RESEARCH PAPER

WADI AGRICULTURE FUTURE INSIGHT: SOIL, TOPOGRAPHICAL, AGRICULTURAL, AND HUMAN PERSPECTIVES IN RAHMA BEDOUIN VILLAGE, HANEGEV HIGHLANDS, ISRAEL

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Received: September 17th, 2021 / Accepted: February 15th, 2022 / Published: March 31st, 2022
https://DOI-10.24057/2071-9388-2021-106

ABSTRACT. The Arab peninsula suffers from intense wadi erosion, which is been expressed by a dense net of wadis that are correlated by overland flows to their surrounded landforms (e.g. loess slopes and rocky grounds). Therefore, the study hypothesized that the wadi reclamation will affect all these correlated landforms. The following objectives were defined: determining the influence of check damming, savanna tree plantation, and grazing on the wadi 'Aboveground net primary production' (ANPP) and determining the influence of wadi ANPP on neighboured area state. Two sites were studied: Project Wadi Atir (PWA) and Rahma. PWA site is located adjacent to Hura Bedouin municipality. The soil is loessial with a dense wadis net. In 2011 the area was leased to the PWA association for its agricultural utilization and conservation. The second site is located on Yeroham hills, Hanegev highland. The area is settled by Bedouin for the El-Azzazma tribe (Rahma village). Half of the area is covered by a 1-2m loess layer, while the other is exposed limestone. Two measurements were carried out to determine the ANPP, manual measurement of the herbaceous biomass weight and SAVI imaging. The finding for both methods indicates a yearly annual increase of 100-150% of ANPP. In addition, a tight correlation was found between the ANPP of the reclaimed wadi and an increase ANPP of 200-450% in the 4m neighboured areal slot. The study of Rahma reveals a positive ANPP feedback loop between the wadi shape, check dams location, and the grazing regime. The study principles may suit wadies all over the Arab peninsula.

KEYWORDS: Wadi agriculture, Rahma Bedouin village, Wadi reclamation and influence on surrounding, Wadies landform

CITATION: Mor-Mussery A., El-Freijat S. (2022). Wadi Agriculture Future Insight: Soil, Topographical, Agricultural, and Human Perspectives in Rahma Bedouin Village, Hanegev Highlands, Israel. Vol.15, № 1. Geography, Environment, Sustainability, p 78-86
https://DOI-10.24057/2071-9388-2021-106

ACKNOWLEDGEMENTS: The Foundation for Conservation of Open Lands®, Israeli Land Authority 2019-2020 and Yeroham municipality. The authors wish to thank Ms. Debbie Goldman Golan and Ms. Hadas Nisan for their encouragement and assistance in Yeroham study, Dr. Stefan Leu. On his highly appreciable assistance in Wadi Attir study and Dr. Gad Ridbo, Field Laboratory Services, Hadera on the implementation of the soil analyses.

Conflict of interests: The authors reported no potential conflict of interest.

INTRODUCTION

The wadies landform represents a highly incised area with a dense net of wadis. Wadi can define as the last phase of the gully erosion evolution, rill, gully (in initial and then after stabilized state), and last one, wadi, (Gong et al. 2011). In the Arab peninsula the wadies area, the wadis, and their connected landform, sized > 2 million km2 and laid mostly over loamy deposits or limestone (Abdel-Fattah et al. 2017), Fig. 1. The wadies areas are settled by indigenous residents mostly from previously nomadic tribes, termed: 'Bedouin' dealing mostly with traditional agricultural practices as grazing (mostly small ruminant and camels) and rainfed crops breeding. The wadies area is characterized by the existence of highly eroded landforms embedded between the wadis as incised loessial plains, salty plains, and rocky grounds, all of them are tightly connected to the existing wadis (Mor-Mussery and Laronne 2020). The integration of the unique three-dimensional shape of the wadi, arid climate (short-termed but intensified rainfall events), reduced vegetation coverage, and thin soil layer leading to flash floods. The floods are resulting in massive sediments removal, an enhanced incision, and rocky karst desertification. As an actively incised landform the size of the wadies area is been rapidly enlarged due to worldwide process, but mostly due to implementation of improper land management and agriculture cultivations in its' neighboured area, resulting, at the end to a reduced agriculture utilization. Recent studies indicate the ability of soil to act as a buffer to

