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From
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Subject
Final implementation and monitoring plan
Muwaqqar catchment, Azraq

1 Introduction

The 2nd component of the 3R project focuses on piloting (a combination of) 3R interventions in various geographical and climatological settings in Jordan. The program's outcome is to actively support the development of a sustainable integrated water management approach by reducing water usage from unsustainable sources and increasing the water supply from sustainable sources. The latter can be achieved by supporting water harvesting and promoting the use of non-conventional and sustainable water resources by implementing 3R interventions.

This document presents the implementation plan for the Muwaqqar catchment located in Azraq governorate, Jordan. Within this implementation plan the catchment's background and key issues are shortly described, together with the tools and analyses used to assess its 3R potential. Based on this, conceptual designs of different types of 3R measures (including their siting) are proposed. The document includes a brief monitoring plan that can be used to determine the current (baseline) situation and to evaluate the biophysical impact of the proposed interventions during later stages.

How to read this document?

Chapter 2 briefly details the sub-catchment's current situation and key issues. Chapter 3 describes the analyses and tools used to assess the 3R potential of the sub-catchment. Chapter 4 describes the adopted implementation approach and the conceptual designs of the recommended interventions, including their siting. Chapter 5 provides a brief monitoring plan to evaluate the effectiveness of the 3R interventions. The next steps necessary for successful implementation are described in Chapter 6.

2 Background of the catchment

Catchment selection

Circa 35 km southeast of Amman, the Jordan University Station for Arid Land Research is located near Muwaqqar. The University Research Station, covering an enclosed area of approximately 2000 dunams (±200 ha), has served as a pilot site for implementing water harvesting measures and agricultural experiments by the Faculty of Agriculture since 1985. Three dams were initially built to harvest floodwater for irrigation. Additionally, various 3R interventions, including floodwater spreading, gabion check dams, and contouring measures, were demonstrated at the site. The absence of upstream protection measures, however, resulted in heavy dam siltation, and due to insufficient maintenance and decreasing interest in the location, its condition deteriorated significantly (Figure 1). As a result, the site lost its use over the last couple of years.

Figure 1. Broken flood water spreading structure (left), and one of the dam reservoirs completely filled with sediments (right).

Under the 3R's project, the University Station will be renovated in collaboration with the Jordan University (Figure 2). As part of this activity, the existing dams were excavated and two additional storage ponds were constructed in early 2024. To prevent siltation of these structures, upstream catchment protection and rehabilitation of degraded lands is key. This is also one of the main reasons why this catchment was selected for implementation:

- Catchment protection and rehabilitation of degraded lands will **reduce future maintenance costs** at the University Station. Besides, it will benefit local communities within the catchment area by **increasing rangeland productivity.**
- Dam siltation and land degradation are major problems throughout the country. Successfully implementing and showcasing the effectiveness of 3R interventions within this catchment therefore has **high upscaling potential**.
- The strong connection with Jordan University increases the **potential for long term engagement** of university staff and students in monitoring and evaluation, and research.
- The University Station and its upstream catchment can serve as **demonstration site** for 3R implementation. The area is located close to Amman and has a good accessibility.

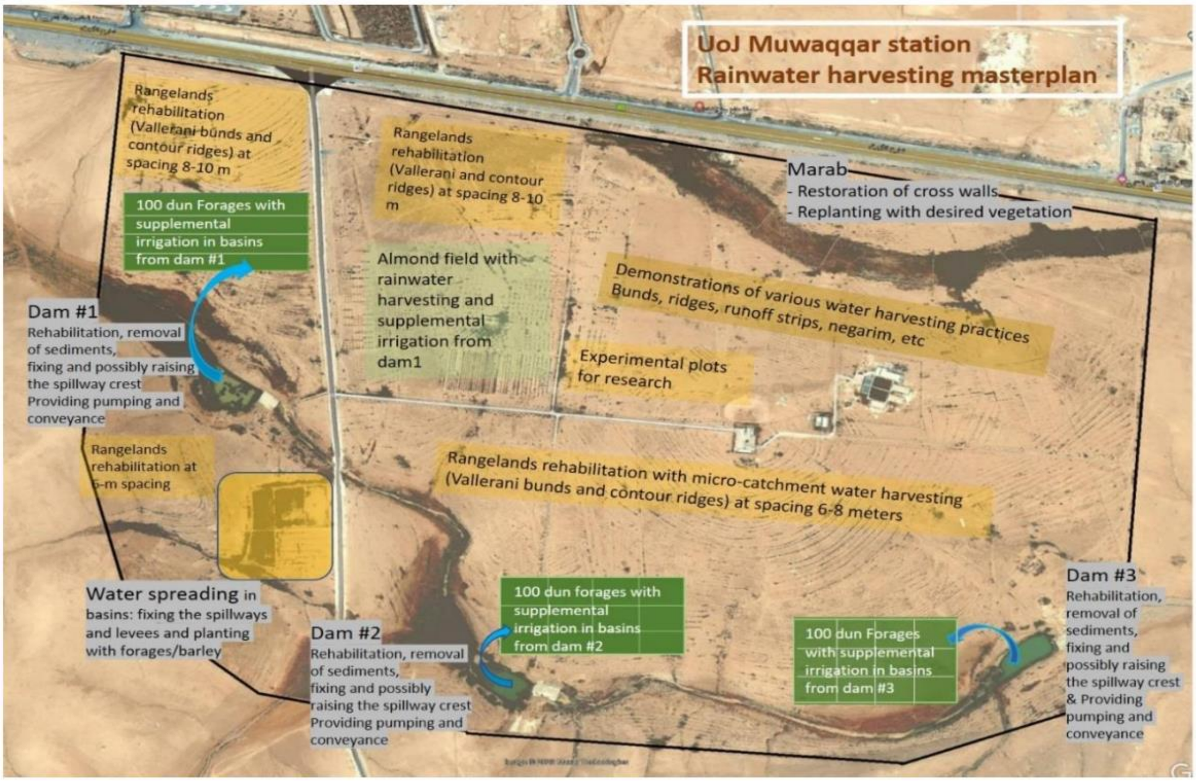

Figure 2. Rainwater harvesting masterplan for the University station as developed by the Jordan University.

Description of the catchment

The Muwaqqar catchment is located at the most western part of the Azraq basin and has an area of ±75 km^2. The area is characterized by an arid to semi-arid climate, in Jordan known as the transitional *Badia*. Rainfall in the sub-catchment is on average 224 mm a year, with the highest values of 270 mm in the northwest and the lowest values of 194 mm annually in the southeast (source: WorldClim v2). Intense rainfall events typically occur during the rainy season between November and April.

In the southeastern part of the catchments, lands are mainly bare. In the wadi bed, some small patches of barley are cultivated. In the upstream area, which experiences slightly higher rainfall amounts, most lands area ploughed for rainfed barley cultivation. This barley is generally not harvested and used for livestock grazing only.

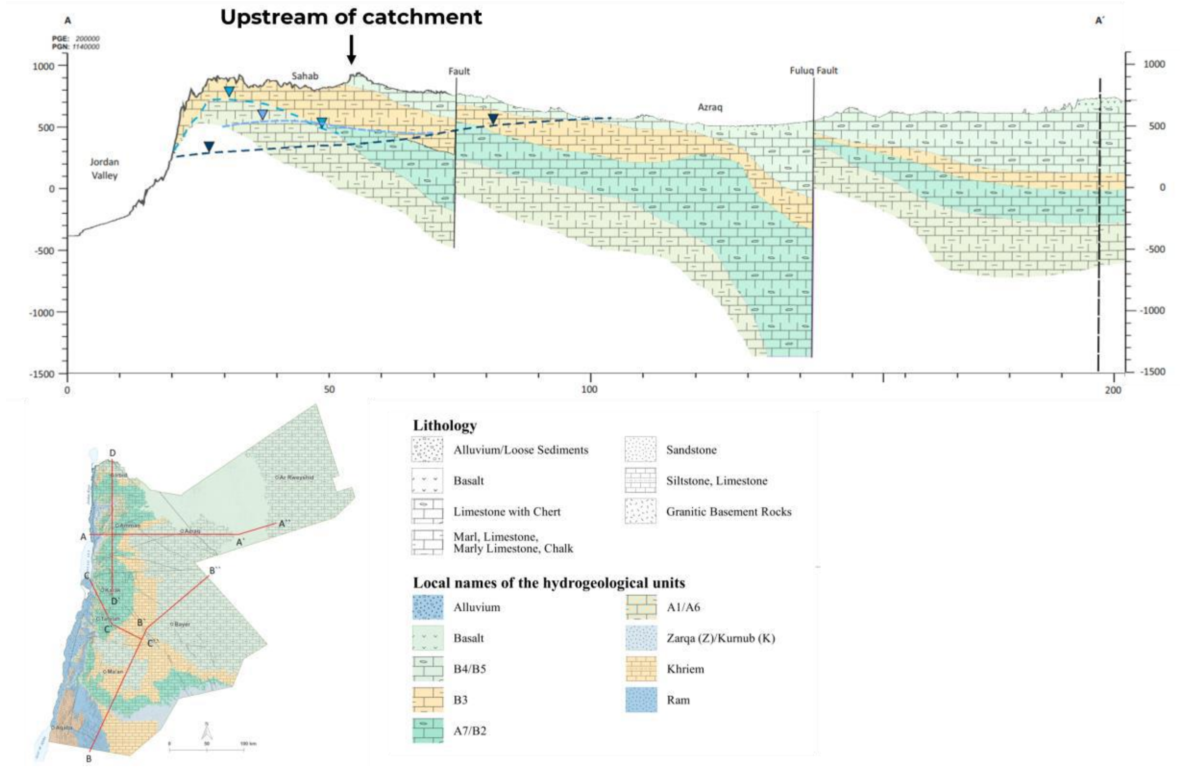

Figure 3. Hydrogeological cross-section adapted from BGR (MWI & BGR, 2019)

Most of the catchment is located on an undulating limestone (chert) plain of the B4/B5 formations (Figure 3). The landscape in the downstream area is characterized by flat to gently sloping lands. Towards Muwaqqar and Sahab, located west of the catchment, the B3 chalk marl formation - known as the Muwaqqar formation - crops out (Figure 4) and the terrain becomes more hilly.

Figure 4. Chalk Marl from the Muwaqqar formation (left and middle) and the limestone-chert from the B4/B5 formation (right).

Soils in the area are characterized by high silt content, strong surface crust, and weak aggregation (Sharaiha & Ziadat, 2008). Based on SoilGrids (Poggio, et al., 2021), the soils can generally be classified as silty clay loams. Soils in the area are shallow on the hillslopes to moderately deep in the valleys. The surface crusts result in poor infiltration capacity, speeding up surface runoff and erosion. The evolving rills and gullies quickly drain the excess water from the catchment, and little water is buffered within the landscape.

From the 1980s to 1990s, the expansion of rainfed cultivation in the catchment was significant (Al-Bakri, Taylor, & Brewer, 2001). Most rangelands changed into lands under rainfed cultivation of barley for livestock. This in combination with irrational ploughing practices and overgrazing aggravated land degradation in the area.

In general, the degradation of rangeland productivity in the Jordanian *Badia* started in the 1950s. After the cancellation of the rangeland protection system and traditional grazing rights (Al-Hima), rangelands were declared as state-owned and open to all. This policy shift resulted in overgrazing and diminished incentives for livestock owners and the *Badia* population to protect these rangelands (i.e. tragedy of the commons). Simultaneously, pressure on the limited resources grew as the number of grazing animals grew. Pastoral communities tended to change from nomadic Bedouin to settled ones. They began to plough marginal land at the borders of the *Badia* to grow cereals for their livestock, and to establish land ownership. Large areas of rangelands were ploughed and cleared of surface rocks, initially protecting the soil against erosion. Eventually, the increase in grazing animals exceeded the rangelands' carrying capacity, leading to widespread destruction of vegetation cover and reduced rangeland productivity. Nowadays traditional grazing rights are still mostly ignored and lands keep suffering from degradation (Al Karadsheh, Akroush, & Mazahreh, 2013).

