The Suitability of the Vallerani System

A case study of the Jordan Badia

BSc Thesis by Joren Verbist

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Abstract

The Al Majeddyeh watershed is located in the Jordan Badia and is severely degraded area, because of overgrazing and conventional ploughing. In small portions, land is rehabilitated through the implementation of Sustainable Land Management practices (SLM). Two of these SLM's are water harvesting techniques. On upstream hillslopes, micro water harvesting is practiced in the form of the Vallerani System. In the downstream, macro water harvesting is practiced. All the water obtained in the upstream areas is harvested here. However, an upstream-downstream conflict occurs, since both water harvesting techniques compete for water. In addition, the Vallerani System requires large investments and encounters the obstruction of market formation. This thesis aims at gaining insights on the suitability of the Vallerani System. An upstream downstream approach has been applied to identify the components of the watershed. Their linkages are qualitatively described in terms of vegetation, erosion, and water. Experts opinions and estimates have been used to model the water storage capacity decay of a Vallerani System over time. Literature research and surveys were done to determine possible implementation bottlenecks from a policy and social perspective. This thesis showed that the Vallerani pit decays over time, reducing its water storage capacity. By showing this, a model was made which showed the possibility of expanding the Vallerani System throughout the watershed while maintaining a targeted amount of discharge in the downstream. The suitability was determined based on these findings. Since the thesis researches a significant knowledge gap and measurements were unavailable due to Covid-19 outbreak, it was not possible to validate the results. The research was validated by the experiences of local SLM-experts. A future validation research is therefore highly recommended.

- *Vallerani - Water Harvesting – Badia - Sustainable Land Management* - Al Majeddyeh, *Jordan* -

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1. Introduction

It is estimated that 380-620 million people in drylands are affected by desertification, this was mostly in South and East Asia, North Africa and the Middle East (IPCC, 2019). Drylands cover 46.2% of the total land mass and homes 3 billion people. Roughly 36 million hectares of rangelands in Jordan, Iraq and Syria are degraded (Karadsheh, Akroush, & Mazahreh, 2012). In 2012 the economic loss due to degradation of the Jordanian rangelands (Badia) was 0.46 percent of the GDP (Karadsheh, Akroush, & Mazahreh, 2012). Agriculture is the main employer for refugees, therefore it is valuable from a humanitarian perspective (See Annex 1: General Background Jordan) (Thiombiano, 2017).

Causes of desertification in Jordan

The combination of urbanization, increase of population (See Annex 1: General Background Jordan) and eat patterns, led to an increased demand for livestock products. Reactively, the amount of livestock increased as well. Therefore, the pressure on land grew, contributing indirectly to desertification.

The change of land ownership and usage has also affected the landscapes. In 1950 the rangelands, Badia, were declared as government land without exclusion, meaning open access (Karadsheh, Akroush, & Mazahreh, 2012). This has led to the tragedy of the commons. Grazing intensified and resulted in overgrazing. The rangelands lost much vegetation, leaving the soil vulnerable for the sub-optimal arid climate, with powerful winds and heavy rainfall events, resulting in erosion.

In addition, in some parts of Jordan, land ownership was established by ploughing, during the governmental surveys. Surface rocks were removed during the ploughing. These rocks were crucial for protecting the soil from wind and water (Karadsheh, Akroush, & Mazahreh, 2012), making the land vulnerable for wind and water (splash and run-off) erosion.

Water Harvesting

Rainfed agriculture in Jordan has limited available water resources making it one of the most vulnerable sectors to climate change, since climate change leads to more extreme events (IPCC, 2007). Therefore, land and water conservation measures to increase available water, such as water harvesting are an important adaptation to climate change (Al-Bakri, Suleiman, Abdulla, & Ayad, 2010), since water harvesting systems have the potential to increase the resilience of the landscapes and involved livelihoods (Dile, Karlberg, Temesgen, & Rockström, 2013).

Water harvesting is the process in which rainwater is caught instead of spilled away, optimizing the total amount of available water. Water could be wasted via run-off and/or evapotranspiration. Therefore, it is key to reduce these. Water harvesting could be done either on macro scale or micro scale. The scale relates to the dimensions of the catchment. Micro-catchments are on a farm scale, whereas macro catchments could be on watershed scale (Oweis, Hachum, & Kijne, 1999).

The additional application of water harvesting is to increase bio-mass production (e.g. yield), either using irrigation or by infiltration.

Al Majeddyeh

The village of Al Majeddyeh is located in a watershed near Amman (Figure 1). The watershed has experienced land degradation caused by the same drivers as explained before. The area is roughly ten square kilometres.

The climate is arid Mediterranean. It is classified as steppe, Bsh in the Köppen classification. The watershed receives less than 130 mm precipitation per year. The average yearly temperature is above 18 degrees Celsius (See Annex 1: General Background Jordan).

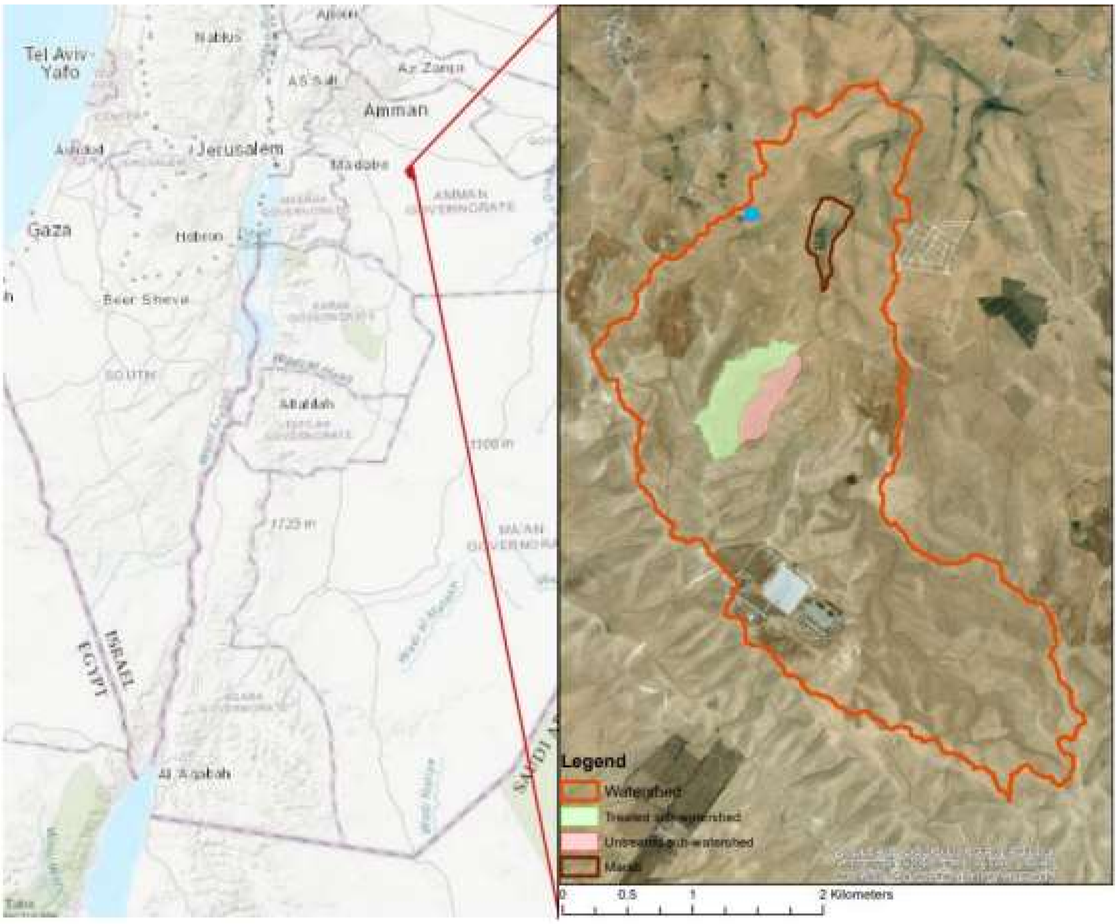


Figure 1: Location of Al-Majdiyya and the research site in the Jordan Badia. Orange outline is the study area. Green indicates the treated sub-watershed, Red the untreated sub-watershed. Brown is the Marab (Goos, 2019).

The dominant economic activity is semi-nomadic agro-pastoralism. These are herders who have a permanent residence, but graze their livestock at different locations. In addition, they plant barley, to feed their livestock. The farmers live in villages likewise Al Majeddyeh.

The watershed has typical upstream-downstream relations. A floodplain (Marab) is located in the downstream. Here, water from the whole watershed is concentrated and harvested. This is considered macro water harvesting (Oweis, Hachum, & Kijne, 1999). A limited area (≈ 12 hectares), as pilot plot, in the upstream area is treated with micro water harvesting structures. The Vallerani System is practiced here.

The Vallerani Plough, named after its Italian inventor, is a modified plough. The conventional plough only loosens up the soil by turning it. This modified plough creates ditches on the contour lines. The ditches are either continuous or intermittent. The plough can construct four hundred pits (micro basins) per hour (Antinori & Vallerani, 1993). The equivalent is one or two hectares per hour. This is a huge improvement considering that traditionally, eighty man/days are required for one hectare (Gammoh & Oweis, 2011).

There are two seedlings of native shrubs, *Atriplex halimus*, planted in the pit constructed by the Vallerani plough in the Al Majeddyeh watershed. The basins hold the water, allowing the seedlings to grow (See Figure 2). Throughout this thesis, the combination of a onetime ploughed Vallerani Pit and therein two seedlings of *Atriplex halimus* is named the Vallerani System.

Figure 2: The working of the Vallerani System (Haddad, Exploring Jordan's Rangeland Transition: Merging Restoration Eperiment with Modeling - A Case study from Al Majdiyya Village, 2019)

The majority of the watershed experiences land degradation. The Vallerani System might improve the watershed. However, since the Vallerani Systems harvests water, it will reduce the water influx in the downstream (Goos, 2019).
In addition, the Vallerani Plough has several complexities in the socio-economic context. The plough and additional machinery are expensive for a farmer (Akroush & Boubaker, 2015). So, support by people and institutions might be an issue as well. Nevertheless, the Vallerani plough is able to plough vast amounts of lands in a short time, reducing the relative costs (Gammoh & Oweis, 2011).

The potential of the Vallerani System is huge, but the system has some possible constraints. The possible constraints are the deterioration of the macro-water harvesting system, the social context, and the bio-physical boundary conditions.

The Research

Problem definition:

The lack of water harvesting, and sustainable management has led to increased land degradation and decrease in biomass productivity, in the Al Majeddyeh watershed.

Research Objective:

To improve the likelihood of adoption for the Vallerani System within the social and biophysical context of Al Majeddyeh watershed by assessing its suitability.

Generic Research question

To what degree is the Vallerani System suitable to improve the Al Majeddyeh watershed?

For further application, the Vallerani System needs to have a certain suitability with respect to the land. A distinction is made between the constraints, i.e., the necessary conditions, and the additional conditions which further facilitate the implementation and potential success of the Vallerani System (FAO, 1980):

- Constraints that must be met:
  A. Implementation of the Vallerani System may not deteriorate the downstream water influx by more than 10% for a yearly 11.5mm rainfall event.
  B. The local bio-physical circumstances must allow implementation of the Vallerani system, e.g., slopes gentle enough to be ploughed. A full description, particular to the Al Majeddyeh watershed, is given in the paragraph Boundary Conditions.

- Additional conditions for further facilitation:
  The Vallerani System is expected to have the following positive impact:
  1. a similar or higher fodder yield than previous land use,
  2. support by local farmers,
  3. Economic improvement of the watershed,
  4. reduced risk of flood damage downstream,
  5. reversing/decrease of land degradation (sustainable).

The degree of suitability based on the constraints and conditions met, is shown in Table 1.

Table 1: Table showing the determination of the degree of suitability.

Degree of suitability		**Constraints**		**Additional conditions**				
		A	B	1	2	3	4	5
NS	Non-Suitable	Not all met		Irrelevant				
S0	Minimally Suitable	Both met		None met				
S1	Slightly Suitable	Both met		At least 1 met				
S2	Moderately Suitable	Both met		At least 2 met				
S3	Well Suitable	Both met		At least 3 met				
S4	Greatly Suitable	Both met		At least 4 met				
S5	Highly Suitable	Both met		All met				

This suitability assessment does not take the economic cost into account. In other words, i.e., the present assessment is not based on the ability of a farmer to pay for implementation of the Vallerani System. This approach has been chosen since ICARDA and NARC (National Agriculture Research Centre) already paid for the costs of the first rehabilitation in this specific area.
Nevertheless, these aspects are separately discussed and to some extent studied in this thesis because they can be considered essential for future suitability assessments.