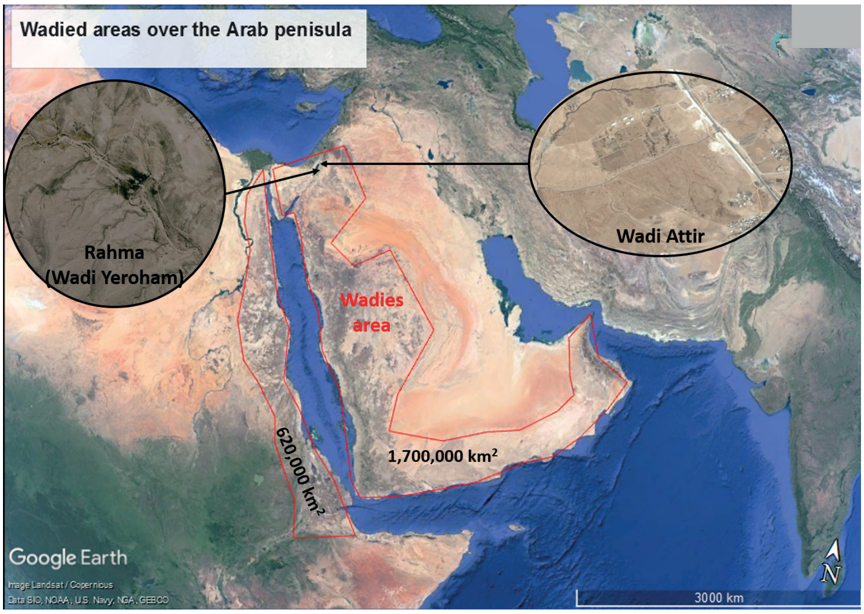

Fig. 1. Wadies areas over the Arab peninsula and the location of the sites of study (GoogleEarth 2020®)

extreme climatic events by the implementation of conservative and rehabilitative practices (e.g. Bai et al. 2019). Therefore, the study hypothesized that adequate agriculture practices implemented in the wadies, such as wadi check damming, implementing of no-tillage and control grazing regimes, and tree plantation may lead to the wadi reclamation and the whole wadies area, and the following objectives were defined: (i) determining the influence of check damming, savanna tree plantation, and management on the wadi reclamation, (ii) determining the influence of wadi reclamation on the neighboured area, and (iii) designing and analyzing in situ cultivation scheme for wadies area reclamation.

MATERIALS AND METHODS

Sites of study

Two study areas were located, Project Wadi Atir- PWA (2011-2019) and Rahma (2020-present).

Project Wadi Atir- PWA

PWA site is located south of the town of Hura on the west bank of Wadi Atir, southern from the Yattir-Eshtemoa confluence and northern to Beer Sheva Valley. The topography is hilly with gentle slopes. The area is underlined by late Cretaceous limestones and composed mainly of loess deposits and rocky ground. The loess was from a quaternary Aeolian source and contained terrestrial clastic sediment, which was formed from wind-blown dust and mainly contained fine particles of silt and clay with about 40% sand (Amit et al. 2006). The area is intensively cultivated by neighboring farmers for cereals breeding and livestock grazing, which resulted in the high incision and dense wadies net crossing it (Mor-Mussery and Laronne, 2020). In 2011, the land was leased to the Project Wadi Atir association for rehabilitation and the establishment of a sustainable arid farming scheme. In 2001 remodeling of the topography was carried by damming previous wadies with check dams, perpendicular to the water flow direction

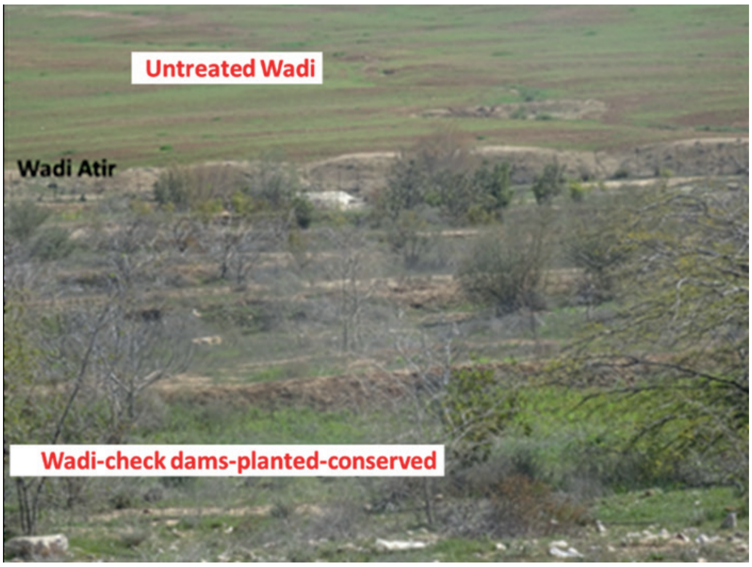

Fig. 2. Wadi Atir site. The check dammed region inside the fenced farm and untreated one, outside the west bank of Yattir stream (2017)

*The savanna trees were from species that are suited for arid regions, as follows. *Acacia raddiana, A. victoriae, Albizia lebbeck, Eucalyptus camaldulensis, Ficus sycomorus, Morus sp., Pistacia lentiscus, Retama raetam, Spartium sp., Ziziphus spina-christi, Ceratonia silique, Punica granatum,* and *Prosopis juliflora*. The trees, which were taken from several nurseries, were 3-4 years old. The trees were planted in a density of 1600 trees ha^{-1} in the 2015 summer.

without interference to the wadi topographic outlines. The site is used to study the influence of check damming, savanna tree plantation*, and different grazing regimes on wadies area fertility changes and rehabilitation (Leu et al., 2020), Fig. 2.