Key issues

The following key challenges are identified within the sub-catchment:

- The major problem in the area is **land degradation leading to soil erosion.** The high variability of the limited rainfall, poor or absent vegetative cover, and the already weak soil structure with strong surface crusts result in high rates of soil erosion. Human interference and unsustainable land management have exacerbated the problem. Mechanized mono-agriculture (barley) and overgrazing by small ruminant herds (sheep and goats) have severely degraded the soils. Fertile top soil is easily flushed away, leading to high sediment loads in the water, siltation of downstream structures, and a reduced productivity of the land.

3 Tools for 3R implementation

This chapter presents multiple tools that can be used for selecting and allocating 3R interventions. The tools provide technical guidance to achieve well-informed and strategic 3R intervention planning.

3.1 Erosion risk mapping using RUSLE

One of the most commonly used soil erosion models is the Revised Universal Soil Loss Equation (RUSLE). Due to the model's relative simplicity and few data requirements, RUSLE is a well-known and universally accepted and implemented empirical soil erosion estimation model. To estimate annual average soil loss due to water erosion in t ha^{-1} $year^{-1}$, RUSLE uses five factors: 1) the rainfall erosivity factor (R), 2) soil erodibility factor (K), 3) slope length and steepness factor (LS), 4) cover management factor (C), and 5) conservation practice factor (P).

$$A = R \times K \times LS \times C \times P$$

The rainfall erosivity factor (R) evaluates the effect that rainfall has on soil erosion in MJ·mm ha^{-1} hr^{-1} $year^{-1}$. Originally, the annual R factor is calculated from detailed long-term records of storm kinetic energy (E) and maximum 30 min intensity (I_{30}). However, due to the extensive data requirements for this standard calculation, many studies use alternative equations depending on the temporal resolution of the available precipitation data (Benavidez, Jackson, Maxwell, & Norton, 2018).

The soil erodibility factor (K) indicates the influence of different soil features - such as soil texture, organic matter content, aggregate stability, and permeability - on the slope's susceptibility to erosion. The K factor essentially denotes the soil loss that would occur on the RUSLE unit plot[1] under a standard condition. Soils with high erodibility, i.e. higher K values, are more prone to erosion, while soils with low erodibility (lower K values) are more resistant to erosion (Ghosal & Das Bhattacharya, 2020).

The slope length (L) and steepness (S) factor reflects the effect of regional topography on the soil erosion rate. It is the ratio of expected soil loss from a field slope relative to the RUSLE unit plot (Wischmeier and Smith, 1978). As the length of the slope increases, the amount of cumulative run-off increases. As the land slope increases, the run-off velocity also increases causing more severe erosion. The initial method of calculating the LS factor uses slope length, angle, and a parameter that depends on the steepness of the slope in percent (Wischmeier and Smith, 1978). A downside of this method, however, is its limited capability in capturing complex topography. As GIS technology advanced over the last decades, determining the LS factor by incorporating upslope contributing area or flow accumulation along with slope gained popularity. Utilizing Digital Elevation Models (DEMs) to compute upslope contributing area and the LS factor, enables the possibility to capture more topographically complex landscapes (Benavidez, Jackson, Maxwell, & Norton, 2018).

The fourth aspect that greatly influences soil loss is the amount and type of vegetation cover. In essence, a dense vegetation cover dissipates the kinetic energy of raindrops before reaching the soil surface, diminishing the effects on soil erosion. This aspect is captured by the cover management factor (C). The unitless cover management factor (C) is directly affected by the vegetation type, stage of growth, and vegetation density. In the simplest scenario, C factors are obtained from literature and assigned to the land cover classes present in the study area by utilizing lookup tables. However, with the emergence of remote sensing technologies, satellite imagery is now commonly utilized to establish a correlation between the C factor and Normalized Difference Vegetation Index (NDVI) (Benavidez, Jackson, Maxwell, & Norton, 2018). Utilizing NDVI offers advantages over the simpler method of using a lookup table. Firstly, lookup tables often provide static C values

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[1] plot that is 22.1 m long, 1.83 m wide, and has a slope of 9%

per land cover type, which may not account for temporal variations in vegetation cover. Additionally, using NDVI allows for a site-specific assessment of vegetation conditions by capturing spatial variations in vegetation cover within a given area. For instance, differences in productivity and vegetation cover may exist even if all lands are classified as grassland. By using the quantitative NDVI values to derive the C factor, a more precise estimate can be made based on the degree of vegetation cover and biomass present in the landscape.

The last factor considered by RUSLE is the conservation or support practice factor (P). The P factor (unitless) reflects the ratio of soil loss under a specific soil conservation practice (e.g. contouring, or terracing) to that of a field with up- and downslope tillage. The P factor ranges from 0 to 1; the more effective the conservation measure at reducing soil erosion, the lower the P factor. Similar to the C factor, values for P factors can be taken from literature. When support practices are absent, the P factor is set to a value of 1.0. Different types of tillage, strip cropping, contouring, or terracing, are common support practices that could be captured by this factor (Benavidez, Jackson, Maxwell, & Norton, 2018; Ghosal & Das Bhattacharya, 2020).

3.2 Input data

R factor

As sub-daily rainfall timeseries of sufficient length are not available for the catchment, the R factor was calculated based on the annual average precipitation obtained from the WorldClim v2 dataset. The equation developed by Eltaif et al. (2010) was used to compute the rainfall erosivity factor:

$$R = 23.61 \times e^{0.0048P}$$

Where, R is the rainfall erosivity factor in MJ·mm ha^{-1} hr^{-1} year^{-1}, and P the annual average precipitation in mm yr^{-1}. The abovementioned equation was developed for Jordan specifically and used in previous studies to estimate soil erosion in Wadi Kufranjah and Wadi Kerak (Farhan & Nawaiseh, 2015; Farhan, Zregat, & Farhan, 2013).

The derived values for Muwaqqar range from 60 in the southeast to 86 MJ·mm ha^{-1} hr^{-1} year^{-1} in the northwest (Figure 7), consistent with the transition from a semi-arid to an arid climate. It should be noted, however, that this is expected to be an underestimation of the erosivity factor. Rainfall in the study area occurs in the form of intensive storms of short duration, meaning that annual average precipitation is rather low. As intense rainfall events over short periods can cause significant erosion compared to steady, light rainfall over an extended period, the influence on soil erosion is not correctly reflected when not taking into account rainfall intensity. The study by Ahmed et al. (2022) also indicated that the R factor is often significantly underestimated in the Arabian Peninsula when using alternative equations based on available rainfall data such as annual rainfall data.

K factor

To calculate the K factor SoilGrids data (Poggio, et al., 2021) was used. SoilGrids contains the spatial distribution of soil properties across the globe at six standard depth intervals and a spatial resolution of 250 meters. In this study, information on the following soil properties were needed: sand content; silt content; clay content; and soil organic carbon content.

Of the datasets, averages of the topsoil (0-30cm) were calculated and the mapped units were converted to the required units (%). Data gaps were filled by using bilinear interpolation. To estimate the K factor, the following equation of the Environmental Policy Integrated Climate model (EPIC) was used (Sharpley & Williams, 1990):

$$K = 0.1317 \times \left(0.2 + 0.3 \times e^{\left[-0.256 \times SAN\left(1-\frac{SIL}{100}\right)\right]} \times \left(\frac{SIL}{CLA + SIL}\right)^{0.3}\right) \times \left[1 - \frac{0.25 \times TOC}{TOC + e^{(3.72-2.95 \times TOC)}}\right] \times \left[1 - \frac{0.7 \times SN}{SN + e^{(22.9 \times SN - 5.51)}}\right]$$

Where, K is the soil erodibility in t·ha·hr ha^{-1} MJ^{-1} mm^{-1}; SAN the sand fraction (%); SIL the silt fraction (%); CLA the clay fraction (%); TOC the soil organic carbon content (%); and $SN = 1 - SAN/100$

The K factor in the study area ranges from 0.06 in the most upstream area to 0.04 in the southeast (Figure 7). Most soils in the area can be classified as silty clay loams, making the spatial distribution of K relatively uniform and the range relatively small. Although, it can be concluded that the soils in the southeast are a little more susceptible to erosion compared to the soils in the upstream area. The K factor tends to increase from the northwest to the southeast, corresponding to the slight increase in silt content and decrease in soil organic carbon towards the downstream area.

LS factor

To capture more complex topography, it was decided to use a method that incorporates contributing area and flow accumulation derived from SRTM 30m DEM. However, calculating the topographic factor by GIS remains an object of controversy due to selection of the applied algorithm (Hrabalíková & Janeček, 2017). As the chosen algorithm strongly influences soil erosion estimates, multiple algorithms were tested by using SAGA in QGIS (Desmet & Govers, 1996; Moore & Nieber, 1991). According to Hrabalíková & Janeček (2017), using GIS-based approaches to estimate LS values generally results in under-predicted soil erosion rates compared to measured soil loss. It was therefore decided to use the method of Desmet & Govers (1996) which resulted in the highest average LS factors.

The calculated LS factor in the study area has a mean value of 4.95 and ranges from 0.03 to 99.61 (Figure 7). The largest values occur in the northwest, which is in line with the region's topography. The steepest slope gradients in the northwest makes this area vulnerable to erosion.

C factor

As previously described, determining C factors through the NDVI calculated from satellite imagery provides benefits over the simpler method using lookup tables. Therefore, we employed this first method to estimate the C factor values. The NDVI is a proxy for greenness of an area and is closely related to vegetation cover. Values range from zero to one, representing bare areas with no vegetation (0) to areas fully covered by vegetation (1).

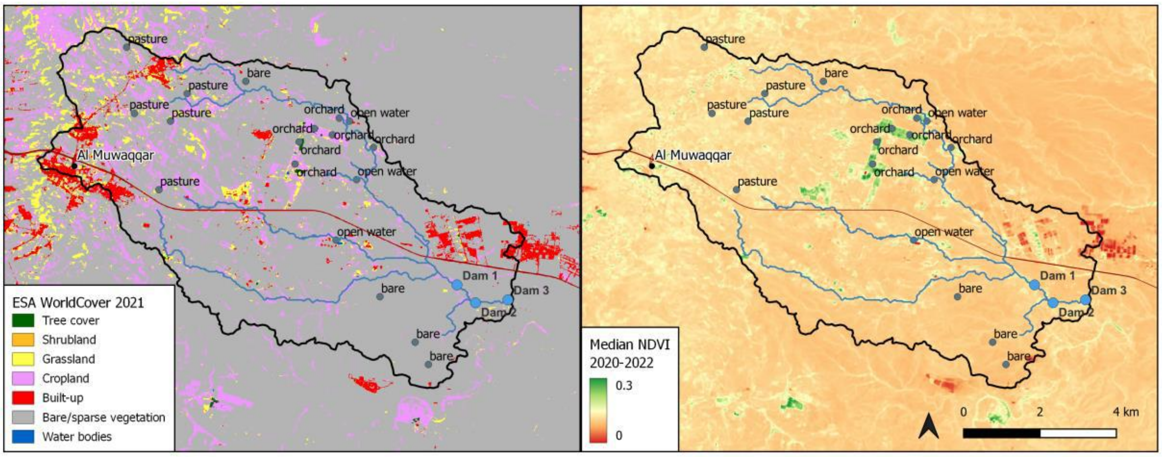

Figure 5. Figure showing the points used to derive the relationship between the C-factor and the NDVI in the study area. The left figure shows the correspondence of the points with the landcover map, and the right figure shows the NDVI at the different locations.