Specific research questions

From the above discussion, it is clear that a profound local knowledge of the watershed and the expected benefits are necessary to consider the implementation of the Vallerani System. Hence the following specific research questions were formulated for this thesis:

1. What are the components of the watershed and what are their (inter)relations?
2. To what degree is the Vallerani System bio-physically suitable in the watershed?
   a. What are the boundary conditions?
   b. What is the effect of time on the water storage capacity of a Vallerani pit?

3. To what degree is the Vallerani System suitable given the local social economic context?

To answer these questions a case study of the Vallerani System for the Al Majeddyeh watershed was performed. This included researching literature, conducting a survey among local farmers, interviewing land management experts and observing the research site. These data were collected and analysed as a basis to formulate model of the dynamic behaviour of the Vallerani System including the decrease in water capacity of the ploughed pits and the mitigation measures necessary to maintain capacity over time. This model has been transferred to ICARDA, the company where the research and internship in Jordan were performed.

2. Materials and methods

The Al Majeddyeh watershed area has been chosen because the area has been exposed to land degradation. Additionally, the site is most representative for the middle Badia conditions of Jordan and has been chosen based on bio-physical representativity features (Strohmeier S. M., 2020) (Haddad, 2019) (Annex 1 Geography & Climate). It is an existing research site of the International Centre of Research Dry Areas (ICARDA). Therefore, there is data and research available concerning the various attributes of the area. Also, local population has a hospitable and cooperative attitude towards scientists. In addition, ICARDA has implemented Sustainable Land Management (SLM) practices. This creates an opportunity to compare, evaluate and further research them.

Watershed

Firstly, the watershed was categorized by upstream, midstream, and downstream. Within these categories there were different landscapes (sub-components) identified. Secondly, an upstream-downstream approach had been used to determine the effect of a (sub-)component on another downstream (sub-)component. These relations have been expressed in three aspects: vegetation, erosion, and water.

These two steps were done and substantiated by field observations and literature research.

Curved Number Method

The Curved Number Method was used to quantify the influx of water in the downstream. The run-off depth of the watershed is obtained from the rainfall depth and given response characteristics, which are related to the land use and its relative area.

Bio-Physical Applicability of the Vallerani System

Boundary Conditions

The boundary conditions of the Vallerani were interpreted as strictly bio-physical. These conditions give the fullest potential of the system in terms of area. The question that was asked is, what conditions should a field/terrain meet for a successful implementation of the Vallerani System. To find these conditions local land management experts of ICARDA, who witnessed and designed the construction of the Vallerani System, were consulted. Also, additional literature research was done.

Vallerani Decay Model

The water storage capacity of a pit is 100% just after construction. This means that if the pit is unfilled, it has 100% water storage capacity. The capacity is 0% when the pit is fully filled, till original surface level. The model does not take possible saturation of a filling into account. The height of the ridge (Figure 2 and Figure 5) does not influence the water storage capacity of a Vallerani Pit, since water would rather spill sideways (Figure 3) (Sprong, 2019) (Strohmeier S. M., 2020).

Figure 3: Vallerani Pit stored with water (Sprong, 2019)

The development of the water storage capacity of a Vallerani Pit over time was predicted by listing all the influencing processing. The processes were identified by local SLM-experts, who are involved in monitoring the Vallerani System. These were than ranked in terms of assessability and significance by the local SLM-experts. The ranking was from one till five. Whereas, one was nihil effect or very hard to assess. And a five was the contrary, very significant or very well assessable. These rankings were then summed, and every process with a total rank of plus four, was taken into account in the model.

The local-SLM experts estimate for each included process a lower limit, an upper limit, and a best estimate. This is done so there is a bandwidth which illustrates the uncertainty. The best estimates come closest to the perceived reality since the SLM-experts used estimates that are observed most often. This should result in a rough pattern/trend.

The model is thus based on the information of the local SLM-experts (Haddad, 2020) (Strohmeier S. M., 2020). Between these data points, interpolation is done. The type of interpolation is also based on the experiences of SLM-experts. In addition, it is considered that after ten years, the processes are in equilibrium, so extrapolation is reasonable (Strohmeier S. M., 2020).

The trapping efficiencies decrease as the Vallerani Pit is filled further. This will be considered by the model. This results in decreasing decay of the water storage capacity.

All the processes are then summed per year. This is used for a cumulative function over time. This is calculated to litre per pit, and then expressed as a fraction of the Vallerani Pit volume. One minus this fraction equals the fraction of the water storage capacity.

This function is extrapolated using the Excel trendline function. The type of extrapolation is exponential with intercept, since this gave the lowest R^2, thus the most accurate.

Processes

Erosion

The eroding forces in the area are wind and water. Part of the resulting erosion will be trapped by a Vallerani Pit. Therefore, only a portion of the eroded material remains in the pit.

Wind erosion

Wind erosion is not measured in the watershed. Dust storms with significant sediment load occur rarely (Strohmeier S. M., 2020). However, especially the trapping efficiency is low as dust layers trapped in the pit (Vallerani structure) can re-mobilize. The amount of sediments originating from wind is observed by the local SLM-experts. The experts estimated this by their observation of fine sand. This process is considered static.

Water Erosion

The erosion from water has been modelled for different scenarios (Haddad, 2019). The thesis of Mira Haddad, a local SLM-expert (ICARDA), is used to determine the temporal degree of erosion. This literature quantifies erosion in ton per hectares per year. Therefore, the effective catchment area of a Vallerani Pit is calculated, giving the number of pits per hectare. This is then used to determine the erosion per pit.
Haddad's model is based on a degraded scenario, which resembles in this thesis's model year zero. In this thesis's model, year ten equals erosion rates of the restored scenario of Haddad's model.

Biomass

The volume of a pit is partly taken by biomass. The seedlings dominantly influence this process at the beginning – at the later stage grasses and recruited vegetation occupies certain volume of the potential water capturing volume.

Above ground: Plant Volume

The planted seedlings have a certain volume. This volume cannot be occupied by water anymore, reducing the water storage capacity of the pit. The volume of the biomass increases over time, as the plants continue to grow. This volume also increases proportionally as the number of plants increase. In this system, two seedlings are planted.
Furthermore, the plants also reproduce. This means that there will be new young plants growing in the pit. These recruitments also take up volume, which is also considered by this aspect.

On the ground: Plant litter/residue

The plants will have leaf fall and or broken branches as result of the wind. The volume of this relates to the stage and volume of the plant.

Trampling

Animals are able to affect the water storage capacity of a pit by trampling. This is process where the pressure of the legs and hooves damages the micro water harvesting structure, and soil will fill the pit. See Figure 4.

Figure 4: Livestock trampling a Vallerani Pit (Haddad, 2020).

Grazing

Trampling can be caused by the grazing of the livestock of the local agro-pastoralists (Figure 4). This is done in systematic way, since livestock is kept within a certain area, until sufficiently grazed and then to the next area. This means that every pit will be grazed, and the chance of trampling is significant

Wildlife

Wildlife (e.g. rabbits) are able to damage the pits. However, this is too much lesser extent because there is a small population of wildlife. And this population does not affect the research site systematically.

Geo Technical

This section concerns the physical qualities of a pit.

Initial instability

The pit is constructed by ploughing. This comes with an initial instability, since angles are large, and soil is loose. Consequently, a pit can partly collapse, reducing the water storage capacity.

Social Context

Literature

Literature was used to determine the local and the policy support for the Vallerani System. However, in terms of policy (institutional) support there was little research done specifically for the Vallerani System. Therefore, literature on water harvesting in general throughout Jordan was investigated. The findings of this literature are applicable on the Vallerani System. This was confirmed after correspondence with the author (Sixt, 2020).

Survey

A survey was conducted to determine the personal support for the Vallerani System by local farmers. The interviewees were farmers who live in Al Majeddyeh and whose fields are located in the watershed. The objective of the first question was to group/identify the interviewees, in order verify the relevance of the person with respect to the Vallerani System. This support was based on a broad interpretation of improvement (e.g. more enjoyable view or economic improvement). The remaining questions were answered ordinal and in relative terms (see Annex 4: The Personal Questionnaire).

3. Results

Watershed Context

Upstream – The Catchment Area

The upstream is a hilly area with slopes between 2% and 30%. Many hilltops are found, these have little to no soil depth and have 30% rockiness. They cover roughly 150 hectares. Also, there is some urban areas, which covers 56 hectares (Figure 1).
The total upstream area with respect to the Marab is approximately 720 hectares. It functions as a catchment area hence the larger area with respect to the downstream. In this area there are two different landscapes: the Vallerani landscape and the degraded landscape.

Degraded Landscapes

The majority of the catchment area is characterized by poor barley cultivation (Haddad, 2019). This area is 690 hectares (including hilltops). Overgrazing and conventional ploughing initiated the land degradation. Less vegetation made the landscape vulnerable for crusting and erosion. The eroding forces are water (rainfall) and wind. This results in rill forming, splash erosion and dust storms. In addition, there is decreasing fodder for livestock, declining the condition and resilience of local agro-pastoralists.

The Vallerani Landscape

This landscape is a rehabilitated version of the degraded landscape. The Vallerani landscape is 30 hectares of which 12 hectares have been used for Vallerani Pits. This difference is due to the presence of hilltops and gullies, which are unsuitable for construction of Vallerani micro water harvesting structures (Goos, 2019) (Haddad, 2019).
The rehabilitation process started on 4 November 2016. Firstly, there is ploughed with the Vallerani Deflino Plough (Gammoh & Oweis, 2011), constructing Vallerani Pits.
Secondly, in December 2016, the pits were seeded with seedlings of the *Atriplex halimus* (Haddad, 2019). *Atriplex halimus* is a native perennial salt bush. This plant is tolerant to salinity and droughts (Essafi, et al., 2010). In addition, *Atriplex halimus* can be cultivated as fodder (Valderrhbano, Mufioz, & Delgado , 1995).
A micro basin has a water storage capacity between 0.500 m^3 and 0.600 m^3 (Gammoh & Oweis, 2011). Ideally, the dimensions (Figure 5) are 0.3m, 0.5m, 0.3m and 4.5m, respectively, height or depth, top width, bottom width and length. The lateral spacing varies from 0.5m and 1m. The spacing between the contours is roughly 7m (Fukai, 2019).

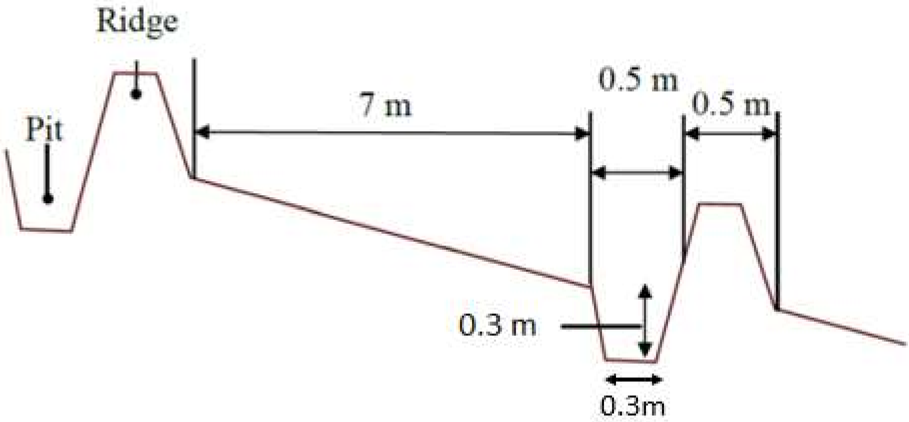


Figure 5: Schematic view of the Micro Water Harvesting structure, the Vallerani Pit (Fukai, 2019).

Comparison

As the below sections will explain. The Vallerani System reverses land degradation by trapping water and sediments, by doing so it allows for the growth of vegetation and decreases erosion.

Water

Mira Haddad (ICARDA) modelled the Vallerani landscape. The model does not consider the initiation period, when the pit is still able to harvest water. The model therefore only takes the vegetation into account and no grazing. The average surface run-off has been modelled for 23.49 mm/year and 19.07 mm/year for respectively degraded and rehabilitated (Haddad, 2019). This means that once the Vallerani pit is filled up, the run-off decreases with roughly 20%.