Rahma site of study

Rahma site is located on the eastern bank of Yeroham ephemeral stream adjacent to the estuary to Yeroham valley, Israel. The area is actively incised characterized by a dense coverage of wadies, in initial and stabilized state and wadis confluent Yeroham stream from its' west and south sides resulting by a wide range of intensively eroded landforms, such as loess slopes, rocky grounds, and salty loess plains (the erosion rate was determined by comparison of orthophotos between 2012 and 2020). The area is settled by Bedouin residents belonging to the El Azzazma tribe, specifically to El-Frejat and Zanoon Hamulas (Big family). The area is long-term agriculturally cultivated for rain-fed wheat breeding, and small ruminants and camels grazing by the village indigenous Bedouin farmers that affected the existing landforms. The following landforms and hot plots were selected in Rahma site (Fig. 3).

Data and Methodology

Significance was determined for all measurements by JMP® ver. 15 α=0.1

Aboveground net primary production (ANPP)

The most observable and affecting factor on the rehabilitation state is the change in vegetation patterns, as expressed mostly by the 'Aboveground net primary production (ANPP). Natural changes, such as differences in rainfall or anthropogenic causes such as cultivation changes or afforestation have a crucial influence on soil health and the rehabilitation state of a given area (Helman et al. 2014). To assess the influence of check dams' construction, plantation of savanna trees inside the 'wadi terraces' (the embedded area between two adjacent check dams), and grazing regime, in Wadi Attir site, two ANPP measurements were carried out. A manual one of herbaceous biomass weight and 'Soil adjusted vegetation index (SAVI) imaging from Landsat 8*. The measurements were carried out on three representative wadies, one without wadi terraces, one with check dams and grazing, and one with check dams without grazing. Two analyses were carried out, one aimed to determine the ANPP changes in the wadies over time, and one analyzed the influence of the existing vegetation of the wadi on its' neighbored area. The calculated values were compared to the reference plot outside the wadies area (Leu et al. 2020).

The manual measurement was carried out when the biomass reached its' maximal size and began to dry (February-March) by randomly annuals harvesting using an iron frame of 20X 30cm six samples for each treatment. The herbaceous biomass was harvested, dried in an oven, 650C for 48hours, and weighted (Sava, 1994).

The manual ANPP measurements were carried out using six randomly selected replicates.

* The SAVI is calculated as follows: (1+L)(NIR-Red)/(NIR+Red+L)while the 'NIR' is the intensity of the emitted Near InfraRed wavelength, 'Red'- is the intensity of the emitted 'Red' one, and 'L' is canopy background adjustment parameter, here L=0.5 (reflects arid regions). The SAVI was calculated from Landsat 8 satellite, pixel size equals 30 X30m. Here for each analyzed wadi, the maximal calculated SAVI of the summer (July-September) was reduced from the spring one (February-May) hypothesizing the calculated value represents the net herbaceous biomass production (Helamn and Mor-Mussery, 2020). The number of replicates ranged between 6 to 15 replicates, based on landform size and Landsat imaging pixel.

Soil properties

Hanegev highlands suffer from extreme drought between 2017 and 2020, which prevents analysis of ANPP, therefore, we focused on soil fertility. The following soil properties were studied: Soil organic matter (SOM), Electrical conductivity (EC), Total Nitrogen, Relative humidity (RH). From each location four, randomly selected samples were taken and analyzed in Hadera Ministry of Agriculture Lab Services. The measurement procedures are summarized in Table 1.

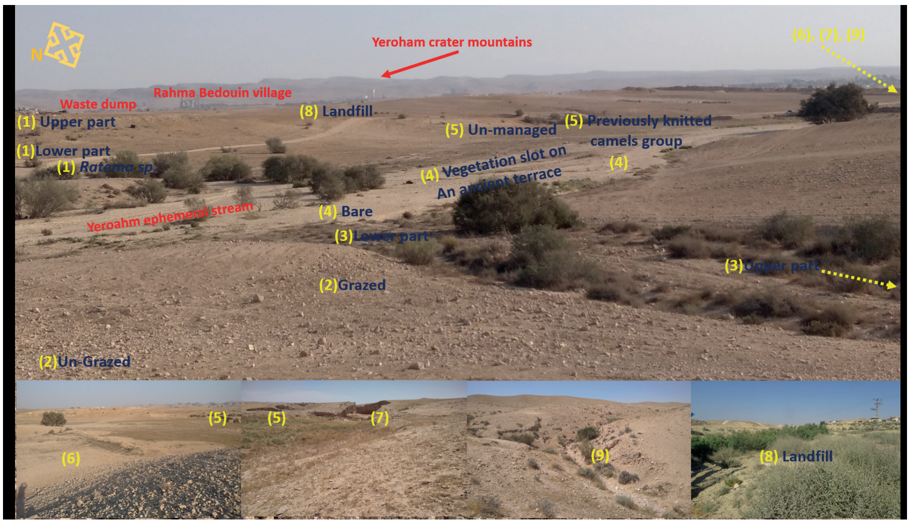

Fig. 3. Rahma site of study, landforms, and hot plots for the study

(1)- Loessial young wadi with a comparison of its upper and lower parts and in an area settled with *Ratema* sp. plots (2)-Rocky slope grazed and un-grazed plots (3)- Mature wadi on limestone, (4) Ephemeral stream bare and on a soil covering an ancient Byzantine terrace plot (5)- Managed aquifer recharge (MAR) cultivated area, which harvests the flood-water from the wadis, built by local Bedouin farmer, unmanaged and with previously knitted camel group plots, (6)- wadis' floodplain, (7) Yeroham ephemeral stream estuary, (8)- Wadi that was used as landfill for construction waste resulted in a salty loess plain with invasive plant species, (9) young wadi on limestone