The relationship was derived by using linear regression. Median NDVI values were calculated for multiple points in the study area reflecting bare areas, pastures and orchards (Figure 5). These values were subsequently related to C-values obtained from a previous study conducted in Jordan (Qaryouti, Guertin, & Ta'any, 2014) and values developed by Wischmeier & Smith (1978)(see Annex 8). The results of the linear regression analysis are shown in Figure 6. For built-up areas and open water reservoirs, the C values were taken from literature and set to 0.05 and 0, respectively. This because both land uses are associated with extremely low NDVI values, which would lead to unrealistically high C factors when considering the derived linear regression function. The resulting C factors for the study area are shown in Figure 7.

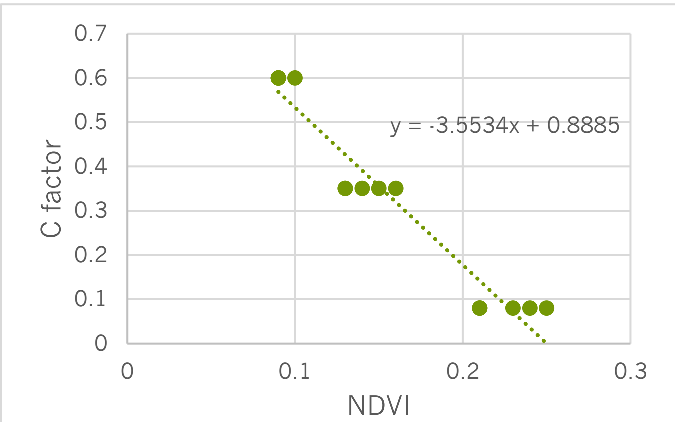

Figure 6. Relationship derived between NDVI and C factor.

P factor

It was assumed that conservation measures are currently non-existent within the study area. Hence, the conservation practice factor (P) was set to 1 for the entire area.

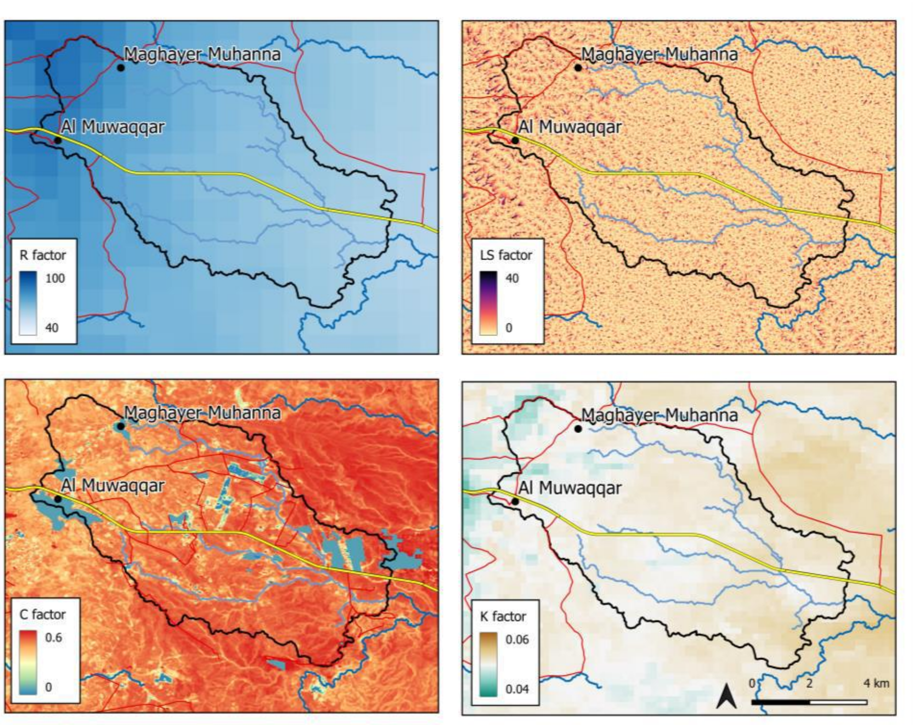

Figure 7. Input layers used in the revised universal soil loss equation (RUSLE).

3.3 Results RUSLE

The results are shown in Figure 8. The annual average soil loss amount within the Muwaqqar catchment is estimated at 7.95 t ha^{-1} yr^{-1}. According to RUSLE, the upstream area is most vulnerable to soil loss due to water erosion, which can mainly be attributed to the higher slopes and precipitation amounts in this region. Very severe erosion rates (>50 t ha^{-1} yr^{-1}) mostly occur in this area, with a maximum soil loss rate of 160 t ha^{-1} yr^{-1}. Lowest soil losses occur in the northeast corner of the catchment where quite some built-up area can be found.

Figure 8 (bottom) shows the average annual soil loss per sub-catchment. As can be seen from the results, the upstream sub-catchments (sub-c. 25, 28, 30 and 31) experience the highest average annual soil loss rates, with sub-catchment 30 and 31 having the highest rates of ±10 t ha^{-1} yr^{-1}. Also sub-catchments 13, 15, 16, and 17 – located in the southeast, upstream of dam 2 and dam 3 – experience relatively high levels of soil loss despite the lower R factor. This is likely to be caused by the lack of vegetation cover in this area and the slightly higher susceptibility of the soils to erosion.

It is, however, important to note that the absolute values of the analysis should be considered carefully. As mentioned before, multiple uncertainties exist in the applied method. For example, the selection procedure of the algorithm calculating the LS factor and the likely underestimation of the R factor as explained in section 3.2 are influencing the absolute soil loss values. Besides, it was assumed that no conservation practices are applied.

Another factor that results in inaccurate estimations of soil loss is the inability of RUSLE to account for erosion due to ephemeral gullies (Benavidez, Jackson, Maxwell, & Norton, 2018). These gullies, which are small channels formed by the erosive forces of concentrated overland flow during rainfall events, can significantly contribute to sediment loss. Although RUSLE considers factors like slope length and steepness, these parameters may not adequately capture the complexities involved in the formation and evolution of gullies. This because more complex geomorphological and hydrological interactions are involved in gully formation. From field observations and Google Earth imagery we can conclude that gully formation is frequently occurring in the sub-catchment, increasing the likelihood of inaccurate soil loss estimations by using RUSLE.

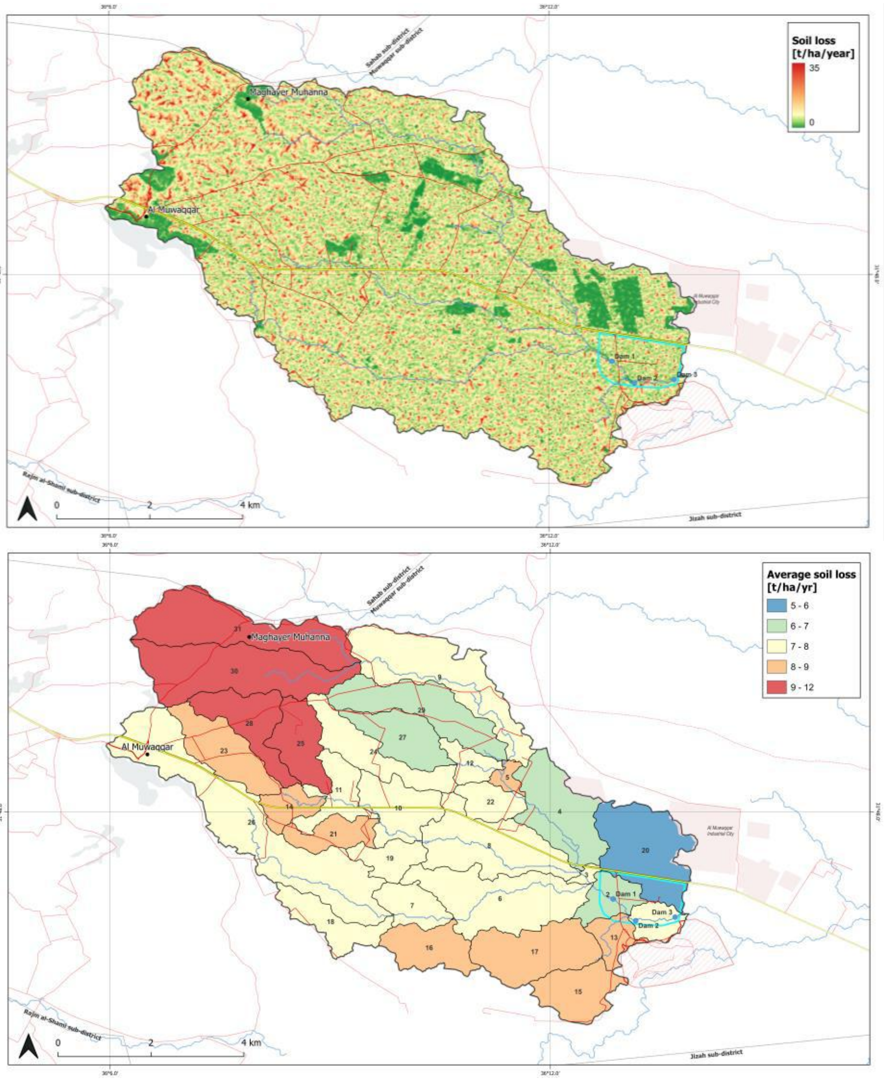

Figure 8. Soil loss map for the Muwaqqar catchment (top), and annual soil loss averages per sub-catchment (bottom). Larger maps are available in the Annex.

Despite RUSLE's limitations, the results still provide valuable information on the spatial distribution of soil loss due to water erosion within the catchment. RUSLE can be a good first attempt at identifying vulnerable areas; the results are therefore used to identify erosion risk zones (i.e. erosion hotspots) which should be targeted for SWC measures in the landscape. In addition, the results are used to select target sub-catchments that are most vulnerable to erosion and should be protected first by the implementation of 3R measures focusing on SWC.

3.4 Validation

Based on available field data derived from INWRDAM, Google Earth imagery and the field visit, a quick validation of the analysis was performed. Overall, it can be concluded that visible erosion on GE imagery is well captured by the results of the analysis, especially in the sloping areas. Pictures from the field also show signs of erosion at the identified erosion hotspots in the upper catchment (Figure 9, top). However, especially in the lower catchment it is notable that not all eroded areas are captured by the identified hotspots. For example, in Figure 9 (bottom) it is evident that gully erosion influenced the landscape, while this area was not identified as erosion hotspot. The fact that RUSLE estimates soil loss through sheet and rill erosion, but not from other types of erosion such as gully erosion (see section 3.3), can explain this fact