Erosion/Sedimentation

The same model concluded that the average soil loss is 3.30 ton/ha/year and 1.27 ton/ha/year for degraded and rehabilitated, respectively (Haddad, 2019). Thus, the Vallerani landscape is able to decrease erosion by approximately 50% once it has reached the equilibrium, when the pit is totally filled.

Vegetation

As Figure 6 shows, the results of Vallerani restoration is visible by more vegetation with respect to the degraded landscape.

The barley cultivation in the degraded landscape is able to provide maximally 2 months of fodder for livestock (Haddad, 2019). The Vallerani System offers a good alternative since *Atriplex halimus* gives similar or higher dry and fresh weight, and is longer available (since *Atriplex halimus* is perennial) compared to barley (Abu-Zanat, Titi, Akash, & Al-Antary, 2020) (Al-Satari, 2014).

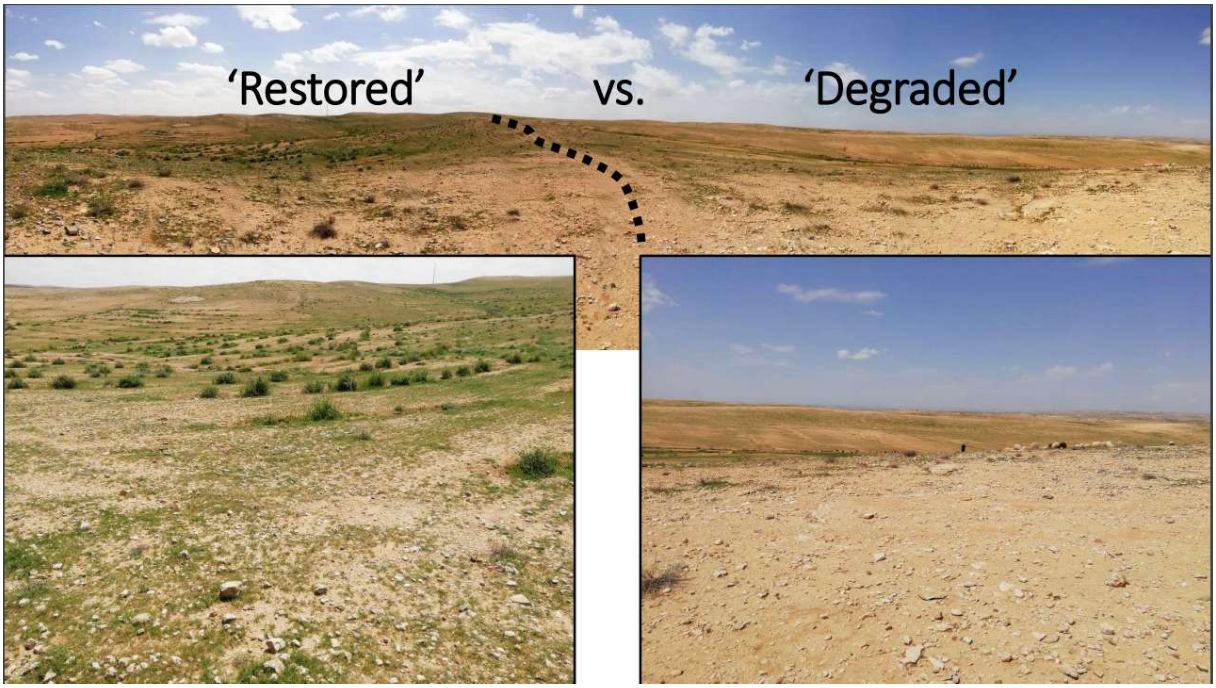


Figure 6: Picture showing the difference in vegetation for Vallerani landscape (Restored) and degraded landscape (Haddad, 2019)

Midstream - Gullies

The gullies function as waterways, concentrating the water from the catchment/uplands to the downstream Marab. Within this component, there are two types, namely the degrading and rehabilitated.

Degrading

The original gullies have little to no vegetation and zero gully plugs. These gullies are mostly located in the degraded landscapes. They are formed naturally as result of lack of vegetation cover and high peak run-off, since there are no upstream interventions e.g. water harvesting. Therefore, the gullies are still eroding and thus expanding. This leads further land degradation and to the endangerment of neighbouring roads and farmlands.

Rehabilitated

The majority of treated gully is found in the Vallerani landscape towards the Marab (downstream). The Vallerani micro water harvesting structures capture some run-off water, decreasing peaks. Therefore, gully plugs, which function as sediment traps, are able to hold instead of being washed away. Gully plugs are made of stone, imported from other areas. This gully is, at some locations, visibly filled with sediments, showing the effect of the plugs (Figure 8). It is also re-vegetated to prevent erosion on the sides. On other further upstream locations, the stone bed is visible, showing no soil depth (Figure 11).

54 gully plugs were established in 2017 (Haddad, 2019). These structures are in two forms, either gabion (Figure 7) or stones (Figure 8). 43 of the structures are from stone and 12 are gabion. Gabion check dams are mostly found downstream, in order to safeguard the Marab, and at locations in the gully which are most unstable. This is often the case where gullies join (Steven, 2017). The maximum

height of a structures is half of the gully depth, ensuring that water remains in the gully (Steven, 2017) (

Figure 7: : Picture of a gabion gully plug (Verbist, 2020)

Figure 8: Picture of a stone gully plug with flourishing vegetation and trapped sediments (Verbist, 2020).

Annex 2: Gully Plug Design).

Comparison

Water

Figure 9 shows the run-off events on 28th of February 2019, for the treated and untreated gullies. The untreated gully (right) has a much higher peak than the treated/rehabilitated gully (left). The catchments areas for the treated and untreated gullies are respectively, 30 hectares and 14.5 hectares (Figure 1), while the run-offs were respectively, 6.4 millimetre and 12.0 millimetre (Goos, 2019). Note that the picture of the rehabilitated gully has a Vallerani landscape in the background, which also contributed to the steadier run-off with respect to the untreated area.

Figure 9: Run-off event of 28th February 2019 for untreated gully (right) and rehabilitated gully (left) (Goos, 2019)

Erosion

Figure 10 shows the collapse, little soil, and a rock bed of an untreated gully. This indicated that erosion is significant for an untreated gully, compared to a treated gully, which has no visible rock bed and no side collapses (see Figure 8).

In addition, Figure 11 shows the difference of the two gullies directly in terms of sedimentation and indirectly in terms of erosion. The rehabilitated gully (right) has no visible sedimentation, while the degrading gully (left) has much more sedimentation, which is also coarser. The pattern of sedimentation shows the junction has much more coarse sedimentation, showing the dominant influence of the degrading gully and the

Figure 10: A picture showing the rock bed of a untreated and collapsed gully (Haddad, 2020)

effectiveness of gully plugs in combination with upstream micro water harvesting.

Figure 11: Picture showing the difference in sedimentation, in a downstream junction. Left coarse sediments coming from untreated gully and right, little sediments coming from treated gully (Verbist, 2020)

Vegetation

The vegetation in the rehabilitated gully is flourishing with respect to the untreated gully. This can been seen from difference in vegetation (green) from Figure 8 and Figure 10. In addition, the plants here created microclimates, allowing the improvement of bio-diversity (Figure 12).

Figure 12: Vegetation in a treated gully (Haddad, 2020)

Downstream – The Marab

Al the water from the catchment area is concentrated here. The water for agriculture is therefore maximized. The slope in this area is less than 2%, resulting in a low velocity of the water. In addition, water spreading structures are made to optimize infiltration, practically meaning surface irrigation.

Figure 13 : Image showing the flooding of the Marab (Extracted from Google Earth Pro on May 20th 2020, satellite image date is Jan. 7th 2019 (Verbist, Strohmeier, & Haddad, 2020)).

This is realized with only rainwater.
The spreading structures are designed as a barrier for flowing water, while at a specific locations the barrier is lower, allowing the water to flow to another field (Figure 13) (see Annex 3: The Marab Design).

Siltation decreases the effectiveness of these dikes and decreases the fertility of the soil, since the sedimentation is not as fertile as the soil in the Marab. Therefore, erosion is undesired **(erosion)**.
This system has led to a significant increase in yield. The barley cultivation is nowadays 5-7 ton/ha **(vegetation)** (Verbist, Strohmeier, & Haddad, 2020). The average traditional hill slope barley cultivation is 50-60kg/ha (Haddad, 2019).
Due to this high realized yield, it is considered that most of the water is demanded downstream, in the Marab **(water)**.

The Curved Number Method

The curved numbers were obtained from literature (Goos, 2019). The land use types were identified as urban, hilltop, streams, rangeland and the Marab. Their curved number and significance were respectively 90 and 5.6%, 90 and 18.10%, 98 and 1.2%, 85 and 73.80%, 85 and 1.30%. The weighted average curved number is 86.341 (see Annex 5: The Curved Number Method).

On the seventh of February precipitation was 11.5 millimetre. This is considered a yearly medium rainfall event and was therefore chosen as measure for the run-off depth. The run-off depth was seven millimetres, based on the rainfall event and the weighted average curved number. By multiplying the run-off depth with the upstream watershed with respect to the Marab, a total volume of 47,061,273 litres was obtained (Annex 5: The Curved Number Method).

Smaller rainfall events were not chosen since these resulted in zero run-off depth. The curved number method requires a precipitation of roughly 6 millimetres or higher.

Biophysical Applicability

The Bio-Physical Applicability consist of two aspects.
The boundary conditions are needed to assess the potential of the Vallerani System. The result is visualized in Figure 14. The figure also corresponds with the land use types (Goos, 2019) but indicates the potential areas for the implementation of Vallerani System as well (Strohmeier S. M., 2020).
The subsequent section describes the next aspect: the effect of time on the Vallerani System.

Boundary Conditions

Slope

The slope needs te be less than 20% (Strohmeier S. M., 2020), otherwise the chance of accidentally tipping the machinery is too large. This heavily depends on the tipping point of the tractor (because of its height), which is used to pull the plough.

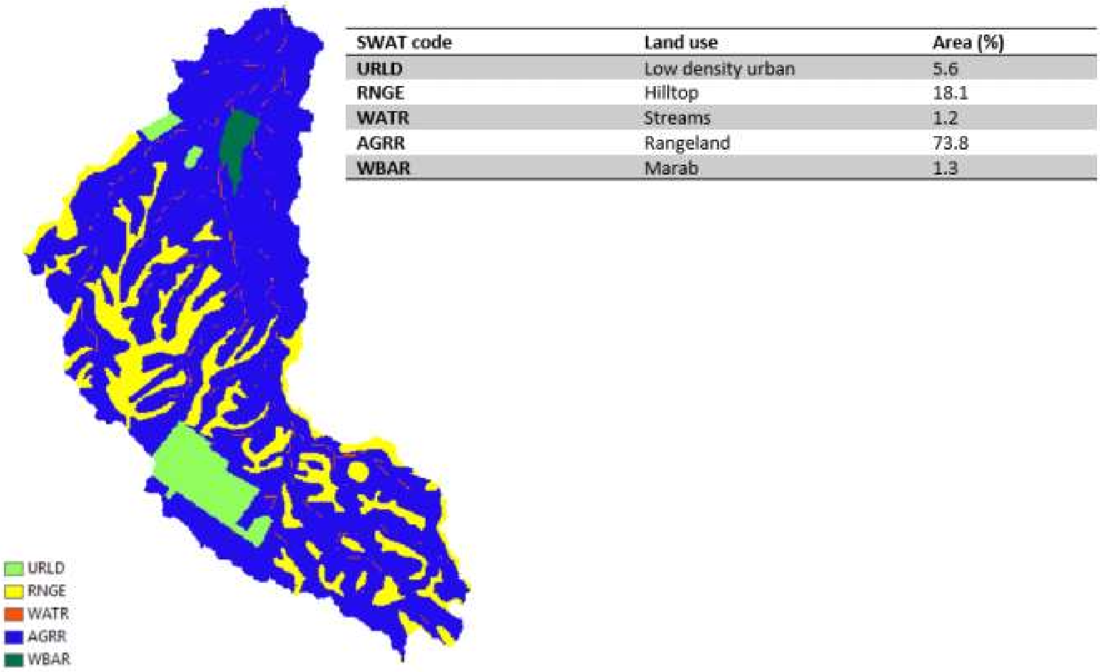
Soil

The plough has a certain plough depth. The plough rips into the soil and cannot touch the rock bed. This rocks otherwise break the blades of the plough. The Vallerani plough, as used in Jordan Badia, requires a soil depth of minimally 40 centimetre (Vallerani & Vallerani, 2013).
The rockiness of this soil may not exceed 30%, since this will also damage the blades too much (Strohmeier S. M., 2020).