Table 1. Soil properties measurement procedure

Soil property	Procedure
SOM (Soil organic matter)	Soil samples were washed with 1% HCl and left in an oven at 105ºC for 24 hours. The dry soil was weighed and transferred to a furnace (650ºC) for 8 hours and then weighed again. The difference corresponds to organic matter concentration (Ben-Dor and Banin, 1989), which calculates organic carbon by multiplying by 0.58 (Carter and Gregorich, 2007) (n=4).
EC	Thirty grams of soil mixed with double-distilled water (1:1) were shaken for 15 minutes at 25°C and then filtered (Whatman No.1) until a clear liquid solution was obtained. Conductivity and pH were tested in this solution.
NH_{4+}, NO_{2-} (for N_{Total})	Content was determined by extraction with 1M KCl followed by colorimetric analyses with Nessler reagent for the soil NH_{4+} Diazotizing reagent for the NO_2. The reading of each of the samples was taken in a spectrometer with a wavelength of 420 nm for and NH_{4+} and 543 nm for the NO_{2-} (APHA, 2017)
Relative humidity (RH)	was determined by comparing the weight of the soil samples and the permanent wilting point based on soil physical properties according to soil texture, before and after drying overnight at 105ºC for 48 hours (Campbell, 2008)
Soil particles size (sand content)	Filtering the soil samples using 1000μm net to take out the organic matter and stones. Using 56 μm for separating the sand particles. Adding water solution with Na_2CO_3 to separate the silt and clay. Drying the phase and weighting (Kroetsch and Wang, 2008).

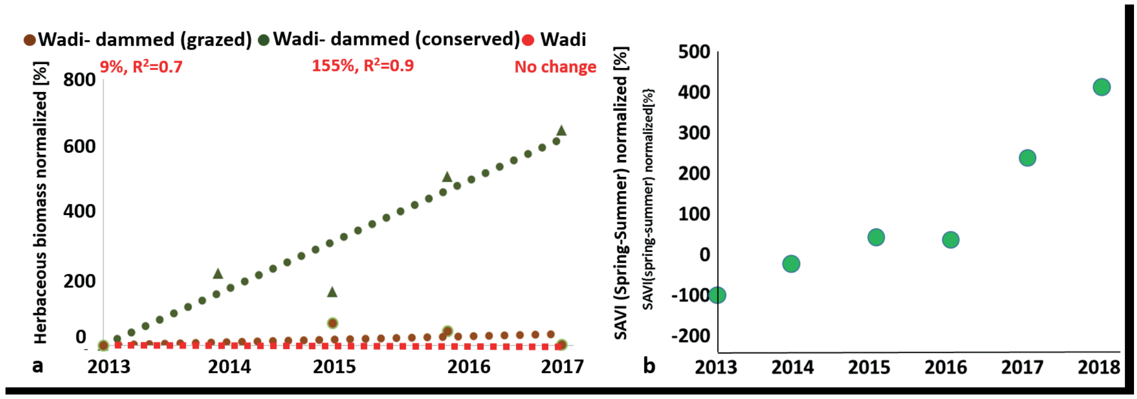

Fig. 4. The ANPP changes over the wadis in Wadi Atir between 2012 and 2018 normalized with reference plot a- Herbaceous biomass [Kg m^{-2}], b- Landsat SAVI for the Wadi. Check dams (conserved)

RESULTS

The ANPP changes over time in the different wadies at PWA sites

In both methodologies for ANPP determination, the manual one and the SAVI-based one, the combination of check dams' construction and conservation from grazing leads to a steep yearly increase of the ANPP in the wadi. Nevertheless, the calculated increase from the SAVI data is lighter than the manual one, possibly to the SAVI calculation limitation (Helman et al. 2020). An important character of the utilization of check dams can be observed from the SAVI data (Fig. 4a), during the 3 years after construction, the yearly ANPP change was lighter than the following years, possibly due to the use of heavy machinery to build check dams. In addition, a light ANPP increase of 9% was additionally observed in the grazed wadi, which possibly can be explained by reduced grazing intensity (Fig. 4b).