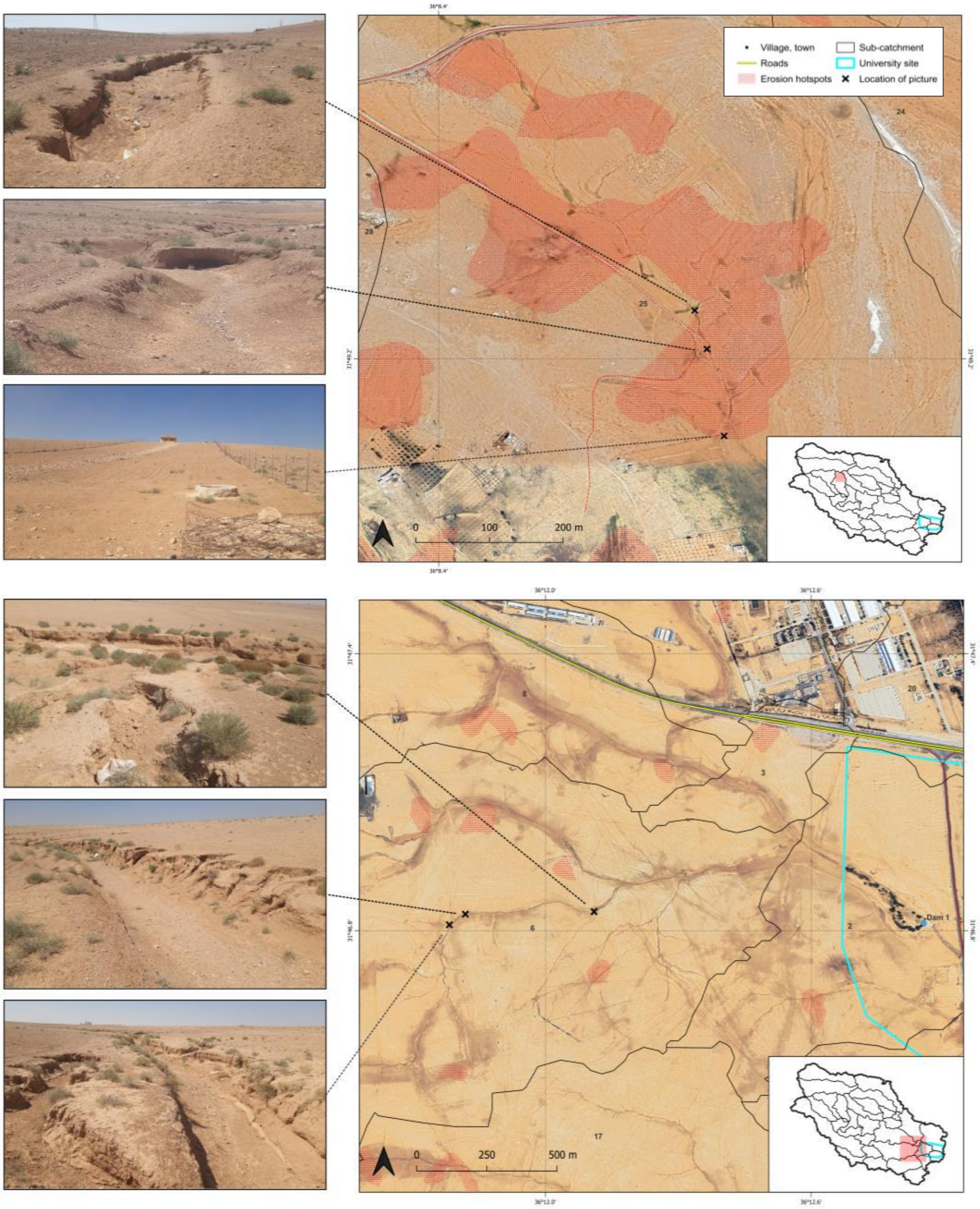

Figure 9. Identified erosion hotspots in the upper catchment incl. pictures from the field validating the erosion (top, source pictures: INWRDAM, 30-8-2023). Gully erosion observed just upstream of the first dam (bottom, source pictures: INWRDAM, 28-8-2023).

3.5 3R potential mapping

The 3R potential map highlights the potential in an area for interventions which promote the 'Retention, Recharge and Re-use' (3R) of water. Here, we particularly focus on 3R measures that would reduce soil loss due to water erosion. The 3R potential is determined based on an area's biophysical context; in this case land cover, slope, and soil loss rates derived from RUSLE are considered. Areas with similar biophysical features are combined into a 3R-zone, which are subsequently linked to interventions suitable for that particular area. Given the focus on soil erosion, less relevant land uses, such as built-up areas, were not considered in the mapping exercise.

In this study, six different zones were identified based on land cover and slope. Besides, areas larger than 2500 m^2 and with soil loss rates exceeding 10 t ha^{-1} $year^{-1}$ were converted into so-called 'erosion hotspots'. These erosion hotspot indicate areas that are prone to soil erosion and where implementation should be prioritized.

The recommended interventions can mostly be categorized as Soil and Water Conservation (SWC) measures. These are measures that are relatively straightforward regarding their technical complexity but can have very high impact. Some general practices, more focusing on behavioral change of local land users, are also incorporated (e.g. grazing management or area closures). These measures can lead to the most permanent change, however, they will take time and effort to implement.

For potential future work and upscaling, the 3R potential map offers stakeholders, government officials, and land and water management planners valuable insight and support regarding the suitability of various 3R measures across diverse biophysical environments. Here, the 3R potential map presents a long list of interventions tailored to the landscape's characteristics and aimed at mitigating soil losses and improving land productivity. Additionally, it indicates priority areas for implementation based on each area's vulnerability to soil erosion.

Figure 10 displays the 3R potential map of the Muwaqqar catchment (a larger map can be found in the Annex). Suitable interventions for each zone are shown in . A description of all interventions is provided in the '3R intervention manual Jordan' (Acacia Water, 2022). Note that gully erosion was not considered in the mapping process, resulting in the exclusion of measures specifically addressing gully erosion from the 3R table. Despite their absence from the table, implementing measures to control gully erosion is strongly advised within the area.

Table 1. 3R potential table linking interventions to the identified 3R zones.

Prioritization			
Zone	**Siting specifications**		
	High erosion risk		Prioritize implementation in this area
Off-stream measures			
Zone	**Siting specifications**		**Interventions**
	Land cover	**Slope**	
	Bare/sparse vegetation	Flat (<5%)	Stone lines, *Vallerani* system, *Negarim* micro-catchments, revegetation with (temporary) area closures, *Al Hima* grazing management
		Gently sloping (5-15%)	Contour stone/soil bunds, *Vallerani* system, revegetation with (temporary) area closures, *Al Hima* grazing management
		Steep (>15%)	Staggered contour trenches, stone walls, revegetation with (temporary) area closures, *Al Hima* grazing management
	Rainfed agriculture	Flat (<5%)	Contour ploughing, *Negarim* micro-catchments (trees), stone lines, contour strip intercropping
		Gently sloping (5-15%)	Contour ploughing, Contour stone/soil bunds, contour strip intercropping
		Steep (>15%)	Contour bench terraces
In-stream measures			
Zone	**Siting specifications**		**Interventions**
—	Wadi		Gabion check dams

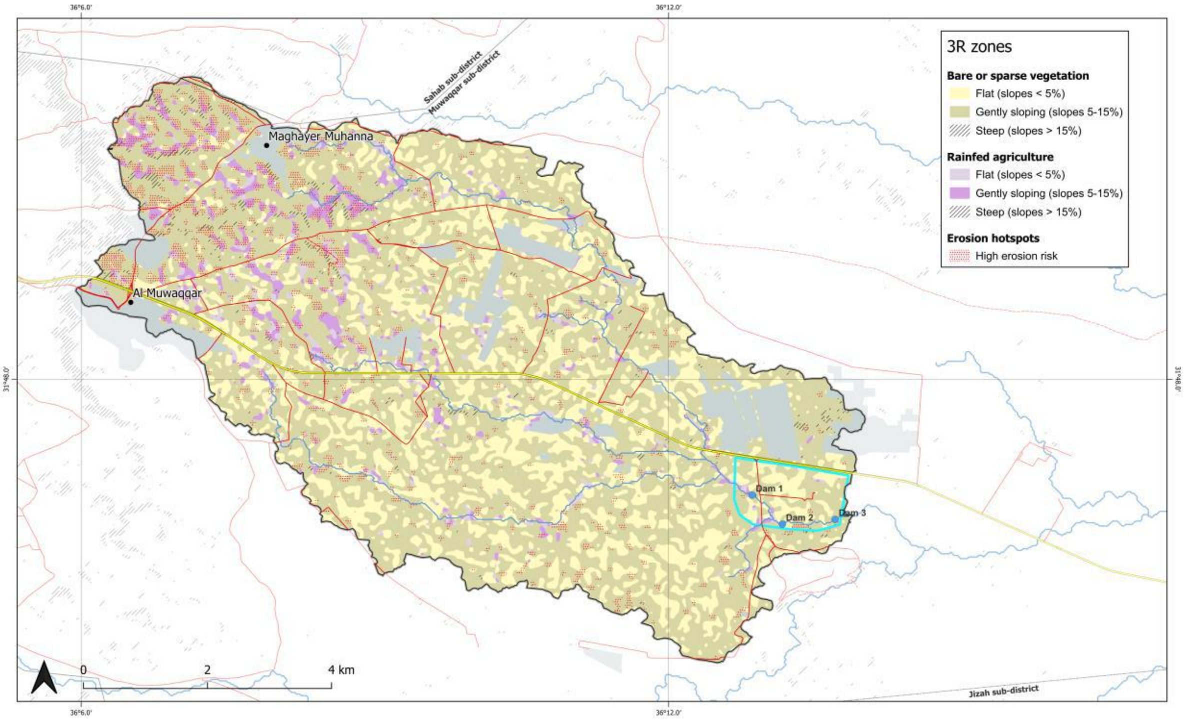

Figure 10. 3R potential map for the Muwaqqar catchment. A larger version of the map is available in the Annex.

4 3R opportunities

Unsustainable land management in combination with unfavourable natural conditions has led to soil erosion at different locations within the catchment. In order to create long-term effective solutions, it is crucial to consider the soil erosion occurring in the upstream catchment area of the University Research Station. When neglecting this issue, siltation is likely to strongly reduce the life expectancy of the storage ponds and frequent maintenance is required increasing future costs. Accordingly, the prime focus of the proposed 3R interventions is to:

Reduce siltation and enhance the long-term efficiency of the storage ponds at the Muwaqqar University site by lowering upstream soil erosion and improving land productivity through the implementation of SWC practices.

To provide effective integrated solutions, it is important to assess the area from a hydrological catchment perspective. A catchment approach takes into account the synergies between Soil-Water-Vegetation, and the potential upstream-downstream influences of these different elements. In specific, the implementation of SWC measures upstream is likely to positively affect the siltation situation downstream. Allocation of 3R interventions should therefore be done from a broader scale, taking into account up- and downstream interconnections.

Another important aspect to consider is the fact that the effectiveness of 3R interventions is often increased when implementing a combination of measures, instead of a single intervention. Implementing a large number of small interventions within one sub-catchment as opposed to one or just a few large interventions in different sub-catchments, can reach more people, is most times at least as effective, and often more cost-effective.

Taking the catchment approach into consideration, four target sub-catchments were selected based on their vulnerability to erosion. As these sub-catchments experience the highest average soil loss rates (Figure 8), implementation of SWC practices in these areas should be prioritized. The 3R map of these target sub-catchments is shown in Figure 11. Due to the limited scope of the 3R project, we will solely focus on sub-catchment 31. Demonstrating the approach in this sub-catchment can provide valuable insights for potential future initiatives in the other designated sub-catchments by other organizations or governmental bodies.