The minimal required soil depth and maximal percentage of rocks excludes all hilltops.

Climate

This aspect is influenced by the plants that are used in the system. Therefore, plants that are planted should be suitable for this climate. Rainier climate allows for the planting of more water demanding plants.
In Al Majeddyeh, the yearly precipitation is less than 130mm. This climate resulted in the choice of the planting of indigenous and drought resistant species: *Atriplex halimus*. Since the climate is uniform in the watershed, it assumed that the particular system is not limited by the climatic conditions.



SWAT code	Land use	Area (%)
URLD	Low density urban	5.6
RNGE	Hilltop	18.1
WATR	Streams	1.2
AGRR	Rangeland	73.8
WBAR	Marab	1.3

Figure 14: Map showing (indicated by blue) the potential area for the Vallerani System in Al Majeddyeh watershed (Goos, 2019) .

Vallerani Decay Model

Ranking

The processes that were listed, were ranked by the local SLM-experts (Strohmeier S. M., 2020) (Haddad, 2020) (Annex 6: Expert Justification Ranking). Overall rankings below 4 are not considered. This excludes trampling by wildlife (Table 2).

Table 2: Outcome of the ranking based on the opinion of local SLM-experts (Haddad, 2020) (Strohmeier S. M., 2020).

CATEGORY	DRIVERS	ASSESS-ABILITY	SIGNIFICANCE	OVERALL
EROSION	Wind erosion (creep/saltation)	2	2	4
	Water erosion	4	4	8
BIOMASS	Above Ground (Atriplex)	4	3	7
	Soil layer (litter)	3	2	5
TRAMPLING	Grazing	2	5	7
	Wildlife	1	2	3
GEOTECHNICAL	Initial instability	2	2	4

Processes

Wind erosion

Most soils are crusted, therefore only light particles can be lifted by the winds, and easily remobilized. Wind erosion is thus small and hardly trapped. It is set at 2mm, 5mm, 10mm per pit per year and 10%, 20%, 30% trapping efficiency, for respectively lower limit, best estimate, and upper limit (Strohmeier S. M., 2020).

Water Erosion
The values used for water erosion are originate from the model of Mira Haddad (ICARDA) (Haddad, 2019). Based on Figure 15 and expert consultation the lower limit, best estimate and upper limit were set at 2.6, 3.35 and 4.1 ton per hectare per year for the degraded scenario, which equals the year 0. The restored landscape resembles year 10, and it's values are 0.9, 1.2, 1.5 ton per hectare per year for respectively, lower limit, best estimate and upper limit (Haddad, 2020). There has been chosen to linearly interpolate these two points.

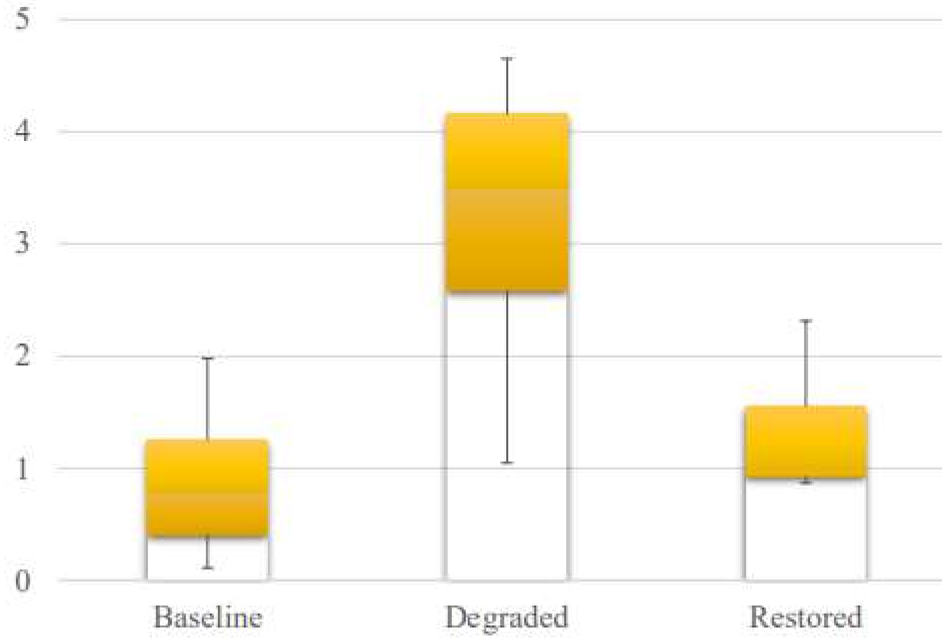


Figure 15: A graph showing the rate of erosion in ton/hectare/year for baseline, degraded, and restored landscapes (Haddad, 2019)

Based on the dimensions of a Vallerani Pit (Figure 5), the total amount of pits per hectare were calculated as roughly 242. In order to express this to volumes, the average soil density was estimated to be 1.3 kilogram per litre (Strohmeier S. M., 2020).

Biomass: Litter & Plant
According to the SLM-expert (Strohmeier S. M., 2020), it was observed that litter correlates with the volume of the plants. Therefore, litter volume was given as a varying percentage of the plant volume and based on the stage of the plant. In addition, the expert stated that the planted seedlings are mature in the fifth year, and that afterwards there were only reproductions (Strohmeier S. M., 2020). Consequently, the volume increases rapidly in the first five years, the pre-mature period (see Figure 16) and flattens out afterwards. However, that is a first approximation and requires validation in the

field.

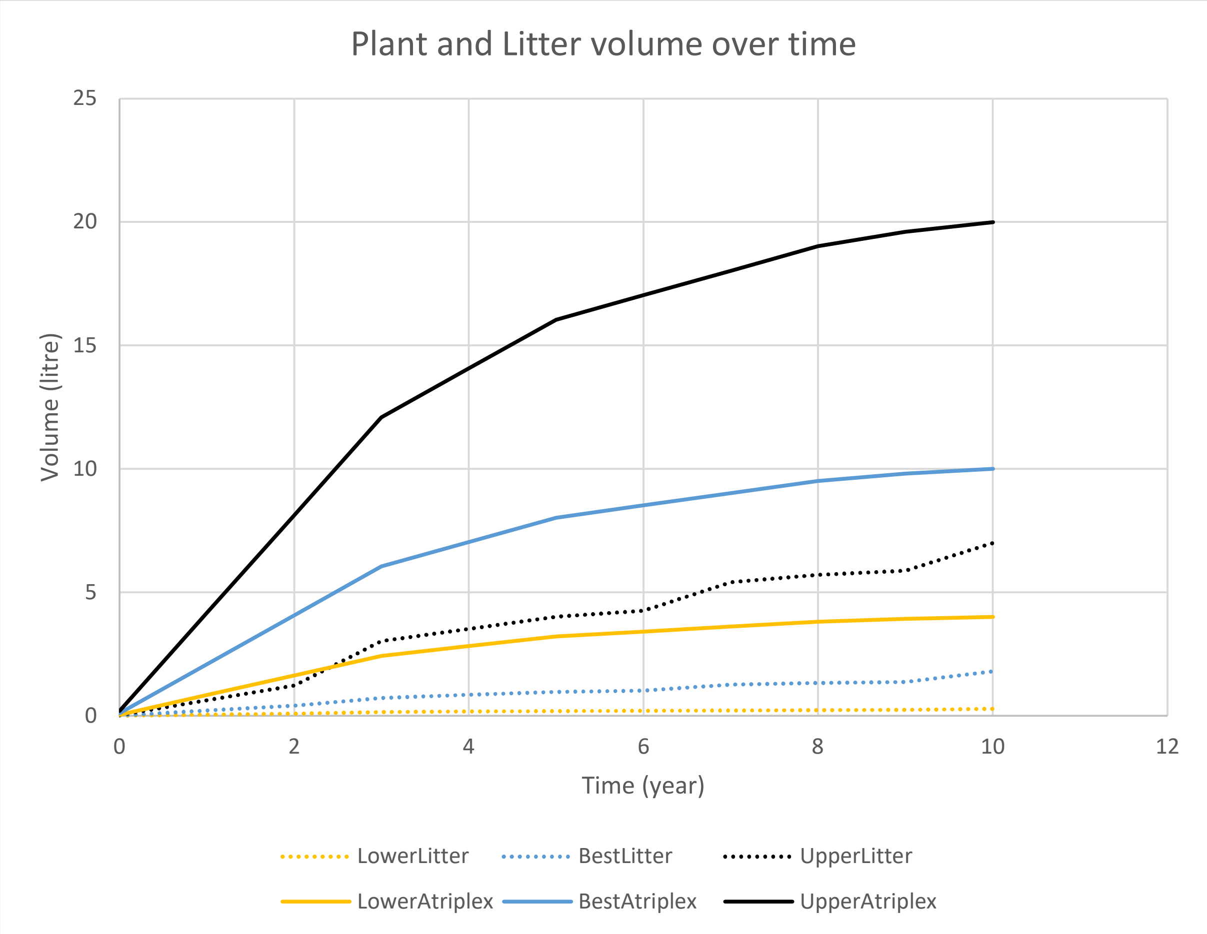


Figure 16: A graph of the increasing volume (litre) of biomass (litter and plants) over time (years)

Grazing

After the implementation of the Vallerani System, it is prohibited to graze the area. The exclusion lasts two years. During these two years the effect of trampling is zero. After this, the effect of trampling is relatively large and decreases as time increases (see Figure 17). This observed in the field, and is due to the fact that soil is relatively lose and the Vallerani Pit is rather instable (Strohmeier S. M., 2020).

Initial instability

In the initial state (period directly after ploughing) of a Vallerani Pit, the soil is very loose. The Seedlings are not yet fully rooted, and no vegetation cover has been established. This means that the pit is quite instable, which leads to soil breaking down into the Vallerani Pit. However, this happens only in the initial period, therefore this only happens in the first year. The lower limit, best estimate and upper limit are respectively 5.4, 9 and 21.6 litre pet pit. After the first year, this process is equal to zero (Strohmeier S. M., The effect of time on a Vallerani Pit, 2020). Since the pit is most likely to be stabilized, preventing further collapses.

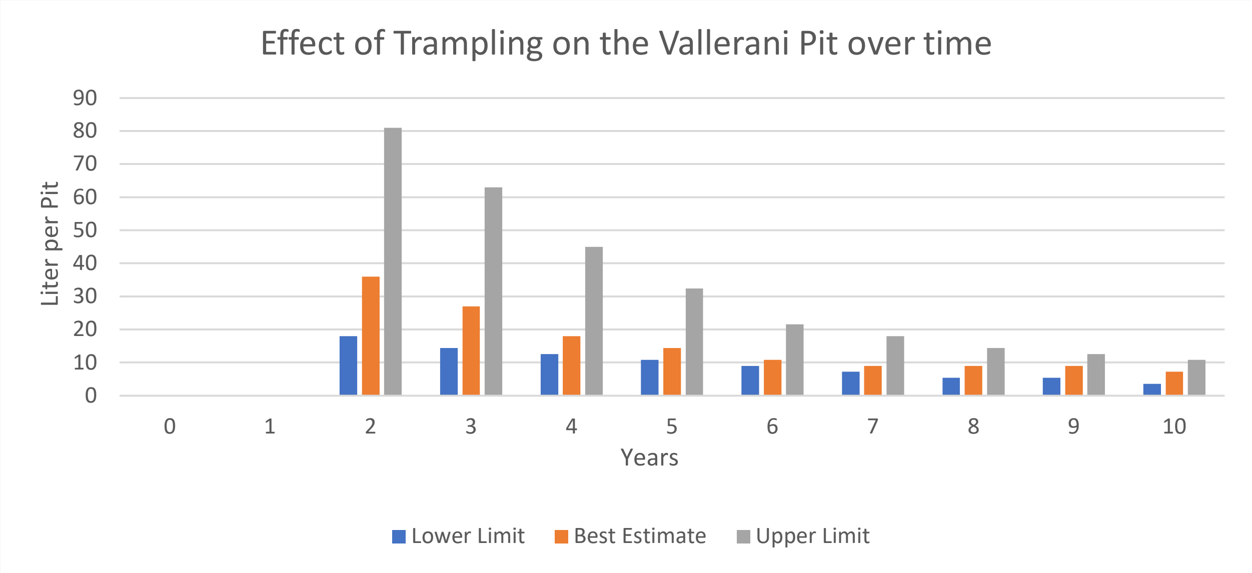


Figure 17: Effect of Trampling by livestock on the Vallerani Pit with respect to Time

Social Context

This paragraph consists out of three sections related to the three aspects, respectively, policy support, local support and personal support for water harvesting techniques.