The influence of wadi reclamation on surrounding area productivity

The correlation between the wadi ANPP of a conserved wadi terrace with constructed check dams and the ANPP of an adjacent area can be observed by comparison of the herbaceous biomass weights in a representative wadi terrace, its' adjacent aerial slots, and embedding area. Such

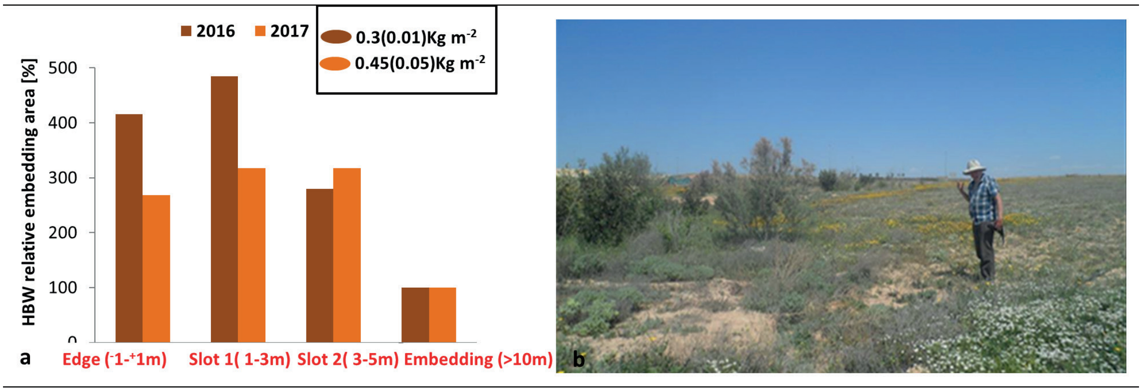

Fig. 5. The influence of representative wadi terrace on the herbaceous biomass of neighboured area.

a- Empirical data from February 2016 and 2017, b- Visual view (Each aerial slot width 2m, 'edge'- wadi terrace edge, 'Embedding- the embedding area, in the upper rectangle- the herbaceous biomass in the wadi terrace, in brackets- the ±SE) correlation was not found before 2016, possibly to lack of influence the in first years after the check damming (Biomass weight- Fig. 5A and local color- Fig. 5b).

The influence of the different wadies area landforms on soil properties

To determine the influence of the different wadies landforms on the soil properties, a crucial step for suiting the breeding crop and the adequate cultivation, three soil samples were randomly taken from each wadies landform covering the profile from surface until 20cm depth based on Figure 3 scheme and wide range of measurements were carried out on each sample including potassium, phosphorus, ammonium, EC, organic matter, granular content, and relative humidity. The main findings are summarized in Table 2. The grazed rocky slopes are characterized by higher organic matter and nitrogen content compared to the un-grazed ones. In addition, higher moisture and fine particle content were observed (possibly due to the animals trampling, Mor-Mussery et al. 2020b), (Table 2, 'a'). The plot was settled by a knitted camel group characterized by higher soil fertility and fine particles content ('b'). The Bedouin-managed aquifer recharge (MAR) demonstrates higher organic matter content compared to undammed wadis flooded plain ('c'). Younger wadi in loess plain has higher sand content and less organic content than adult one located in an area with exposed limestone and loess deposits (rocky slope), ('d'). Similar soil properties were found in the area over the ancient Byzantine agriculture terrace slot in Yerohan ephemeral wadi, except a little higher moisture content in the agriculture terrace slot and Nitrogen ('e'). The *Ratema sp.* in the loess wadi increased the organic matter, moisture, and fine particles contents reflecting high ecosystem engineering activity ('f').

Results summary

a. The afforestation and ecological management of the wadis raised their and their surrounding area productivity.

b. The wadies area is characterized by versatile landforms that are correlated by overland flows.

c. The landform versatility is accompanied by different soil chemical content.

d. Successful reclamation of wadis has to take into consideration the local soil, geographic outlines, flora, fauna, and previous agriculture utilizations (from ancient eras and Bedouin ones).

e. Grazing is taking an important role in the wadi ecosystem's functioning.

DISCUSSION

The high rehabilitative efficiency of wadi with adequate constructed, savanna tree planted and grazing managed check dams over wadi in an arid area is well demonstrated in PWA findings. Nevertheless, implementation of the determining principles for wadi reclamation in the wadies area of Rahma is highly challenging, due to its' active cultivated manner, the existence of ancient agriculture ruins (e.g. stone dams, wells, and agriculture terraces) that have to be conserved, and ecological 'hot spots' (Mor-

Table 2. The influence of different wadies landforms, ancient agriculture ruins, and Bedouin practices on soil properties