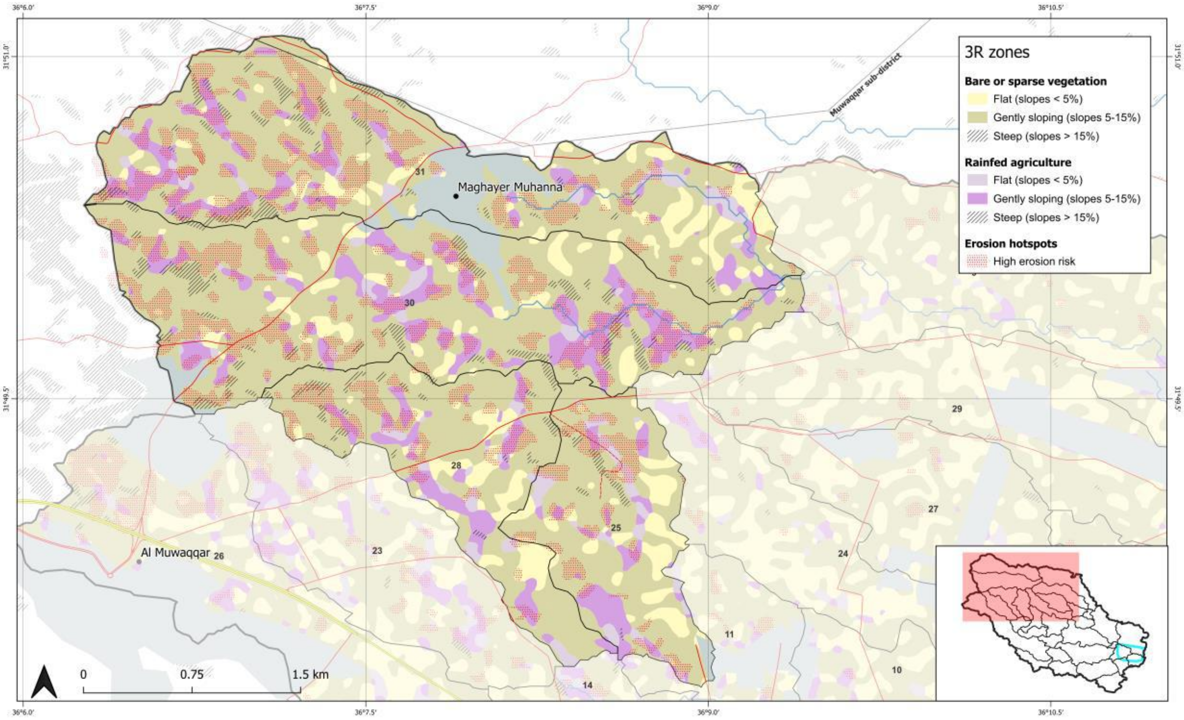

Figure 11. 3R potential map of the selected target sub-catchments. The sub-catchments were selected based on their high vulnerability to erosion. We will focus on sub-catchment 31.

4.1 Recommended interventions

According to the 3R map, the target area exists mostly of gently sloping lands with bare or sparse vegetation (Figure 11). Most lands have been ploughed for rainfed cultivation of barley. The analysis yielded the following long list of interventions suitable for target sub-catchment 31:

- Contour ploughing
- Stone lines
- Contour bunds (stone/soil)
- Staggered contour trenches
- Stone walls
- *Negarim* micro-catchments
- *Vallerani* system
- Revegetation with (temporary) area closures
- *Al Hima* grazing management
- Contour strip intercropping
- Contour bench terraces

Based on the desk study a few potential locations were identified. The field visit confirmed and/or provide additional information for making the final decisions on the selection and allocation of interventions.

During the field visit, it was noted that some hills are more degraded compared to other similar or neighboring hills. This was evident, for example, in sub-catchment 31, where the southwestern part was more degraded than the northeastern region (Figure 12). The presence of Bedouins residing on the southwestern hills suggests that overgrazing is the likely cause of this degradation. In the northeastern part, some interventions were already implemented within the landscape (e.g., soil bunds and stone walls), and the land was still covered with barley instead of being overgrazed (Figure 12, left). These differences indicate that it is likely that land ownership or other institutional arrangements strongly influence the state of the rangelands.

Figure 12. Example of implemented soil bunds (left), and the degraded hills with Bedouins in the southwest of the sub-catchment (right).

Accordingly, the interventions mainly target this southwestern part (Figure 13). Below are brief descriptions of the potential SWC interventions suitable for the chosen locations. In addition to the proposed interventions, promoting contour ploughing among farmers is most important and likely the most straightforward and cost-effective measure.

Please note that this selection represents only a subset of the possibilities within the sub-catchment. Besides, it should be noted that measures preventing gully erosion were not incorporated in the 3R mapping exercise. Nevertheless, some recommendations on these type of measures are provided as well since gully erosion is a common phenomenon in the study area.

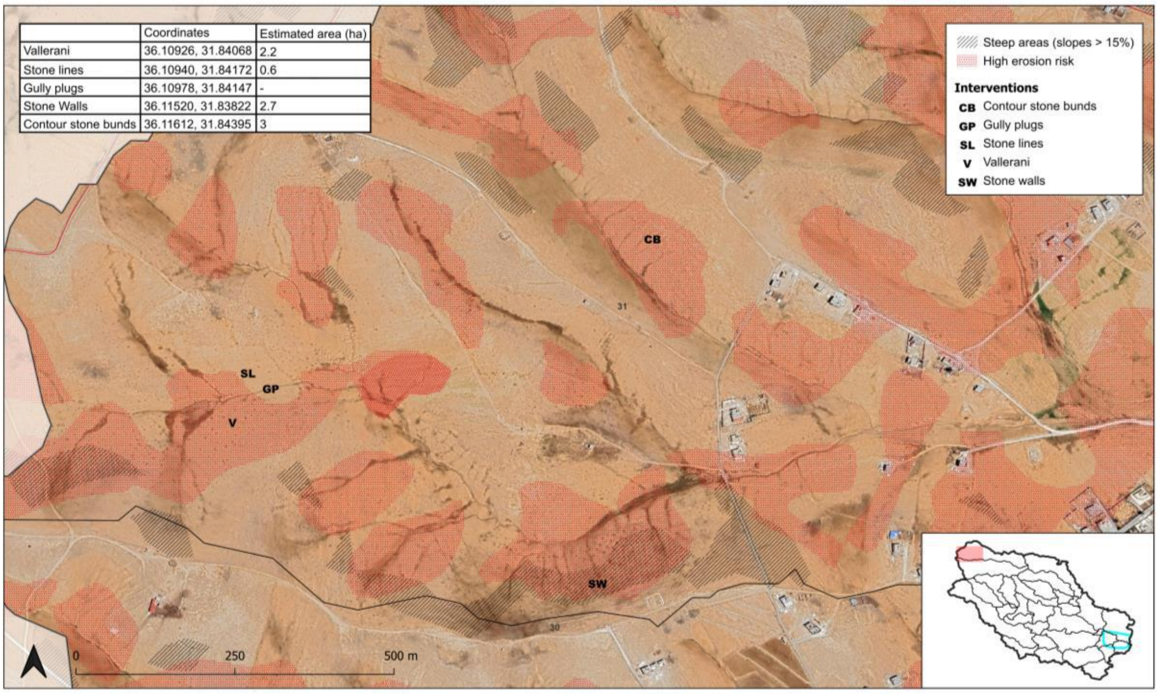

Figure 13. Allocation of interventions in target sub-catchment 31 based on the 3R assessment and field visit. A larger version of the map is available in the Annex.

1. The construction of **stone walls (SW)** is advised on the steeper slopes with sparse vegetation cover. By constructing stone walls, slope lengths are reduced, lowering surface runoff amounts and controlling soil erosion. Besides, soil moisture retention and soil quality is improved, which eventually benefits vegetation growth. As sediment is retained behind the walls, water contamination due to high sediment loads will likely be reduced. This technique is already familiar and implemented within the same sub-catchment, which probably strengthens social acceptance and increases the likelihood of successful implementation (Figure 14).

   An example of implementation in Afghanistan can be found here: https://qcat.wocat.net/en/wocat/technologies/view/technologies_1723/

Figure 14. Implementation of stone walls on very steep slopes in Afghanistan (left), and implementation in sub-catchment 31 in Jordan (right).

2. In the flatter areas, **stone lines (SL)** can be used to conserve the soil and reduce runoff. The stones are placed along the contour lines and serve to slow down runoff water thereby enhancing infiltration and retaining sediment. Stone lines are particularly effective for water harvesting on flat to gently sloping terrains (<5%) in semi-arid regions (Figure 15). The distance between the lines is a function of the slope and availability of stones of different sizes. It is recommended to keep the lines 20 m apart from each other for slope < 1% and 15 m for slopes between 1-2%. If stones are available in the immediate surroundings, the implementation is relatively straightforward and cheap.

   More information can be found here: https://www.greener.land/index.php/product/stone-lines/

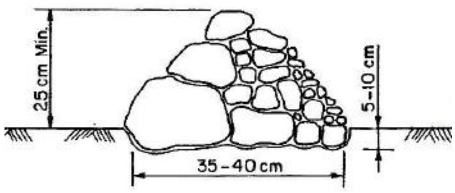

Figure 15. The target area with visible signs of erosion (left), and a cross-sectional illustration of a stone line (right).

3. On the foot slope (with sufficient soil depth) of the degraded hill, the construction of ***Vallerani* (V*)*** micro-catchments can reduce the amount of runoff and reduce soil erosion (Figure 16). *Vallerani* ploughing is a form of micro-water harvesting and can support vegetation recovery and/or rehabilitation of degraded rangelands. The overall idea is to construct small water harvesting pits (or trenches) along the contour by using a specific plough so that runoff water can be captured and infiltration is supported. This intervention can be combined with **revegetation** of native seedlings for fodder production. Due to the harsh climatic conditions selection of appropriate species is key. A commonly used species is *Atriplex halimus*, a shrub that is native to the region, well-adapted to the harsh climate and a protein-rich fodder species. When revegetating, it is essential to protect the newly planted seedling for two to three growing seasons before being grazed by livestock. This protection period aims to provide sufficient time for the new seedlings to establish properly. It also facilitates the re-establishment of native plant species and replenishment of the natural storage of seeds (soil seed banks) in the soil.

   An example of the successful implementation of the *Vallerani* system in Jordan can be found here: WOCAT SLM Technologies

Figure 16. The hill to target (left) and an example of Vallerani's in Jordan (right).

4. The construction of **contour stone bunds** on the sparsely vegetated hills with thin soil cover can reduce soil erosion and increase soil moisture by intercepting surface water runoff. Stone bunds are similar to stone lines, however extra stability is needed as they are applied on steeper terrains. It is therefore important to dig a shallow foundation. Soil will build up behind the bunds and native species or barley can be planted in between the bunds. By doing so, the vegetation cover will recover, eventually providing fodder for livestock. The stone bunds should be constructed along lines of equal elevation (contour lines). The spacing between the bunds depends on the steepness of the slope. The stone bunds could be constructed with locally available material and by using a cash-for-work program in which the local community is involved so that ownership is created.

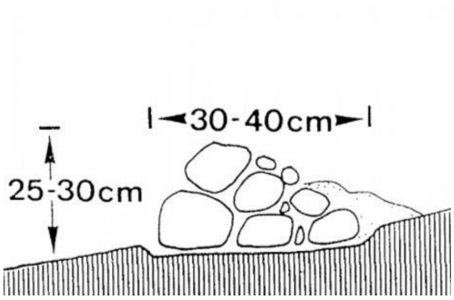

Figure 17. Target area for stone bunds (left), and cross-sectional illustration of a stone bund.

5. At different locations within the sub-catchment signs of gully erosion were observed from satellite imagery and in the field. Although gully erosion was not mapped, implementation of **gully protection measures** is advised. In general, treating gullies in early stages is easier and requires less labour and investment than in later stages when the gully has grown. It is therefore recommended to start controlling emerging gullies as soon as possible. Safely conveying water through the gully can be achieved by reducing its speed and erosive force. It is important to note that a single intervention is rarely effective in preventing gully erosion. Instead, a combination of gully rehabilitation measures and upstream SWC measures - as provided above - is recommended. The most suitable measure

depends on the size and stage of the gully. Below different possibilities are explained:

a. Where the gullies emerge, gully plugs (or loose rock check dams) could dissipate energy and regulate gully formation. The construction of a **cascade of gully plugs** positioned sequentially within a gully system will reduce the velocity of runoff and prevent the deepening or widening of the gully by accumulating sediments behind the structures, gradually filling up the gully. Additionally, gully plugs enhance infiltration and might allow groundwater recharge. Eventually, the trapped sediments can be used as arable land, which can provide additional income to the farmers.

