8	208.9	68.2	60	33
Hebron	1,007.5	489.5	131.4	49	27
Bethlehem	636.3	466.3	48.2	73	10
Tubas	413.4	270.6	12.4	65	5
Jericho	619.1	490.4	0.2	79	0

[a]% of the governorate area;
[b]% of the rough grazing area in each governorate.

very high) suitable (100%) for the plantation of olive trees. More than 70% of the total areas in Ramallah, Nablus, and Jenin governorates are highly suitable for olive plantation followed by 42%, 28%, and 19% in Jerusalem, Hebron, and Bethlehem. In Tubas and Jericho governorates, 76% and 96% of areas respectively seemed to be least (very low to low) suitable for olive plantation.

The combined mapping between the OLS map and A, B, and C areas of the Oslo accord (Palestinian-Israel peace process agreement) indicates that about 52% of the total highly OLS areas are located in areas A and B.

Thus, as these areas administratively are under Palestinian control, future olive interventions in these areas are possible and sustainable. Additionally, the combined mapping between the OLS map and the existing rough grazing areas indicates that the highly OLS areas are located in the rough grazing areas in the northwest governorates. Accordingly, there is a good potential for the expansion of olive tree plantation in the rough grazing available areas in these governorates to utilize such areas and as such enhance rainfed olive production in Palestine.

The developed OLS map in combination with the outputs of combined mapping will help potential stakeholders to identify and prioritize potential sites where olive trees can successfully be planted, especially, in high rainfed potential areas. Finally, more research should be conducted by considering new criteria such as economic, socio-cultural, and environmental conditions and limitations.

To conclude, this research study will help the ministry of agriculture (as a key player) to adopt efficient and sustainable agricultural land use planning to further improve the olive sector in Palestine.

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