	EC	RH[%]	Ntotal[mg kg^{-1}]	SOM[%]	Sand[%]
(a) Influence of grazing on a rocky slope					
Grazed rocky slope	0.75(0.1)	30(1.0)	85.3(30.0)	1.5(0.2)	53(10)
No-grazed rocky slope	1.4(1.0)	37(3.05)	44.9(7.0)	0.2(0.2)	61(3.0)
(b) Influence of knitting camel group for a month					
Untreated	0.55(0.06)	39(1.45)	42.8(16.3)	3.05(0.45)	61.7(5.0)
Knitting plot	1.44(0.04)	29(2.5)	65.75(6.45)	16.9(14.2)	54.7(2.0)
(c)Managed aquifer recharge area vs. Wadis flooded plain					
Managed aquifer recharge	0.55(0.06)	39(1.45)	42.8(16.3)	3.05(0.45)	61.7(5.0)
Wadis flooded plain	N/S	N/S	N/S	0.7(0.6)	48.7(6.0)
(d) Loess wadi (young) vs. Loess/lime stone wadi (adult)					
Loess wadi (young)	0.3(0.16)	27.6(0.5)	19.6(12.5)	2.1(0.24)	85.7(9.0)
Loess/lime stone wadi (adult)	1.1(0.12)	39(1.1)	59.6(5.9)	2.7(0.35)	72.0(3.7)
(e) Vegetation slots over ancient agriculture terraces vs. Untreated area(Yeroham stream)					
Untreated area	0.25(0.02)	26.7(0.85)	40 (*)	0.3 (*)	86.7 (*)
Vegetation slots	0.6(0.04)	29.0(0.9)	51.5(9.25)	0.9 (0.5)	88.7 (2.0)
(f) Influence of Ratema sp. on the soil properties of the loess wadi					
Loess wadi (young)	0.3(0.16)	27.6(0.5)	19.6(12.5)	2.1(0.24)	85.7(9.0)
Loess wadi(young)-Ratema sp.	0.44(0)	29.6(0)	12.1(0)	2.3(0)	78.7(0)
EC- Electrical conductivity (salinity), RH- Relative humidity, N- Nitrogen, SOM- Soil organic matter four samples per each plot, '*'- one sample mix of 3 plots, In brackets- ±SE					

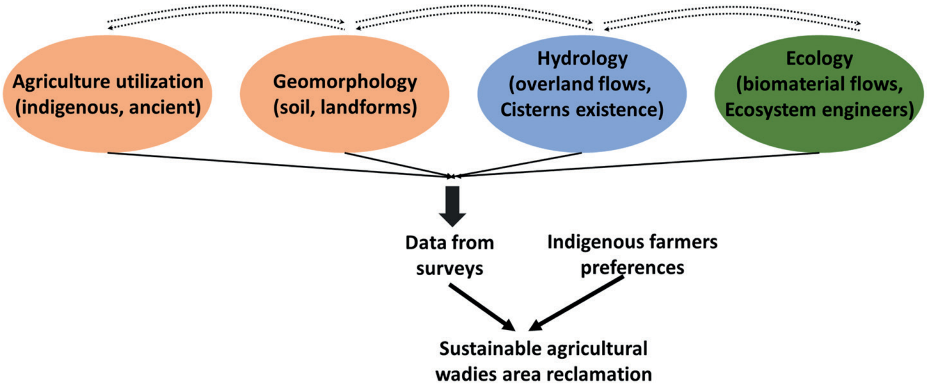

Fig. 6. Scheme for a successive wadis area reclamation

Mussery et al. 2020a). The steps for a successive agricultural reclamation of the wadies area are summarized in Fig. 6.

The first phase is surveyed by experts aimed to suit the reclamation design to the wadis area. Four surveys are suggested, including ecology, hydrology, geomorphology, and agriculture utilization, each of them has to be treated with relation to the other ones. Here, each unit will be described with samples from this and other studies.

(i) Ecology survey.

The first study action is an examination of the biomaterial flows over the wadies and their connected landforms. The close view reveals that the wadis with the expanded vegetation up-slopes are characterized by grazing on the slopes, while in the other without the grazing the vegetation expansion up-slopes missed. This finding enables us to illustrate the whole mechanism that correlates the wadi shape, wadi terraces, grazing on slopes, and vegetation expansion up slopes, as follows. The formed ecological feedback loop in the wadi terraces as empirically approved in the PWA site is been intensified by floods enriched with animal excrement and nutrients (Mor-Mussery et al. 2020b) (Fig. 7).

The intensification of the ecological feedback loops in the wadi terraces caused in turn to vegetation expansion (and land rehabilitation) up-slopes. As many wadies areas, the Rahma area was intensively cultivated at ancient times by its' indigenous residents, nevertheless, due to temporal landform changes, lack of documentation by its' farmers, and lack of maintenance or abandonee of these plots, the principles of reimplementation of these cultivations or land management practices are missing and the only way to determine the principles is indirectly by a detailed analysis of the ecological pattern of these plots (Jackson 2011).

Except for the determination of the biomaterial flows over the wadi, analysis has to be carried out to determine the local ecosystem engineers. Data from this survey may be used for increasing the crop yield, as plantation the *Rathem sp*. that form fertile soil patches and host pollinators for crops even in the drought season (Fig. 8a). An additional unique landform characterized by sandy soil in wadies area is Nabakcha. Until recently the Nabakha was concerned as a seasonal landform caused by an accumulation of sand from wind storms over the shrub root system (Li et al. 2020). Nevertheless, recent studies claim it can be used for agriculture utilization after its' stabilization with organic matter (Fig. 8b).