   Stones are usually collected from nearby sites making the construction of gully plugs inexpensive. Due to their loose nature, their effectiveness is limited to small-to-mid-scale gullies or low-order channels like in the most upstream sub-catchments. In the higher order channels, where flood energy is higher, bigger structures, such as gabion check dams, are required. It appears that establishing numerous loose rock check dams uphill could be just as effective in regulating water runoff and controlling gully erosion as a small number of concrete- or gabion-check dams located downstream (Stavi, Siad, Kyriazopoulos, & Halbac-Cotoara-Zamfir, 2020). Several crucial design and construction aspects that should be considered to minimize the risk of failure are shown on the next page (Stavi, Siad, Kyriazopoulos, & Halbac-Cotoara-Zamfir, 2020; Knoop, Sambalino, & Steenbergen, 2012):

   An example of gully plug implementation in Jordan can be found here: https://qcat.wocat.net/en/wocat/technologies/view/technologies_5862/

b. Very small gullies with very little water flow can be stabilized by **reshaping and revegetation**. Steep gully heads and gully banks should be shaped to a gentler slope (about a one-to-one slope). The use of vegetative material in gully control offers a low-cost and permanent protection when well-managed. Plants can help bind soil particles together with their roots, reducing soil erosion and gully formation. However, vegetative gully control might be difficult here due to the arid conditions. Selection of the right species is therefore crucial and should be done by a local expert.

c. Where gullies are wider and flood flows becomes larger, the construction of **gabion check dams** can help to slow down water flow and trap sediments in the flood water. The general design considerations displayed in the textbox below are also valid for gabion check dams. To prevent structural failure, regular maintenance of gabions is necessary to avoid displacement or deformation of the cages and to monitor for wire breakage. (Stavi, Siad, Kyriazopoulos, & Halbac-Cotoara-Zamfir, 2020)

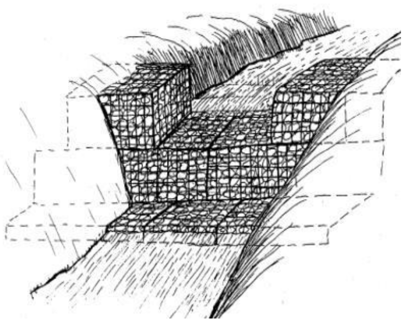

Figure 18. An illustration of a gabion check dam.

Important general design considerations for check-dams

- An adequate spillway should be constructed for safe disposal of water
- A foundation should be dug into the banks and gully bed. The foundation should include the width of the spillway
- The edges and it's base should be properly keyed into the gully banks and bed. Construction on bedrock directly can be challenging due to the need for a stable foundation and anchoring system. However, there are possibilities; for example, by drilling holes into the bedrock and using anchors. Consulting an experienced engineer familiar with construction on bedrock is strongly recommended.
- For loose rock check dams the construction of wing-walls to protect the wings of the check dam is advised. Wing-walls depart from the main dam wall and are directed upslope at a 30-45% angle
- In case of multiple sequential structures, proper spacing between the successive dams should be ensured based on the dam's height and channel slope.
- The height should be carefully considered. In general, low check-dams are less likely to fail than high dams. Higher dams retain larger amounts of water, which may increase pressure and consequently result in seepage and undermining.
- Large rocks should be placed on the downstream side of the dam to dissipate the energy of water falling through the spillway and protect the dam's toe.

More information on gully restoration can be found here: https://www.bebuffered.com/downloads/ManualonGullyTreatment_TOTFinal_ENTRO_TBIWRDP.pdf

General recommendations

Most abovementioned interventions are hard measures and imply the construction of physical structures. Soil erosion and siltation issues are, however, resolved not only by reducing soil loss through the implementation of such hard measures, but also by proper land management through soft measures focusing on community-scale efforts and decision-making. 3R implementation is in general most effective when hard and soft measures are combined. Some additional recommendations for the catchment are therefore provided below. These recommendations focus on the soft path and strive to improve the overall productivity of land.

1. Improper tillage practices, i.e. ploughing up-and-down slope, exacerbates soil erosion. Despite that it was observed at many locations within the study area. The implementation of **contour ploughing** is an effective and very simple alternative to traditional ploughing that prevents soil erosion. Contour ploughing involves tilling the soil along the contour lines of the land, creating a series of small ridges and furrows. By doing so, water is intercepted and slowed down as it flows downhill, reducing the impact of rainfall on the soil and allowing water to penetrate deeply into the soil. To reduce soil losses and stimulate the lands productivity, promoting contour ploughing among the farmers is strongly advised.

2. The implementation of the **'Al-Hima' land management** system could prevent further degradation of the rangelands in the catchment. 'Al-Hima' is a historical

and traditional system of land management in the Arab region that encourages the sustainable, shared use of common resources amongst local communities. What underlies 'Al-Hima' is the development of grazing protocols through which herds are regularly and systematically moved to 'rested' areas with the intent to maximize the quality and quantity of forage growth (Myint & Westerberg, 2015). By allowing the 'resting' lands time for regeneration, the vegetation can renew energy reserves, rebuild shoot systems, and deepen root systems. This all maximizes overall biomass production in the long-term and prevents further erosion. Another, more formal, term for such a system is managed rotational grazing.

3. When new seedlings are planted as part of the proposed interventions (e.g. in combination with *Vallerani's*), **(temporary) area closures** are advised. Area closures refer to the practice of fencing-off an area in order to protect it from human use and animal interference. The main objective of area closure is to allow natural regeneration and rehabilitation of degraded lands within the enclosed space. Area closure enhances natural regeneration and helps to restore organic matter and a healthy soil structure. The action can be temporary - until a certain degree of recovery has been attained - or permanently. If applied permanently, area closures can be combined with **cut-and-carry** practices; this means that grasses can be cut for the feeding of livestock from the enclosed space. By excluding livestock trampling and extreme grazing soil and vegetation is preserved, resulting in a greater productivity and reduced runoff. The closures can be realized by fencing or by (community) agreements. Another possibility is the planting of a live fence of cactus or similar thorny vegetation.

4. Another alternative to the traditional cultivation of barley, which involves ploughing up and down the slope, is **contour strip intercropping** of barley with other drought-resistant crops. Strip intercropping helps to slow or stop runoff and trap moving soil particles. Previous experiments conducted at the Jordan University Station for Arid Land Research have shown that the best practice to control both runoff and soil loss is to intercrop barley with vetches in strips along the contour, using a high plant density (350 plants m^{-2}) (Sharaiha & Ziadat, 2008). Intercropping barley with the fodder shrub *Atriplex halimus* in marginal areas in Syria has also shown promising results, increasing barley yield, providing additional fodder sources, and reducing the likelihood of soil erosion (Ghassali, et al., 2011).

5 Monitoring plan

To assess the effectiveness of the proposed measures, a monitoring plan is drafted. Monitoring allows us to measure the actual impact of the proposed interventions over an extended period. It helps identify changes in, for example, vegetation cover, soil moisture status, groundwater recharge and erosion rates. By comparing monitored data with baseline conditions, it is possible to assess whether the selected interventions are achieving their intended objectives.

Long-term monitoring also generates valuable data and lessons learned that can be shared with other regions and projects in Jordan. It contributes to the collective knowledge base, enabling the replication and scaling up of successful 3R interventions. The obtained data can inform best practices and guidelines, and support future decision-making processes, fostering a more evidence-based approach to 3R implementation in the country. Monitoring data also facilitates effective communication and collaboration among different stakeholders involved in SWC initiatives.

Despite the short project duration, setting up a monitoring network is strongly advised for abovementioned reasons. Preferably, monitoring continues for a 5 to 10 year period to be able to assess the long term effects. This, however, requires a strong commitment to the monitoring and evaluation process beyond the timespan of the project, and is only possible when there are direct incentives for the people involved. In this case, the University of Jordan is strongly involved and has a direct incentive. Therefore, university staff are strongly encouraged to engage in long-term monitoring and evaluation.

The suggested monitoring plan focuses on the monitoring of the biophysical impacts of the proposed interventions within the catchment, as well as at the University station:

1. To estimate the potential recharge resulting from infiltration from the storage ponds, it is strongly advised to **monitor water levels** in the ponds. The most common method for water level measurement is to use an electronic pressure transducer that is submerged in a stilling well (or a steel 2" tube with perforations), in which the water level moves with that of the pond. The sensor is connected to a datalogger and a modem, so that the data is automatically transmitted at regular programmable intervals to a dedicated server. It is recommended to install pressure sensors in each of the different ponds and one sensor in front of the first pond to **measure the inlet of water**. Measuring the water height at the inlet can help estimate discharge by using the water levels in the pond, the volume of the ponds, and the duration of the flood flow (i.e. the time it takes to fill the pond).

   An example of a suitable sensor is the TD Diver (van Essen, the Netherlands; https://www.vanessen.com), which is an absolute pressure and temperature measurement device integrated in a 22 mm diameter stainless steel tube that also contains the datalogger and power supply (Figure 19). The Diver has sufficient memory for two years of continuous measurements at 15-minute intervals and costs around €500 each. As long as the Diver is not submerged in water it measures atmospheric pressure. Once the Diver is submerged this is supplemented by the water's pressure: the higher the water column the higher the measured pressure. Due to variations in atmospheric pressure, barometric compensation is needed to convert the Diver pressure readings into water level data. To do this, the air pressure measurements from the telemetric meteorological station can be used. The barometrically adjusted water values can be related to a reference point such as a staff gauge. With each Diver, it is advised to install a staff gauge for visual water level measurements as reference. Staff gauges can also be used to measure the increase in sediment thickness in the ponds after a flood event.

More information on the Diver and its installation can be found in the product manual: [TD-Diver-DI8xx-ProductManual-en (vanessen.com)]

Figure 19. Example of pressure sensors (left and middle). The left sensor represents an absolute pressure and temperature sensor with the datalogger integrated in the housing. The middle sensor is air pressure compensated with a capillary vent in the cable. On the right an example of a floating evaporation pan is shown.

2. To be able to estimate recharge, water level monitoring should be combined with **evaporation measurements of the open water surface** of the ponds. Evaporation can be monitored using a floating water pan with a Diver (as described above) to measure the change in level of the water surface (Figure 19, right). The water pan should be refilled regularly (e.g. by a student) and placed at a location in the pond which is not adversely affected by shading.

3. Turbidity of the flood water can be analyzed by taking water samples and carrying out a sediment analysis in a laboratory to obtain the **Total Suspended Solids (TSS)**. Taking samples after the flood event or in the storage ponds will not give accurate representations of the TSS as coarser grained sediments will have settled down. It is therefore important to take the samples during a flood event at a location in the wadi (e.g. at the water level monitoring station before the first pond). As the dams are located at the University station, analyzing TSS could be an interesting research topic for bachelor or master students.

4. **Groundwater level monitoring** at one or more sites is advised to determine the seasonal and interannual variation in groundwater due to precipitation input, recharge (from the storage ponds and upstream measures) and groundwater outflow of the area. Although it may take a long time before increases in recharge might be manifest in groundwater level increases, long-term measurements will show developing trends in groundwater levels. If possible, measurements should be made in different geological formations. Pumping tests may be used to estimate aquifer properties. It is recommended to start with the rehabilitation of the existing monitoring well at the University station.

5. To measure **changes in soil moisture** content at the *Vallerani*s, the installation of TEROS 12 sensors is advised. TEROS 12 is a long-life, accurate and easy-to-install sensor with sharpened stainless steel needles that easily slip into the ground (Figure 20, left and middle). The sensors (± €300 each) have to be connected to a data logger to be able to perform telemetric measurements. One single data logger (YDOC), costs about €600 euros, has three sensor ports and is solar powered. To be able to measure the effect of the trenches on soil moisture content, one sensor can be installed in the bottom of the pit, while a second sensor can function as reference and be placed outside the pit or trench. The sensors can be installed at different depths to measure, for example, top soil moisture, soil moisture in the root zone or, in case of vegetation with a fairly shallow root system, below the root zone to quantify the amount of water draining down the profile. For each location (*Vallerani*), it is advised to install at least two sensors inside, and two reference sensors outside the trench or pit to account for spatial differences. The collected data can be used for student research.