Policy Support

Clear policy concerning water harvesting is still missing in Jordan. There are three blocking mechanisms, which prevent the development of water harvesting (Sixt, Klerkx, & Griffin, 2018)

Finance and donors

Since Jordan is a developing country (United Nations, 2019) financial resources are scarce and the reliance on donor is large. The limited finances directly impact the ability of the national government to support knowledge development and the sharing of it. As a result, the awareness of water shortage is limited among farmers, decreasing the legitimacy of the potential/development of water harvesting techniques.

In addition, the limited financial resources impact the ability of the government to allocate resources (e.g. subsidies) in order to create a market for water harvesting.

The lack of legitimacy obstructs entrepreneurial activities concerning water harvesting. This lowers the advocacy for water harvesting by entrepreneurs. Also, without financial infrastructure and sufficient protection for water harvesting, entrepreneurial activities will decrease, which again limits advocacy. This creates a vicious cycle (Sixt, Klerkx, & Griffin, Transition in water harvesting practices in Jordan's rainfed agricultural systems: Systemic problem and blocking mechanisms in an emerging technological innovation system, 2018).

Donors are able to influence the national policies as a consequence of Jordan reliance on foreign aid. Donors have helped to build capacity for National Centre for Agriculture Research and Extension (NCARE) which helped the spread and diffusion of knowledge of water harvesting. However, donors tend to prioritize engineering-orientated water harvesting techniques, since these results are easy to measure and show. Upon completion of aid projects aiming at promoting water harvesting, the funding stopped. Which led to obstruction of entrepreneurial activities. (Sixt, Klerkx, & Griffin, Transition in water harvesting practices in Jordan's rainfed agricultural systems: Systemic problem and blocking mechanisms in an emerging technological innovation system, 2018).

Vision

The promotion of water harvesting throughout Jordan is restrained by different visions by various (e.g. governmental) actors. For example, there are subsidies for groundwater extractions (Al Naber, 2018), this substitutes the willingness to invest in water harvesting. In addition, the focus for water harvesting is much more on macro scale instead of on-farm micro-water harvesting (Sixt, Klerkx, & Griffin, Transition in water harvesting practices in Jordan's rainfed agricultural systems: Systemic problem and blocking mechanisms in an emerging technological innovation system, 2018). This contributes to the negative legitimacy of water harvesting.

Institutional

Formal and informal institutions play a role in a legitimizing water harvesting. The official policies (e.g. subsidy for groundwater extraction) delegitimize water harvesting as an option for additional water.

Locally, there is an informal/cultural institution called the *wasta.* This means that people who know people help each other and could be seen as nepotism. This is particularly visible by land tenure. A select group of farmers was able to become wealthy, which allowed them to generate influence. This influence allowed them to obtain more land and thus wealthier.

Therefore *wasta* plays a key role in maintaining the subsidies for groundwater extraction as long as it serves the purposes of the powerful, even though this subsidy is unsustainable and therefore destined to be reduced and/or abolished, which is acknowledged by the interviewees (Sixt, Klerkx, & Griffin, Transition in water harvesting practices in Jordan's rainfed agricultural systems: Systemic problem and blocking mechanisms in an emerging technological innovation system, 2018).

Market Obstruction

The limited finance, lack of common vision and current institutions, negatively impact the legitimacy of water harvesting technologies and that negatively affects the entrepreneurial activities. This leads to the obstruction of market formation for water harvesting technologies (Figure 18).

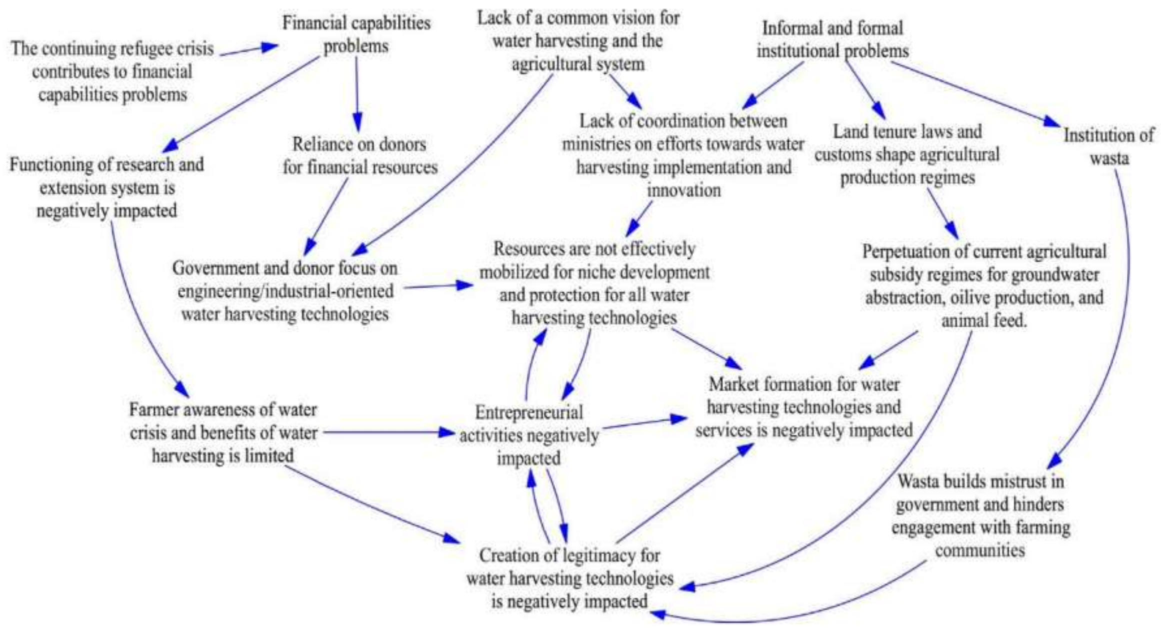


Figure 18: Schematic overview of the processes related to creation of a market for water harvesting (Sixt, Klerkx, & Griffin, Transition in water harvesting practices in Jordan's rainfed agricultural systems: Systemic problem and blocking mechanisms in an emerging technological innovation system, 2018).

Local Support

Willingness

In 2015 Samia Akrhoush (National Centre of Agriculture Extension) and Boubaker Dhehibi (International Centre of Agricultural Research in Dry Areas) conducted a research to predict the willingness of a farmer to adopt water harvesting technologies in the Jordanian Badia.
The target population were local famers in the Jordan Badia, specifically the two rural villages: Al Majidyya (40 households, 250 inhabitants) and Muharib (30 household, 190 inhabitants). In both villages, farmers experience water shortages and degradation of arable land. The data was collected via focus group discussion.
Akroush and Dhehibi state that a minority of the farmers would need a new set of skills and knowledge with respect to water harvesting technologies. Indicating that there is no substantial knowledge gap.
The paper reveals that most of the questioned farmers were driven by profit maximalization and risk minimization. A minority of the farmers had environmental protection as strong motivation. From this, it is concluded that economic incentives could be key drivers for adoption. Additionally, water harvesting techniques will increase the resilience of a farm, largely reducing risks.
However, a minority of the farmers has a long-term (>10 years) planning. This is a constraint for adoption, especially the Vallerani plough, since this is initially a huge investment (200,000 JD) for a single farmer, thus a long return period. For comparison, a Jordanian earns on average roughly 3,000 JD per year (The World Bank, 2018). In addition, the paper states that half of the farmers have severe short term (<10 years) financial constraints.
It is concluded that farmers are very unlikely to invest in the Vallerani plough. This machine costs 68,000 JD and the tractor to pull the plough costs 132,000 JD. So, the needed investment is totalling 200,000 JD. The researchers also commented that it is unlikely that a farmer would invest in something with only one task (Akroush & Boubaker, 2015).

The paper concludes that farmer perceived water harvesting technologies as a good thing. They still faced major problems in the application of such technologies. Therefore, the out-scaling of the Vallerani System would be unlikely.

Personal Support

A survey was taken during this research in order to generate insights about the personal experience of farmers with respect to the Vallerani System specifically (See Annex 4: The Personal Questionnaire).
The result of the survey was that farmers had knowledge of erosion and that farmers perceived the Vallerani System as positive, and that they recognized its potential. Importantly, the interviewed farmers experienced economic improvement as result of the Vallerani System. Additionally, it was perceived that economic activities in the area increased.
The survey also shows that the farmers were willing to bound themselves to a grazing plan in order to improve the Vallerani System. This is crucial since overgrazing is the main initiator of land degradation in the area.

4. Discussion

Interpretations

Watershed

Figure 19: Picture of a failed gully plug (Verbist, 2020)

There is a typical upstream-downstream relation in the watershed. Since water is macro harvested in the watershed, it is important to look to the watershed from that perspective if an improvement is to be suggested.

Figure 19 and Annex 9: Failed Gully Plugs, show that gully plugs fail. This indicates that there are too little upstream measures, such as the Vallerani System (Comparison midstream, 3-20). If the amount of failed check dams increases, the Marab is in danger. Therefore, the Vallerani System could be out-scaled consequently decreasing the risk of flood damage in the Marab.

As explained, the Vallerani System stops degradation by allowing plants to grow (The Vallerani Landscape, 3-16) (Haddad, 2019). Thereby, it also gives higher or similar fodder yield (Comparison Catchment Area, 3-16). This combination of increased sustainability and higher or similar yield could make the watershed and its agro-pastoralists more resilient.

Vallerani Decay Model

All the processes combined are visualized by the compound lines (Figure 20). The dashed line shows the trendline. Exponential trending with intercept has been chosen since this had minimal R^2. The graph shows that the reduction in water storage capacity is indeed significant.

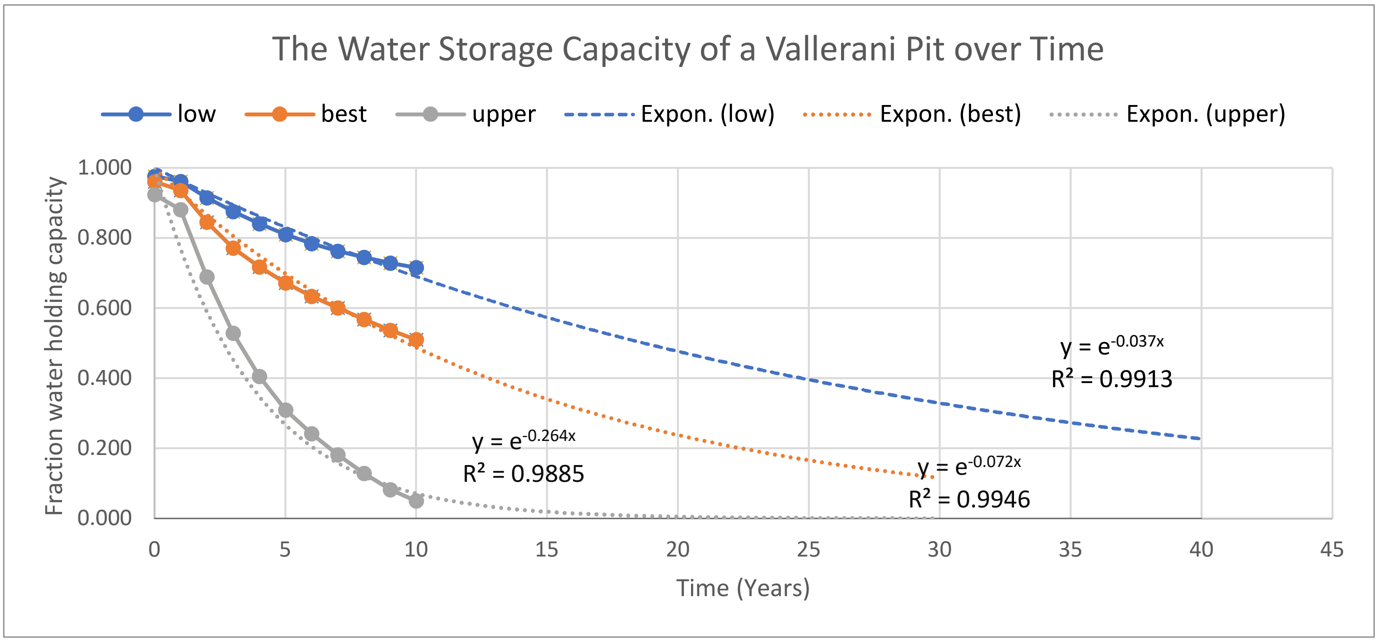


Figure 20: The Water Storage Capacity (fraction) of a Vallerani Pit over Time, with prognose.