(ii) Hydrology survey

The hydrology survey aimed first and foremost to design a sustainable agriculture utilization with minimal additive irrigation (Hrachowitz et al. 2011). In addition, water pools and cisterns have also high landscape and tourism importance (Akash 2012). The study was carried out in drought years, therefore cisterns were not located, and nevertheless, oral data from local Bedouin locate several cisterns in the site of study at rainy years.

(iii) Geomorphology survey

The geomorphology and soil affect the ecology of the area and, as a result, agriculture utilization. In the wadies area, the geomorphology also play important role in the

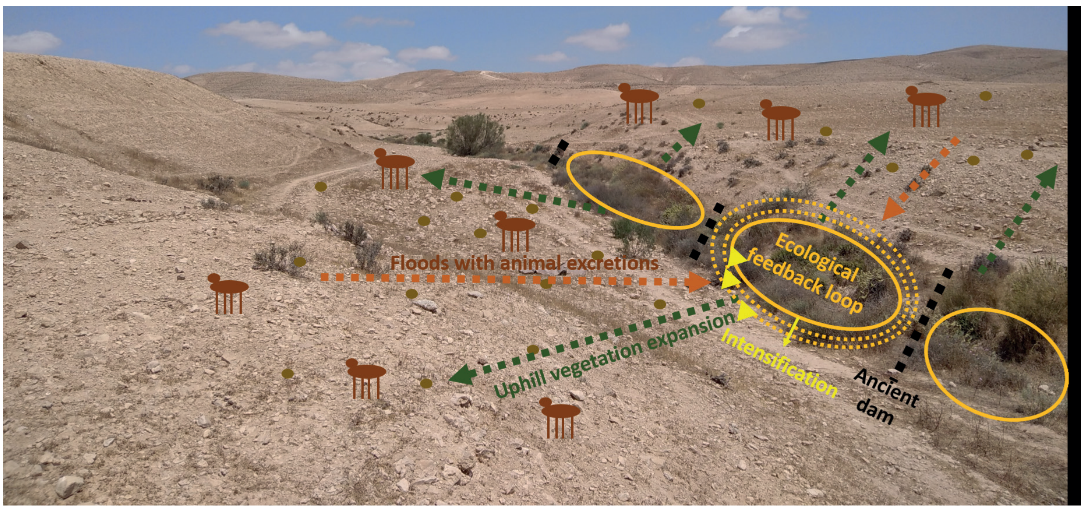

Fig. 7. The high ecosystem functioning in the wadi caused from the channel, banks patterns, and the dam's existence. This functioning may be intensified by an adequate grazing regime in the wadies area leading to up slopes vegetation expansion and rehabilitation of the whole area. Rahma, 7/2020

landscape visibility for tourism (Elassal 2020). Therefore, here we studied plots with different soil characters as loessial, sandial, and regolith ones with a wide range of natural and remodeled landforms (e,g. Fig. 8e, 8f)

(iv) Agriculture utilization survey

Adequate cultivations and land management practices may accelerate the whole wadies area rehabilitation by increasing the soil water holding capacity (Mahe et al. 2005), CO2 sequestration into organic matter (Bai et al. 2019), and soil thickness by an enhanced bedrock weathering (Pawlik et al. 2016). Therefore, we studied first and foremost plots that caused from current Bedouin cultivations and land management practices as ones used to temporarily locate and transport knitted camel groups on the soil (Fig. 7g). Using natural arid regions suited trees for breeding orchard trees and groves with a reduced supplementary irrigation need (Norfolk et al. 2013; Shen et al. 2017) (Fig. 8h).

In addition, analysis of ancient archaeological ruins is crucial, because ancient dams over wadi may form a highly productive environment due to the high stone coverage (Bruins et al. 2019). The high vegetative slot along Yeroham stream with high moisture and sediments contents (Fig. 3, Table 2) may indicate the potential of planting fruit trees suited to wet regions (Hüneburg et al., 2020). In addition, reclamation of such ancient agriculture terraces may increase their current influence on soil fertility until reaching sustainable agriculture utilization of the land (Fig. 8c& 8d).

Finally, after collecting the data from the surveys, it is crucial to build a sustainable cultivation design with