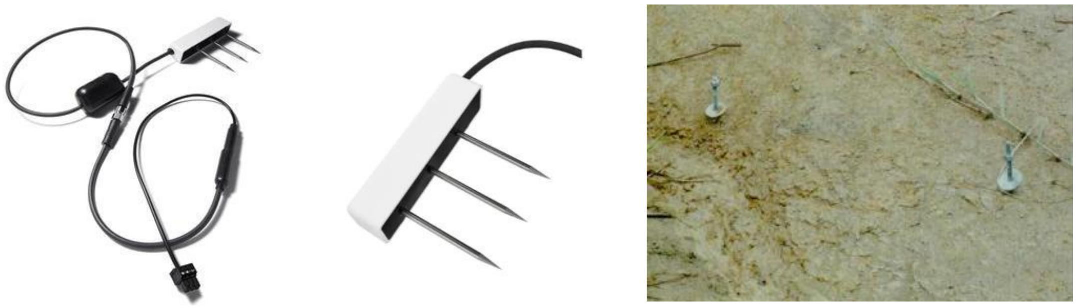

Figure 20. TEROS 12 sensor for soil moisture measurements (left and middle). Example of erosion pins with washers (right, source: SERC Carleton College).

6. An inexpensive and intuitive method to **estimate hillslope soil erosion and deposition** within the catchment is to use erosion pins. Erosion pins are suitable for measuring erosion at long time scales such as annual erosion rate; however, it is challenging to use the erosion pins for estimating soil erosion in short time scales (e.g. a specific rainfall event or specific day). The method uses metal pins that are driven into the ground perpendicular to the slope, with a washer at a known distance from the top of the pin (Figure 20, right). In theory, erosion undermines and lowers the washer, resulting in a new distance from the pin top that equals the depth of erosion that occurred between measurements. An increase in distance from top of the pin to soil surface indicates erosion; a decrease indicates deposition. The washer around the pin facilitates the measurements. It is advised to install at least 20 erosion pins in a grid on, for example, the stone bunds hillslope. By placing a transect of pins just behind the bund (upslope) the accumulation of sediment behind the bund can be monitored over the years. Another series of pins should be installed in between the bunds to monitor erosion. Ideally, a second - reference - study plot with an additional 20 pins will be installed on a hill with similar characteristics. In this manner, the effectiveness of the intervention can be evaluated. The measurements have to be carried out by an observer (e.g. student research) after each rainy season and after each dry season. The pins should be inspected for damage or disturbance throughout the season.

7. To **monitor potential biomass enhancements** within the catchment, a trend analysis with remote sensing data can be carried out. A proxy that can be used for this study is the Normalized Difference Vegetation Index (NDVI). The NDVI is an indicator of greenness of an area that can be derived from satellite imagery. NDVI is closely related to vegetation cover and soil moisture. Values range from zero to one, representing bare areas with no vegetation (0) to areas fully covered by vegetation (1). To set the baseline an analysis of the historical NDVI should be performed, which afterwards can be compared to future data to assess potential changes in vegetation cover.

8. The **accumulation of sediments in the storage ponds** can also be monitored by using erosion pins (or the staff gauges). In each reservoir it is recommended to install at least three erosion pins. After a flood event, an observer (or student) can measure the deposition of sediments. To carry out the measurements, the ponds have to be dry.

9. **Chloride mass balance monitoring** uses access to phreatic groundwater to analyse for chloride concentration. Chloride is a conservative element and combining measured groundwater chloride concentrations with those of precipitation and with precipitation totals allows for the calculation of recharge using the mass balance equation. Access to precipitation and groundwater also allows for the estimation of evaporative losses from oxygen and hydrogen isotopes.

10. **Soil loss or deposition rate monitoring** can be done using soil ^{137}Cs or ^{210}Pb isotope studies. A reference site should then be identified where erosion or deposition has not occurred in the past 60 years.

6 Next steps

- Before any activity can start, **discussions with the land owners** are key. When lands are privately owned, the landowner's consent and willingness to cooperate is required for successful implementation. Incentives for farmers to cooperate (e.g. improved access to fodder, improved soil fertility) should be communicated clearly so that the reason for implementation will be understood by the community. **Awareness raising and capacity building** is an important part of this. If the interventions are not socially accepted they will not be long-term sustainable.
- A qualified local engineer has to be contracted to develop the final designs. When constructing on bedrock, special attention has to be paid to ensure that appropriate construction techniques are used to create stable and effective structures. The team should collectively **evaluate the final designs** made by the engineer, before implementation starts.
- Where possible, it is advised to use a cash-for-work program for implementation. By **setting up cash-for-work programs** and involving the local community, ownership can be created. Due to this participatory approach, community members are more likely to support any future calls to assist in repair or maintenance work. Besides, it will increase the likelihood that any communal benefits are shared in a fair way.

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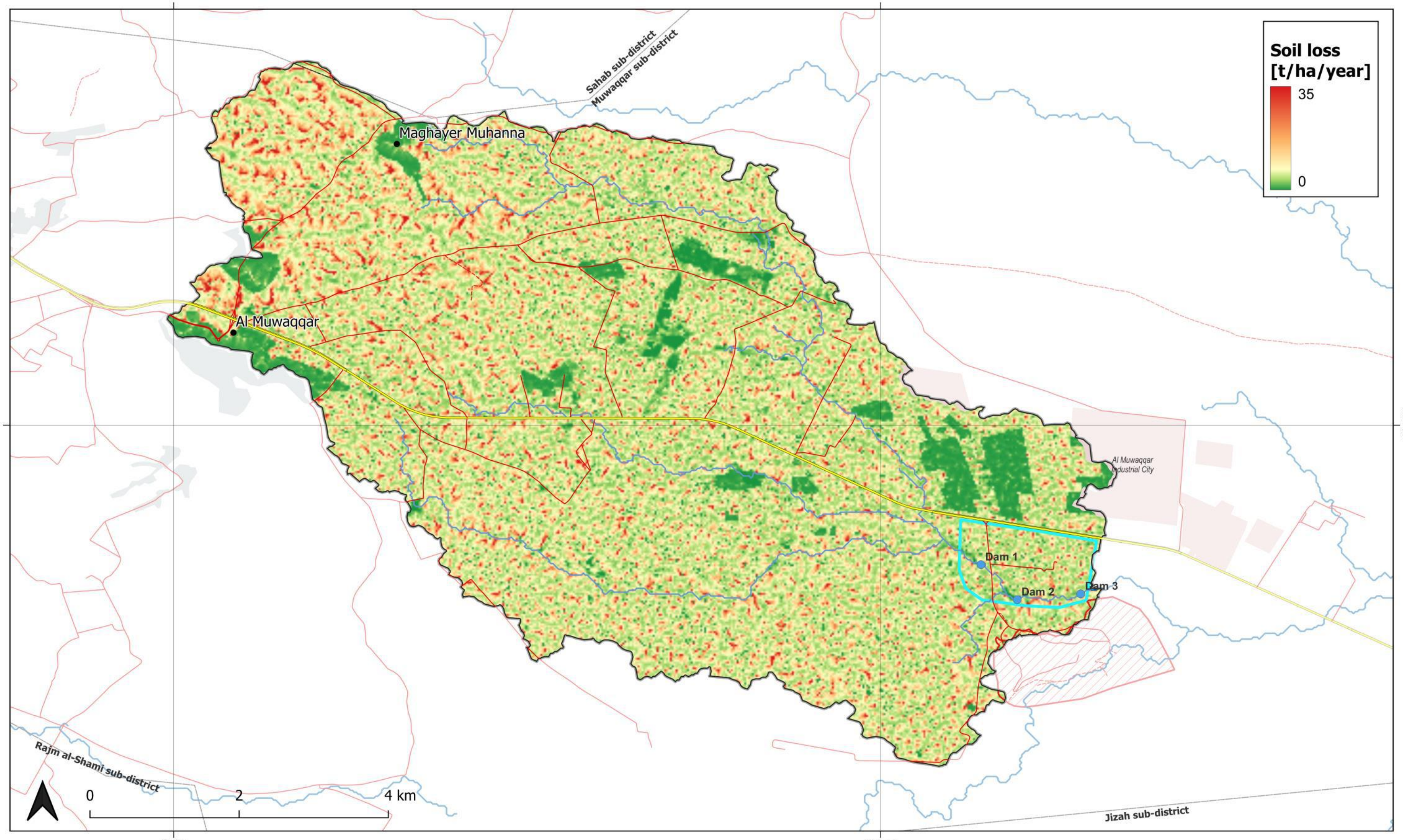
8 Annex

Table 2. Left: C factor developed by Wischmeier & Smith (1978), and right: C factors developed for Jordan (Qaryouti, Guertin, & Ta'any, 2014).

Land cover	*C* factor
Inland marshes	0
Salt marshes	0
Sclerophyllous vegetation	0.005
Broad-leaved forest	0.001
Coniferous forest	0.001
Mixed forest	0.001
Cultivation, with significant areas of natural vegetation	0.05
Non-irrigated arable land	0.05
Moors and heathland	0.05
Moors and heathland	0.05
Transitional woodland shrub	0.05
Sparsely vegetated areas	0.05
Discontinuous urban fabric	0.05
Industrial or commercial units	0.05
Mineral extraction sites	0.05
Fruit trees	0.08
Olive groves	0.08
Complex cultivation patterns	0.08
Natural grasslands	0.1
Burnt areas	1
Beaches, dunes, sands	1

code	Name	C VALUE
1	Dead Sea Water	0
2	Pastures	0.35
3	Vegetables	0.22
4	Sands(treated as bare soil)	0.5
5	Tree Crops	0.20
6	Basaltic Rocks (treated as a bare soil)	0.5
7	Chert Plains(treated as bare soil)	0.5
8	Dry Mudflat(treated as a bare soil)	0.5
9	Wet Mudflat(treated as a bare soil)	0.5
10	Dams (treated as urban) (most attenuation)	0.01
11	Urban Fabric (most attenuation)	0.01
12	Open Forest	0.05
13	Wadi Deposits (treated as bare soil)	0.5
14	Bare Soil / Bare soils (plowing along slope (0.85)	0.5
15	Closed Forest	0.001
16	Field Crops	0.22
17	Waste Water Plants (trial and error ,horticulture)	0.06
18	Quarries	1