Also in the field, there was an extreme case observed: A Vallerani Pit has been observed which was almost fully degraded after 5-10 years (Strohmeier S. M., 2020). This corresponds with upper function in the graph (Figure 20), which shows the most decline.

Expansion and Decay of The Vallerani System

As is previously defined, the Vallerani System must meet the constraints. One of which is the limited deterioration of the influx of discharge in the Marab with a yearly 11.5-millimetre rainfall event. The curved number method showed that such an event would result in 47,061,272 litre discharge. This corresponds with 4,706,127.2 litre available water for storage by the Vallerani System. Therefore, the initial constructed amount of Vallerani is set on 8,715 (≈ 36 hectare), since each Vallerani Pit initially stores 540 litres. The yearly decay of the implemented Vallerani Systems is 7% for the best estimate of the decay. Based on the most realistic estimates, this means that every year, two additional hectares could be ploughed with Vallerani Pits, while supplying the Marab with the targeted amount of water (90% of the generated run-off) (See Annex 8: Plan).

Social Context

The social context shows that farmers are willing to adopt water harvesting techniques (Akroush & Boubaker, 2015). However, they have severe problems to adopt to them because of financial constraints, especially for the Vallerani System. In addition, local farmers perceived the Vallerani System as positive (See Annex 4: The Personal Questionnaire)
However, in order to out-scale the Vallerani System, there should be policies in place which increase the legitimacy and by that the entrepreneurial activities (Sixt, Klerkx, & Griffin, 2018). This would give opportunity for market formation. This may overcome the financial constraints that farmers experience.

A promising market would be the out rent of the Vallerani Plough, since the cost per hectare are relatively low (Gammoh & Oweis, 2011) but the initial investment is too great for a single farmer. In addition, the government is already owner of a small number of Vallerani Ploughs (Gammoh & Oweis, 2011). The government could rent them out to farmers in order to increase the sustainability of the agricultural sector.

Reliability

Field observations

The conclusions drawn are from intensive and frequent field visits accompanied by local SLM-experts. The experts were able to approve or disapprove conclusions. In addition, there is literature (Haddad, 2019) (Goos, 2019) about the watershed, which align with this thesis. Therefore, the conclusions can be deemed reliable. Nevertheless, more modelling and measurements could be done to (quantitively) describe the linkages between each component. This would strengthen the conclusions drawn in this thesis.

Vallerani Decay Model

Further calibration by measurements is currently impossible due to the interference of Covid-19. In addition, literature on the effect of time on a Vallerani Pit is missing (Vallerani S. , 2020), indicating a major knowledge gap. This means that this thesis cannot be compared to similar research to validate. Nevertheless, the model is generally reliable since it is based on experiences of SLM-experts and the bandwidth is rather large. If the processes are understood and measured better, this bandwidth could be narrowed, decreasing the uncertainty. Eventually, the model provides knowledge on specific gaps and uncertainties – as a motor for potential future studies to be conducted.

There are assumptions (See Annex 7: The Time-Model), that bring uncertainty and should be validated. The resulting key questions are (Strohmeier S. M., 2020):

- How does the Vallerani-induced ecosystem transition develop over time?

  - Do restored landscapes attract more wildlife? And if so, does this translate in more significant trampling?

- What are the key-driving processes of the Vallerani-induced rehabilitation approach?
  - What is the approximate timescale of degradation of the Vallerani water harvesting intervention?
  - What are the interrelationships of the processes?
  - Does the trapping efficiency decrease as the pit fills, and to what degree?
- Is the porosity of the various sediments significant? If so, what is the potential water content of all the volumes and for each sediment?

Furthermore, research should be done to validate the estimates. This is specifically needed for the wind erosion, grazing and initial instability. These processes were never well studied in the research area, and according to their significance they should be subject to further research. Photogrammetry could be used to quantify (Strohmeier S. M., 2020).

The best moments to take conduct photogrammetry are dry periods, before and after grazing and in the initial period for respectively, wind erosion, trampling by grazing and initial instability. However, wind erosion is still unreliable since these sediments are able to remobilize. Therefore, photogrammetry could be misleading as well. This is an aspect that should be considered before developing a research plan. A valid preparatory question is how significant is the remobilization of sediments by wind erosion?

Once these questions are answered, the processes understood and measured, ranking based on sensitivity and uncertainty could be done for certain time periods (e.g. every two year). This gives insights in which processes are most uncertain, thus need further research. In addition, it shows which aspects are dominant at what times.

Curved Number Method

The Curved Number method used in this thesis is somewhat unreliable. This is because only the CN-numbers and percentage of land use were known for the whole watershed. However, only the catchment area of the Marab is to be considered. Therefore, the relative area of a land use (and its Curved Number) may change, changing the weighted average of the CN. This changes the run-off depth as well. A validation should be done, to know the relative areas of the considered land use types with respect to the upstream area of the Marab.

To bring this model closer to reality, there should be looked to multiple rainy seasons in order to determine the likelihood of the occurrence of a certain storm. The storm chosen in this thesis is most likely to return yearly (Strohmeier S. M., 2020). However, a storm of this magnitude could occur more times per year.

Planning

As has been previously explained both the amount of discharge in the Marab and the decay of a Vallerani Pit are inaccurate. This makes the planning of the expansion of the Vallerani System throughout the watershed inaccurate. In addition, 10% has been chosen as permissible decrease of water in the Marab. This 10% is nevertheless chosen without a beforehand study. Therefore, a validation should be done to determine how much water is available to expand the Vallerani System.

Personal Questionnaire

As explained, Covid-19 interfered the survey. Therefore, the results of this questionnaire showed in this thesis, should not be considered reliable. Since there were only two interviewees. However, it gives an impression. But in order to rely on the results, the questionnaire should be conducted among significantly more farmers.

5. Conclusion

Based on the findings of this thesis, it can be concluded that the Vallerani System is Highly Suitable (S5, Table 1) within the framework of the previously defined constraints and conditions. The present findings show that the Vallerani System preserves downstream water influx by more than ten percent (Constraint A: Expansion and Decay of The Vallerani System, 4-31) when expanded by two hectare per year. It is furthermore demonstrated that the Vallerani System is applicable in the watershed with its boundary conditions and current terrain characteristics (Constraint B: Boundary Conditions, 3-23). Additionally, the Vallerani System brings similar or higher fodder yield compared to the hill slope barley cultivation (Condition 1: Comparison Upstream Areas, 3-17). Present survey results and literature show that the Vallerani System is perceived positively and would be further supported by local farmers (condition 2: Local Support, 3-29). Also farners experienced relative economic improvement (Condition 3 Personal Support, 3-29). The Vallerani System furthermore reduces the risk of flood damage downstream (Condition 4: Interpretation of the Watershed, 4-30) and reverses land degradation (condition 5: Comparison of Upstream areas, 3-17).

As mentioned and discussed in the text, the suitability assessment done did not consider the capital required to implement the Vallerani System. Nevertheless, this thesis has also researched the role of this aspect and related ones. It can be concluded that the initial investment (purchase of the machinery) is currently a [too] large burden for a farmer to bear; the absence of market formation for water harvesting make it hard to see this change for the better in the near future. Hence these economic considerations negatively impact the local suitability of the Vallerani System. External driving forces like ICARDA have however shown technical feasibility and beneficial application results.

As a final conclusion: the Vallerani System can be considered Highly Suitable if the implementation is economically facilitated as it was for previous implementation in Al Majidyya watershed or if a market would be established for water harvesting overcoming financial constraints of farmers. Without either one, the realistic suitability of the Vallerani System is thus lower.

Future research

It is advised that future research should aim to quantify and to validate the suggestions and model presented in this work. This would best be conducted by monitoring the Vallerani System over time, in particular the decline of the water storage capacity, e.g., focussing on the processes filling up the pit, as described in the discussion (Vallerani Decay Model, 4-31). More and potentially more accurate data would render a more reliable decay model which is a crucial aspect in the suitability determination.

A second meaningful addition would be a more concise validation of the Curve-Number method used in this thesis (Curved Number Method, 4-32) as would be the estimate for the crop water demand of the crops cultivated in the Marab. The balance between these numbers is available water that can be used for expansion of the Vallerani System (Planning, 4-32). Consequently, the suggested validations would lead to a more accurate rate of the expansion of the Vallerani System.

Another angle for future research would be a deep-dive into the economic and/or policy rather than technical aspects, e.g., how to create a market for the Vallerani System to make implementation affordable for farmers? This thesis has shown that intrinsic support for the Vallerani System by farmers is high but that the cost and policy (institutional) support are bottlenecks for wide-scale usage of the Vallerani System. As a suggestion: future research could investigate the potential role of the Jordanian government as the owner in a rent-based market.

Deepening economic and policy aspects as suggested above into well-defined additional suitability conditions for the Vallerani System will render a more comprehensive consideration of suitability beyond the mainly technical focus presented here. It is hoped that the present work is a viable starting point for further study on the basis of the suitability of the Vallerani System investigated.

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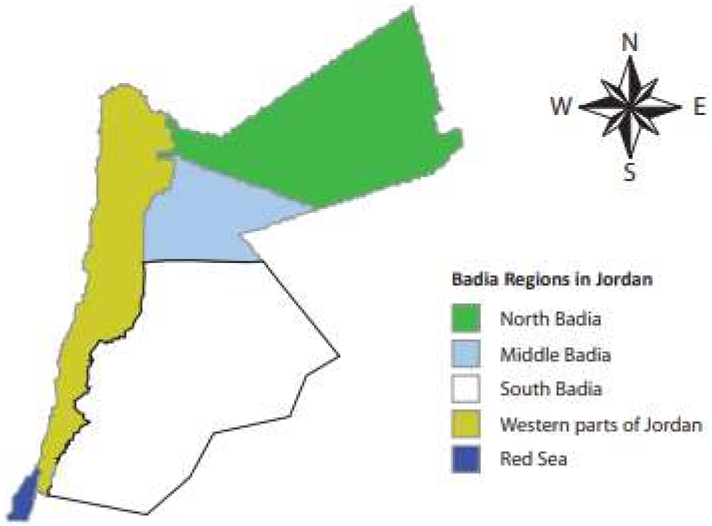
7. Annex

Annex 1: General Background Jordan

Geography & Climate

Jordan is a country located in the Middle East (31'57N – 35'56E), bordering Syria, Iraq, Israel/Palestine, and Saudi Arabia. It has one coast, at the Red Sea, named the Gulf of Aqaba.

The climate for Jordan is generally classified as BSh in the Köppen-Geiger classification, a semi-arid climate (Karadsheh, Akroush, & Mazahreh, 2012). This means that summers are dry, and the annual temperature is above 18 degrees Celsius (Jordan, sd). Thus, Jordan is characterized by dry and rainy seasons. The dry season is from May until September. Therefore, the rainy season is from October until April/May. However, Eastern Jordan, where the Badia/rangelands are located, has more arid climate. Badia form 90 percent of the land (≈81,000km^2), these are desert/steppe like landscapes. The yearly rainfall here is less than 200 mm (Karadsheh, Akroush, & Mazahreh, 2012).



Politics & Demography

In a troubled subcontinent dominated by conflicts, Jordan is a safe haven. Throughout modern history it has been mostly stable and secure. This is because of continuity of the Hashemite monarchy and the support from on the one hand Israel, US and EU and on the other hand Saudi Arabia and other Arabic countries (El-Anis, 2018). However, this has its consequences. The influx of refugees from other parts of the Middle East, such as Palestine, Iraq and most recent Syria, has been significant. The demography of Jordan has totally changed due to this. According to The Jordan Times, the country hosts 2.9 million refugees on an original population of 9.5 million. This 2.9 million consists of 1.3 million Syrians, 636 thousand Egyptians, 634 thousand Palestinians, 140 thousand Iraqis, 31 thousand Yemenis, 23 thousand Libyans and approximately 200 thousand of additional nationalities (Ghazal, 2016).

In 2016-2017 the influx of Syrian refugees was 660 thousand (Thiombiano, 2017). Eighty percent of the Syrian refugees lives outside camps. The majority of this eighty percent works in the agricultural sector (Thiombiano, 2017).