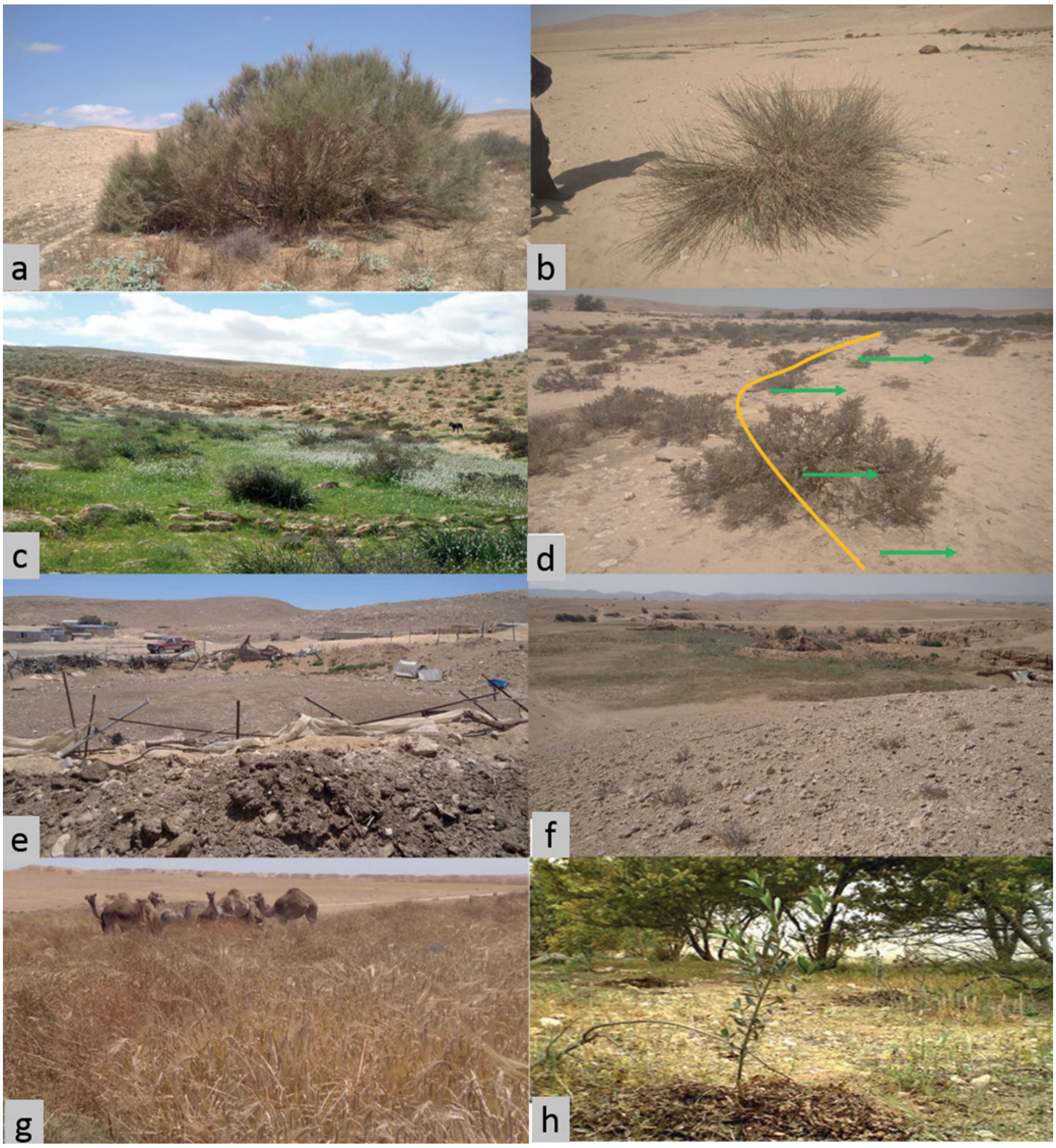

Fig. 8. Ecological, ancient agriculture facilities utilization, wadies areas landforms, and indigenous Bedouin agriculture knowledge hot plots with potential for commercial and sustainable agricultural utilization in wadies arid areas

Ecological: (a) Nebakha settled by Anabasis articulate may be used as a fertile island for crop breeding in sandy wadies area. (b) The Ratema sp. may serve as successful ecosystem engineers to cultivated areas by forming fertile patches and places for bee grazing and other fruit tree pollinators. Ancient agriculture facilities utilization: (c) Reclaimed Byzantine wadi dams may be used for agriculture (Shualim wadi, Photo by S. Leu, 2019), (d) Ancient Byzantine agriculture terrace with current influence on their neighbored area soil fertility, for managed aquifer recharge (MAR) crop breeding. Wadies area landforms (e) Gully terraces, which represent the area between adjacent check dams along the wadi, may be used for agriculture using the flood-water for irrigation, the loess check dams are stabilized by manure layers (f) A Bedouin managed aquifer recharge (MAR) area on wadies flooded plain for cereals breeding, Indigenous Bedouin agriculture knowledge (g) Acacia victoriae that sheltered grove trees, Yattir farm 2016. (h) Temporary locating and transporting of a knitted camel group over the cultivated area, which serves as 'manure management action' (Norris et al. 2020) aimed to increase the soil fertility of the cultivated area.

the indigenous farmers based on suitability to the wadis areas, profitability, and their preferences as previously demonstrated on grazing (Mor-Mussery et al., 2019).

CONCLUSIONS

Wadies area is a highly sensitive landform. From one side, they are intensively incised, which requires intermediate intervention to halt the incision, but from the other side, such an intervention must not damage the picturesqueness of habitat due to the unique geographic outlines, ecological flows, existent of ancient remains, and the indigenous farmers, which increases its' tourism value. Therefore, only sustainable agriculture reclamation of these areas will conserve their uniqueness and supply work to their inhabitants.

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