Water Harvesting 3Rs
Retention-Recharge-Reuse

INWRDAM WATER DIPLOMACY

ACACIAWATER

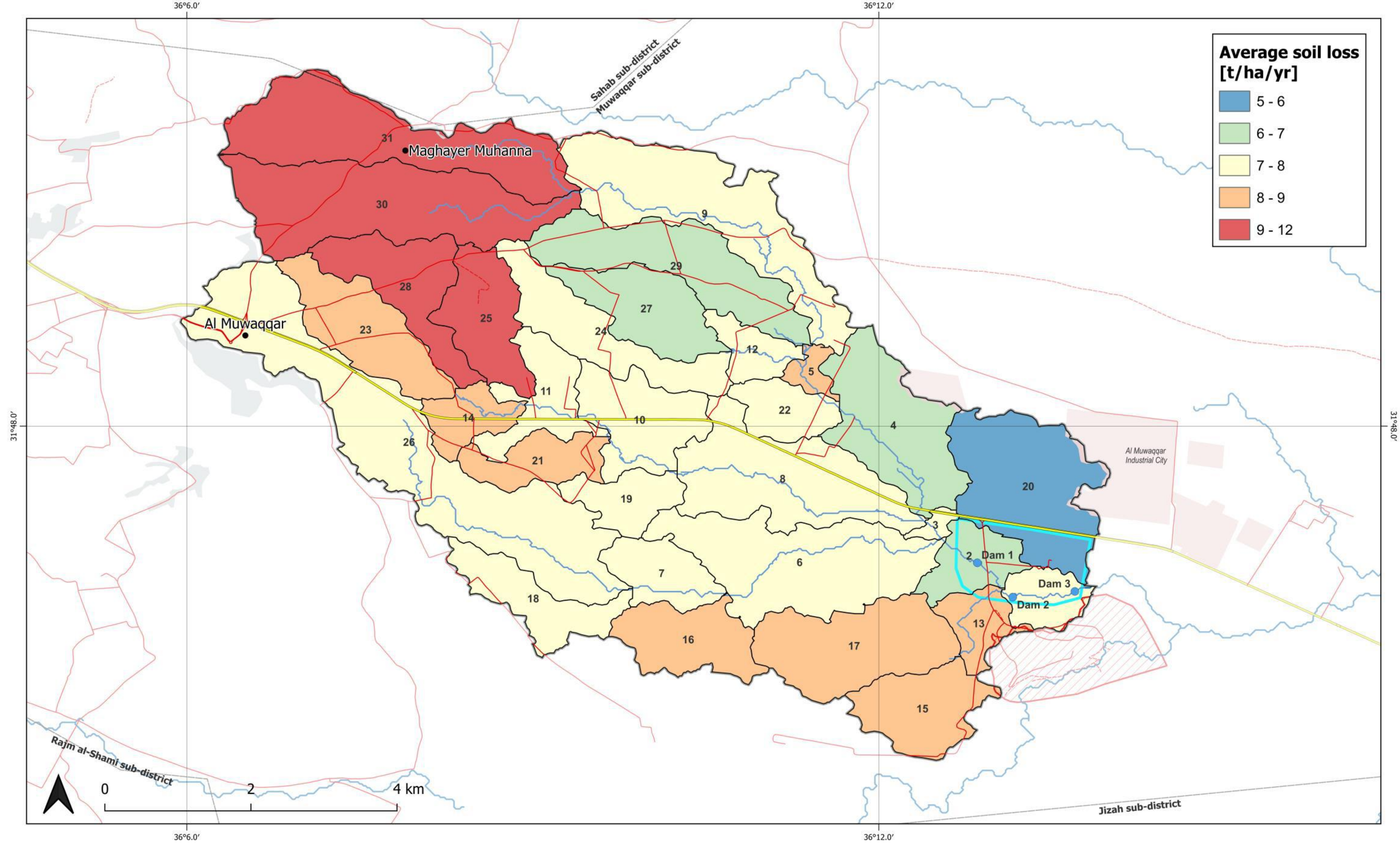
UNESCO | IHE DELFT

- Village, town
- Main road
- Road
- Wadi
- Governorate boundary
- University site
- Sub-catchment

Erosion risk map of the Muwaqqar sub-catchment - 3R Jordan

Draft version

Scale:	1:35000	**Date:**	Jan. 2024
Map format:	A3	**Projection:**	WGS 84
Author:	Acacia Water		



Water Harvesting 3Rs
Retention-Recharge-Reuse

INWRDAM WATER DIPLOMACY

ACACIAWATER

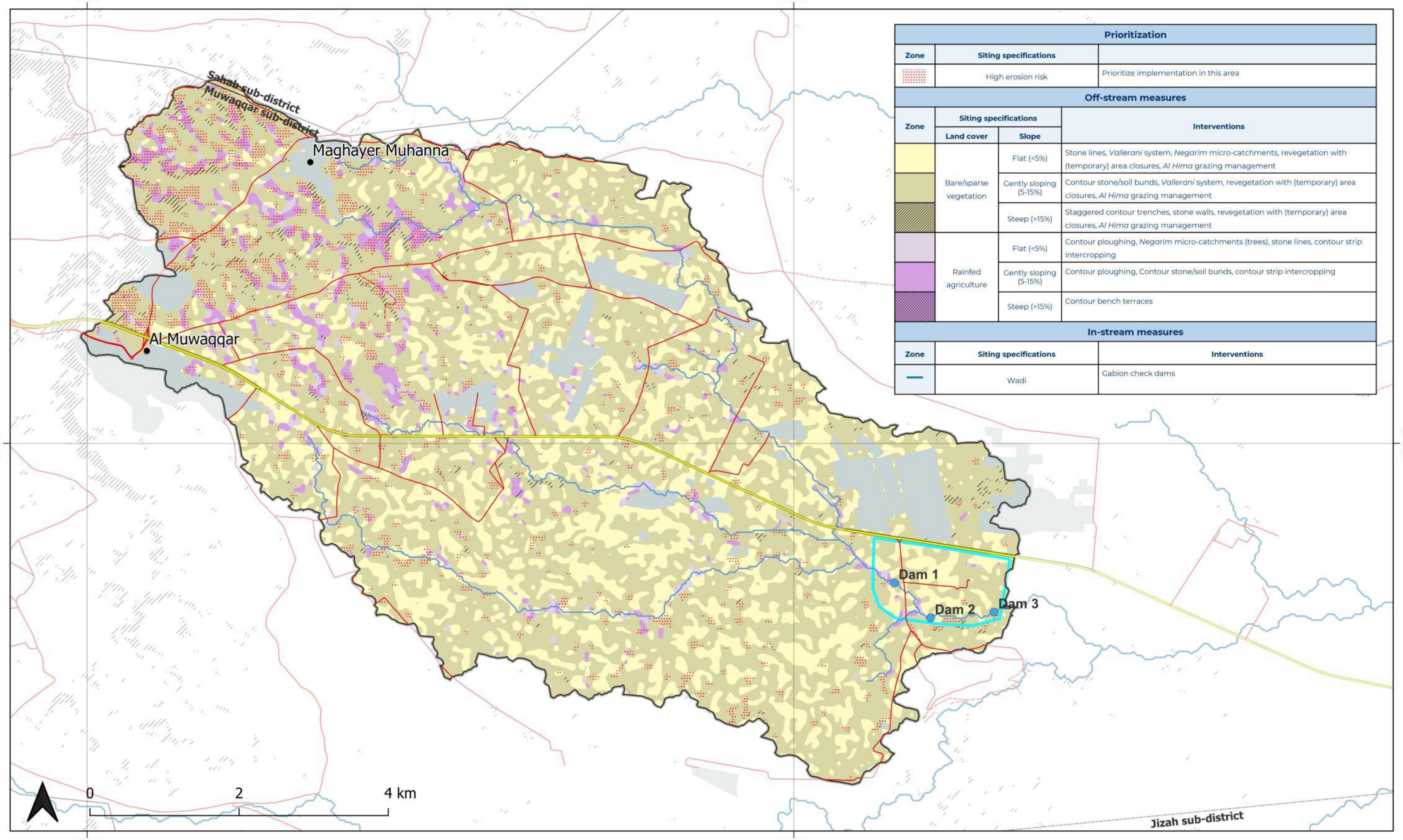
UNESCO | IHE DELFT

Village, town	Governorate boundary
Main road	University site
Road	Sub-catchment
Wadi	

Erosion risk map of the Muwaqqar sub-catchment - 3R Jordan

Draft version

Scale:	1:35000	**Date:**	Jan. 2024
Map format:	A3	**Projection:**	WGS 84
Author:	Acacia Water		



Water Harvesting 3Rs
Retention-Recharge-Reuse

INWRDAM WATER DIPLOMACY

ACACIAWATER

UNESCO | IHE DELFT

- Village, town
- Governorate boundary
- Other land uses
- Main road
- Road
- University site

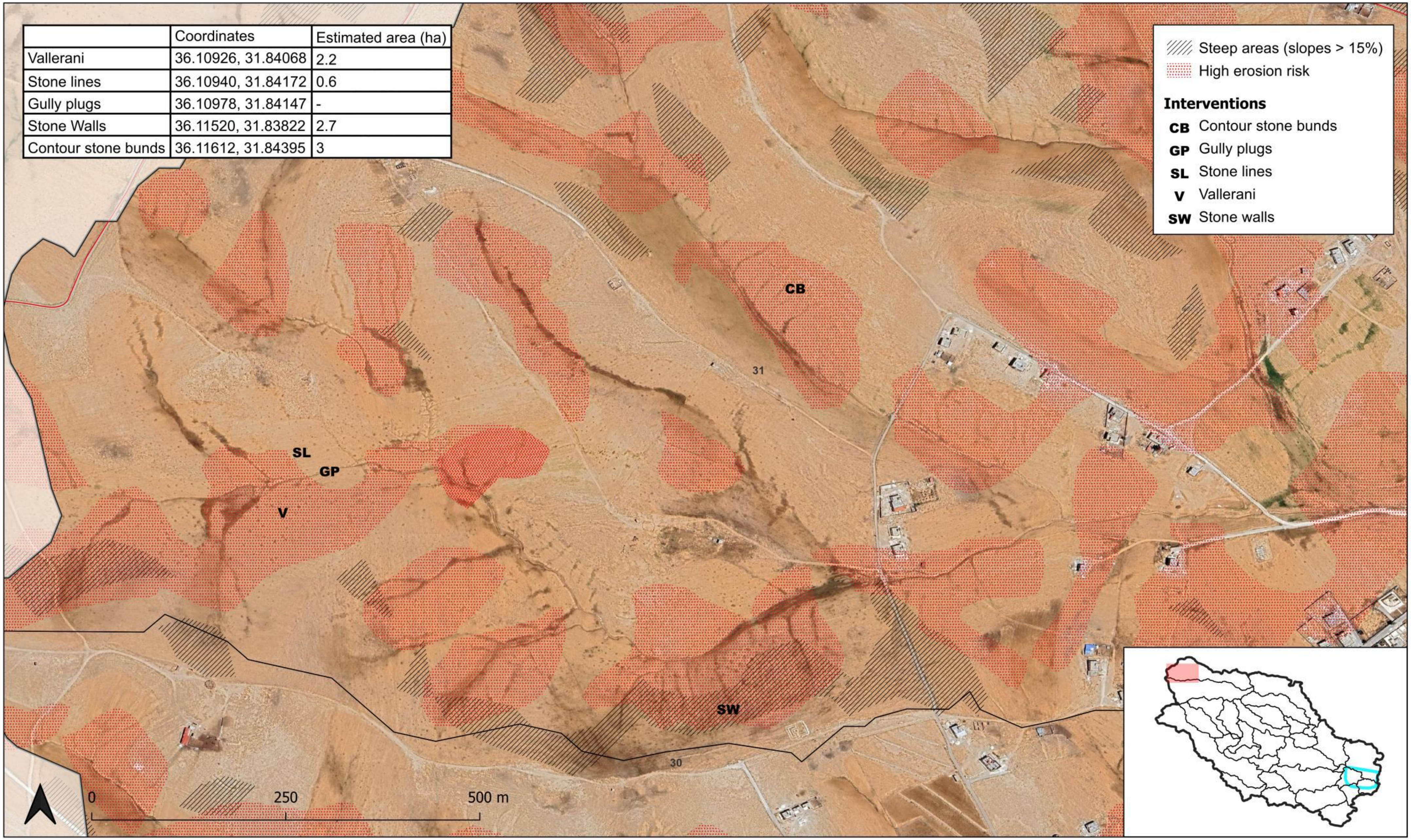
3R potential map of Muwaqqar catchment - 3R Jordan

Final version

Scale: 1:35000 **Date:** May 2024

Map format: A3 **Projection:** WGS 84

Author: Acacia Water



	Coordinates	Estimated area (ha)
Vallerani	36.10926, 31.84068	2.2
Stone lines	36.10940, 31.84172	0.6
Gully plugs	36.10978, 31.84147	-
Stone Walls	36.11520, 31.83822	2.7
Contour stone bunds	36.11612, 31.84395	3

▪ Village, town
Governorate boundary
Main road
Road
Wadi

Intervention allocation map for sub-catchment 31 - 3R Jordan

Final version

Scale:	1:9000	**Date:**	May 2024
Map format:	A3	**Projection:**	WGS 84
Author:	Acacia Water		