Annex 2: Gully Plug Design

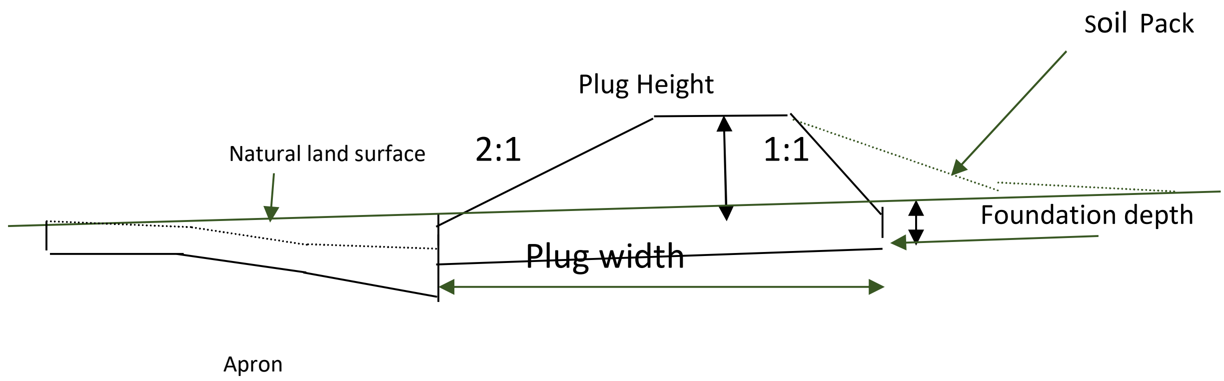
This text is copied from the gully plug design report (Steven, 2017).

Design of Structures

All the gully plugs have to be anchored strong enough to resist water flow and prevent bypass from the side banks. A foundation also is required for all structures depending on their dimensions and on the nature of the bed. The foundation depth for the planned structures ranged between 0.2 to 0.35 meters. The anchoring of gully plugs ranged between 1 and 1.5 meter. This depends on the existing condition of the banks at each structure location. All the gully plugs will be provided with an apron at the downstream edge that is around 3 to 4 times the heights of structures. The apron will start from below the bottom level of the foundation and gradually level half way down.

All gully plugs were designed to have a height maximum 0.5 the depth of the gully. So each structure will pass water flow downward but keeping it inside the gully. Gabion structures used will have a sort of spillway from the top but at the same time protecting the banks. The configuration will slightly differ from the normal stone structure but the idea is to have protection at the sides and a spillway at the middle.

The upstream front of each gully plug will have a side slope of 1:1, while the downstream front of the plug will have a side slope of 2:1 (not counting the apron). The slopes at the two sides will greatly increase the base width of the plug and improve their stability.

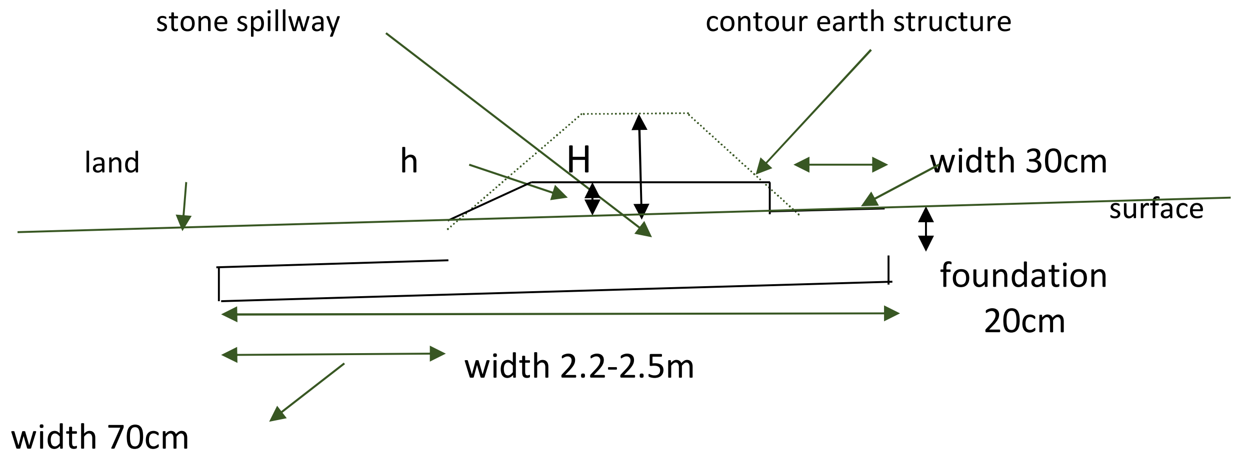


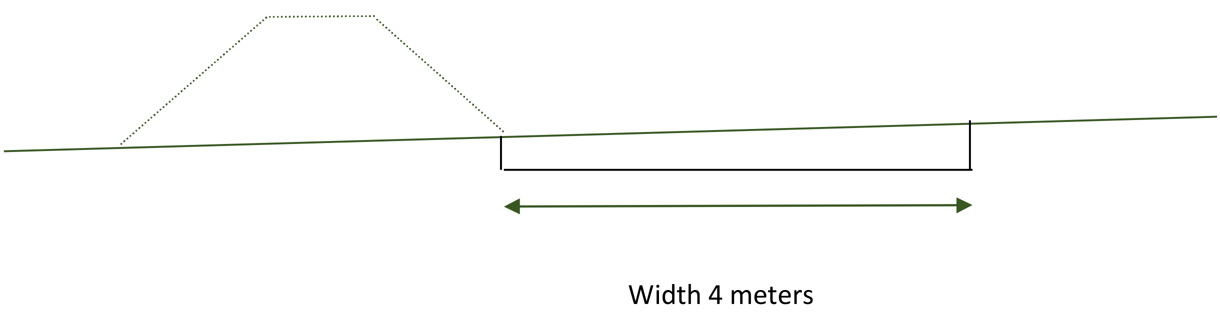
The gully plugs will be provided with an amount of soil that is resulting from the fondation to form a triangle with the structure at the upstream side this will improve the function of the gully plug in storage more water and in trapping sediments. At the other side of each structure, the slope of the side is meant to tackle the over flow of water along the drop to safely return to the gully bed level without causing additional erosion.

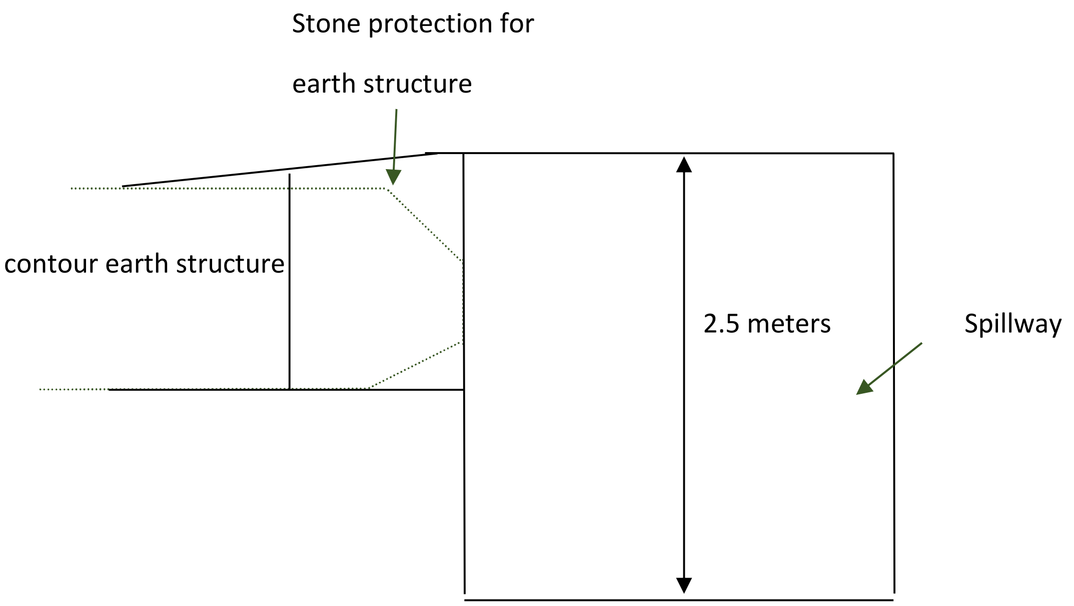
Annex 3: The Marab Design

This text is copied from the Marab Design Report (Strohmeier S. , 2017)

Based on the above calculations, we suggest considering a dam spillway length of 50-60m; practically designing the first three Marab dams with spillway height of 0.05m only and length of 60m, slightly buffering the peak wave. The next spillways (4 to 6) may have a length of 55m and 0.10m spillway height. The remaining spillways will have a spillway height of 0.15m and a spillway length of 50m. The emergency spillway height will be set at 0.10m above the design spillway height.







Annex 4: The Personal Questionnaire

The questionnaire consists of twelve questions. The first question is to determine the relation between the interviewed subject and the Vallerani System. The answers on the remain questions are scaled from -3 to +3. Where a -3 is very negative and +3 very positive. There is also an option to choose Not Applicable (NA).
The interviewed subjects worked closely together, therefore they answered each question the same way. Their answers are made bold and highlighted in grey in the questionnaire below.

What is your relation to agriculture?

a) **Direct (farmer/herder)** b) Indirect (e.g. butcher/transporter) c) None (e.g. city worker)

1. Are you affected by erosion?

NA	**-3**	-2	-1	0	1	2	3

2. What is/was the effect of erosion on your yield/income?

NA	**-3**	-2	-1	0	1	2	3

3. Do you think erosion should be stopped/solved/overcome?

NA	-3	-2	-1	0	1	2	**3**

4. Do you believe that degraded/eroded lands should be rehabilitated?

NA	-3	-2	-1	0	1	2	**3**

5. Would you be willing to let your livestock graze sustainably in order to prevent/stop erosion? (not to overgraze)

NA	-3	-2	-1	0	1	2	**3**

6. Do you know the Vallerani rehabilitation?

Yes	No

7. Has the Vallerani project let to relative economic improvement? (e.g. more fodder, less travel time etc)

NA	-3	-2	-1	0	1	2	**3**

8. Do you think the Vallerani rehabilitated lands are a positive development in the area in terms of economic activities? (e.g. more agricultural activity, tourism)

NA	-3	-2	-1	0	1	2	**3**

9. Has the Vallerani rehabilitation led to a change in life experience? (e.g. more enjoyable view/landscape)

NA	-3	-2	-1	0	1	2	**3**

10. Do you think the Vallerani like rehabilitation has potential for other degraded areas?

NA	-3	-2	-1	0	1	**2**	3

11. Would you support this? (e.g. by sustainably grazing, open-up property)

NA	-3	-2	-1	0	1	2	**3**

Annex 5: The Curved Number Method

DATA RAINY SEASON 2018/2019 (GOOS, 2019)

DATA	**Precipitation (mm)**
28 DECEMBER 2018	2.75
17 JANUARY 2019	5.25
9 FEBRUARY 2019	11.5
10 FEBRUARY 2019	5.00
28 FEBRUARY 2019	36.75

Precipitation Events 2018-2019 rainy season	Heavy	35.75mm		0.3575dm
	Medium	11.5mm		0.115dm
	Upstream area of Marab	7.2km2		720000000dm2
Curved Numbers	**Landuse**	**Percentage of watershed**		**CN**
	LowDensityUrab	5.60%		90
	Hilltop	18.10%		90
	Streams	1.20%		98
	Rangeland	73.80%		85
	Marab	1.30%		85
Weighted Average CN = **86.341**				
Symbol	**Formula**	**Outcome**		
Potential maximum retention (S)	(24500/CN)-254	29.75858514mm		
Run-off (Q)	((p-0.2*S)^2) / P+0.8*S	heavy	14.90907256mm	107345322.4 Litre
		Medium	6.536287866mm	47061272.63 Litre

Annex 6: Expert Justification Ranking

This annex shows the expert justification on the ranking. The following is stated in an email by ICARDA (Amman) SLM-expert, Stefan M Strohmeier on 18/06/2020.

<u>Wind Erosion:</u> Can generally have a large impact in arid areas - some literature tells in such around 130mm rainfall zones more than water erosion; however we know from the local context the quite clay-silty soil tends to surface crusting, which is degraded, but also protective. There are dust storms in certain season and dust devils, but most of the dust trapped in the micro water harvesting pit might be re-mobilized (through subsequent storms). Only fraction which stays is the dust which is there at the first rain of the season. Overall, from local experience, I would not have seen very deep dust layers in the pit (in top

of the water compacted hard crust in the pit from the end of the last season) at the onset of the rainy season. I do not expect wind erosion as a very driving process.

Water erosion: I guess not much to say - the numbers are from Mira's MSc, merging local (runoff plot) observations with physical modelling. Our numbers are solid. Can be a driving factor, but still not the main dominant one.

Biomass above ground: The out planted seedlings (e.g. stem) take some cm3 space from the beginning. We consider only biomass within the potential ponding depth. We have vegetation measurement and monitoring, and we know the vegetation development quite well. Together with grasses and recruitment we can estimate the volume roughly and its temporal development. It assess-able and probably quite dominant (bit I would still not expect it as 'the most dominant').

Biomass litter: this is a fraction of the biomass, which makes sense. Also, it has a temporal distribution as a fresh seedling does have still even proportional less woody parts. We gave it an estimate, but from local checks (e.g. taking a piece of the crust and looking how much straw, dead leaves, ... are in the soil crust) gives an idea about percentage. Would require another study to separately look at this if we feel its dominant.

Trampling: Might be dominant - we saw it during grazing activities. But: its very hard to assess. It would need a before and after (grazing) assessment maybe using photogrammetry. Interesting, but not yet done. However, we have an expert estimate on how many mm might get down-trembled to the Vallerani bed. First grazing is sure more damage as the structures are more edgy and steep, and the Vallerani ridge is not compacted yet. This will change over time and will get less with the Vallerani getting a smoother shape (through trembling over the years). However, there is 'huffing' even later, which could throw some soil into the pit as goats may especially graze and huff the annual grasses patches upstream of the Vallerani; also - at a bit later stage with upcoming habitat quality, more wildlife might follow. Rabbits can dig quite a bit and throw sediments in the pit...

Initial stability: When the Vallerani is freshly plowed the soil is loose, and the structure is destroyed and even some soil clods are thrown around. The Vallerani ridge has the geotechnical steepness stability of the lose soil, as you would scoop it from a bucket - uncompacted. There are 2 processes happening in the first months: 1) the whole ridge settles through its own weight and changes shape (this can even free up more space - we dont know) - which happens from lose density (around 1.1 g cm-3) to semi compacted (around 1.2 g m-3), which might come to around 5-10% change in height, and 2) wind and first rain erode a lot, which is not really wind or water erosion as we consider it, but 'rim erosion', which means edges get erodes and also larger clods fall down - including that the first rain comes on the very unprotected and broken soil, which washes out massive fine sediments. After some time and 1-3 rainfalls the structure gets more stable and compacted (and a slight and protective surface crust develops) - then the initial instability should not be over. The process is significant at the beginning (first months) but happens basically only then - at the long term it loses its overall dominance. Not so easy to assess (maybe photogrammetry), but also overall not dominant at the long term.

Annex 7: The Time-Model

Assumptions

1. Trapping efficiencies decrease as the Vallerani Pit fills.
2. Restored lands can be realized in ten years.
3. The transformation from degraded landscapes to restored landscapes is linearly in terms of water erosion.
4. There are no interlinkages (e.g. if water erosion increases, trampling decreases).
5. Wildlife population remains low and its trampling effect thus insignificant.
6. The amount of litter is related to stage of the plant and the volume of the biomass.
7. All the volumes are considered to not take water in.

One dimensional values (heights or depths) were translated to volume by multiplying it with the average horizontal area. Which is the average width times the pit length.

Pit Dimensions

Pit Dimensions used for the Time Model

Pit	Plants	#Atriplex per pit	2	
	length	Length Pit	450 cm	4.5 m
	trapezoidal cross section	Top Width	50 cm	0.5 m
		Bottom Width	30 cm	0.3 m
		Height or Depth	30 cm	0.3 m
	average pit horizontal area		18000 cm^2	1.8 m^2
	pit volume	540000 cm3	0.54 m3	540 litres
Pit density	Lateral Interspace		100 cm	1 m
	Contour Interspace		700 cm	7 m
	Pits/ha		242.42	

Water Erosion

soil density (ρ)	1.300390117	kg/l = ton/m3		
trapping efficiencies (η)	LowerLimit	best	UpperLimit	
	85%	95%	99%	
	LowerLimit	Best	UpperLimit	
Soil loss yr 0	2.6	3.35	4.1	ton/ha/yr
soil loss yr 10	0.9	1.2	1.5	ton/ha/yr

Netto Water Erosion [litre/pit]			
Years	LowerLimit	Best	UpperLimit
0	7.01039625	10.09528781	12.87565538
1	6.552024188	9.447381281	12.0591504
2	6.093652125	8.79947475	11.24264543
3	5.635280063	8.151568219	10.42614045
4	5.176908	7.503661688	9.609635475

5	4.718535938	6.855755156	8.7931305
6	4.260163875	6.207848625	7.976625525
7	3.801791813	5.559942094	7.16012055
8	3.34341975	4.912035563	6.343615575
9	2.885047688	4.264129031	5.5271106
10	2.426675625	3.6162225	4.710605625

Wind Erosion

	LowerLimit	Best	UpperLimit
trapping efficiency	0.1	0.2	0.35
volumetric (mm/pit)	2	5	10

Netto wind erosion [litre/pit]			
Year	LowerLimit	Best	UpperLimit
0	0.36	1.8	6.3
1	0.36	1.8	6.3
2	0.36	1.8	6.3
3	0.36	1.8	6.3
4	0.36	1.8	6.3
5	0.36	1.8	6.3
6	0.36	1.8	6.3
7	0.36	1.8	6.3
8	0.36	1.8	6.3
9	0.36	1.8	6.3
10	0.36	1.8	6.3

Biomass: Atriplex

	volume/seedlings [cm3/plant]		
Year	LowerLimit	Best	UpperLimit
0	20	50	100
10	2000	5000	10000

	Biomass [Litre/pit]			
Weight	Year	LowerLimit	Best	UpperLimit
1	0	0.04	0.1	0.2
0.2	1	0.832	2.08	4.16
0.4	2	1.624	4.06	8.12
0.6	3	2.416	6.04	12.08
0.7	4	2.812	7.03	14.06
0.8	5	3.208	8.02	16.04
0.85	6	3.406	8.515	17.03
0.9	7	3.604	9.01	18.02

0.95	8	3.802	9.505	19.01
0.98	9	3.9208	9.802	19.604
1	10	4	10	20

Biomass: Litter

	Percentage of the Biomass		
year	Lower	Best	Upper
0	5%	10%	15%
1	5%	10%	15%
2	5%	10%	15%
3	6%	12%	25%
4	6%	12%	25%
5	6%	12%	25%
6	6%	12%	25%
7	6%	14%	30%
8	6%	14%	30%
9	6%	14%	30%
10	7%	18%	35%

Netto Litter [litre/pit]			
Year	Lower	Best	Upper
0	0.002	0.01	0.03
1	0.0416	0.208	0.624
2	0.0812	0.406	1.218
3	0.14496	0.7248	3.02
4	0.16872	0.8436	3.515
5	0.19248	0.9624	4.01
6	0.20436	1.0218	4.2575
7	0.21624	1.2614	5.406
8	0.22812	1.3307	5.703
9	0.235248	1.37228	5.8812
10	0.28	1.8	7

Trampling: Grazing

	trampling [mm/pit]		
year	LowerLimit	Best	UpperLimit
(protected) 0	0	0	0
(Protected) 1	0	0	0
2	10	20	45
3	8	15	35
4	7	10	25
5	6	8	18
6	5	6	12
7	4	5	10

8		3	5	8
9		3	5	7
10		2	4	6

Trampling [litre/pit]			
Year	LowerLimit	Best	UpperLimit
0	0	0	0
1	0	0	0
2	18	36	81
3	14.4	27	63
4	12.6	18	45
5	10.8	14.4	32.4
6	9	10.8	21.6
7	7.2	9	18
8	5.4	9	14.4
9	5.4	9	12.6
10	3.6	7.2	10.8

Initial Instability

		mm/pit	
Year	LowerLimit	Best	UpperLimit
0	3	5	12

Trampling [litre/pit]			
Year	LowerLimit	Best	UpperLimit
0	5.4	9	21.6
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0

Final

Time	All Processes Summed [Litre/Pit]		
Year	LowerLimit	Best	UpperLimit
0	12.81239625	21.00528781	41.00565538
1	20.55802044	34.44066909	63.94880578
2	45.88487256	83.42614384	167.6694512
3	67.21711263	123.0825121	254.3755917

4	85.91874063	152.2197738	320.7802271
5	102.3857566	177.2279289	374.2633576
6	116.4082804	197.5525775	415.3874832
7	128.1843123	215.6689196	453.2436037
8	137.713852	233.2066552	486.9802193
9	146.7129477	249.9400642	517.8825299
10	153.4588233	264.5542867	547.0891355

Time	All Processes Summed [Pit Fraction %]			Waterstorage Capacity of a Pit [%]		
Year	LowerLimit	Best	UpperLimit	LowerLimit	Best	UpperLimit
0	0.02	0.04	0.08	0.98	0.96	0.92
1	0.04	0.06	0.12	0.96	0.94	0.88
2	0.08	0.15	0.31	0.92	0.85	0.69
3	0.12	0.23	0.47	0.88	0.77	0.53
4	0.16	0.28	0.59	0.84	0.72	0.41
5	0.19	0.33	0.69	0.81	0.67	0.31
6	0.22	0.37	0.77	0.78	0.63	0.23
7	0.24	0.40	0.84	0.76	0.60	0.16
8	0.26	0.43	0.90	0.74	0.57	0.10
9	0.27	0.46	0.96	0.73	0.54	0.04
10	0.28	0.49	1.01	0.72	0.51	0.00

Time	Incl. decline correct [%]		
Year	LowerLimit	Best	UpperLimit
0	0.976	0.961	0.924
1	0.962	0.936	0.882
2	0.915	0.846	0.690
3	0.876	0.772	0.529
4	0.841	0.718	0.406
5	0.810	0.672	0.310
6	0.784	0.634	0.242
7	0.763	0.601	0.182
8	0.745	0.568	0.129
9	0.728	0.537	0.082
10	0.716	0.510	0.050

Annex 8: Plan

Input Data of the Plan to expand the Vallerani System (obtained from the Time-Model and CN-method)

Vallerani initial Water Storage	540 Litre per pit

Pits per Hectare	242 pits/hectare			
Area per pit	41.25m^2 per pit			
Permissible Downstream water decrease	10%			
Water storage decline	function WS=e^bt		Yearly decay of storage (%)	
	b value		1-EXP(b)	
	Upper	-0.2637	23%	
	Best	-0.0718	7%	
	Lower	-0.0371	4%	
		Rain	Run-ff depth	Run-off (100% water downstream)
Precipitation Event 2018-2019 rainy season (yearly)	Medium	12 mm	7 mm	47,061,273 Litres

PLAN FOR EXPANSION VALLERANI FOR BEST DECAY ESTIMATE (YEARLY RAINFALL OF 11.5MM)

TIME	Total Installed		Added	Percentage of water downstream		
YEARS	Number	Hectare	Hectare	Upper	Best	Lower
0	8,715	36	-	90%	90%	90%
1	8,715	36	-	92%	91%	90%
2	8,715	36	2	93%	91%	90%
3	9,319	38	2	94%	91%	90%
4	9,881	41	2	95%	91%	89%
5	10,446	43	2	95%	91%	89%
6	11,010	45	2	96%	91%	89%
7	11,575	48	2	96%	91%	89%
8	12,140	50	2	96%	91%	88%
9	12,704	52	2	97%	91%	88%
10	13,269	55	2	97%	91%	88%
11	13,834	57	2	97%	91%	88%
12	14,398	59	2	97%	91%	88%
13	14,963	62	2	97%	91%	87%
14	15,528	64	2	97%	91%	87%
15	16,093	66	2	97%	91%	87%
16	16,657	69	2	97%	91%	87%
17	17,222	71	2	97%	91%	87%
18	17,787	73	2	97%	91%	87%
19	18,351	76	2	97%	91%	86%
20	18,916	78	2	97%	91%	86%
21	19,481	80	2	97%	91%	86%
22	20,045	83	2	97%	91%	86%
23	20,610	85	2	97%	91%	86%
24	21,175	87	2	97%	91%	86%
25	21,739	90	2	97%	91%	86%
26	22,304	92	2	97%	91%	85%

27	22,869	94	2	97%	91%	85%
28	23,433	97	2	97%	91%	85%
29	23,998	99	2	97%	91%	85%
30	24,563	101	2	97%	91%	85%

Annex 9: Failed Gully Plugs

Pictures showing failed gully plugs at different locations. Each photo is a different location (Verbist, Picture from Al Majeddyeh watershed, 2020).