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Potential of Traditional Adaptation Measures in Mitigating the Impact of Climate Change

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Abstract: With the rapid changes in climate, minimizing their impact has become vital in all countries, especially in the countries most vulnerable to climate change effects. Yemen is one of the countries facing several challenges that exacerbate the impact of climate change on multiple sectors, including water resources and agriculture. This paper documents and addresses the role of traditional techniques practiced by smallholder farmers in rural villages of the Yemeni highlands for adapting to climate change. The measures are innovative and independent of state support and can be practiced in the future to mitigate the effects of climate change on agriculture and water resources. The findings of future projections on the region reveal an increase in precipitation and temperature, leading to more frequent floods and higher evaporation rates. Therefore, maintenance of agricultural terraces, construction of rainwater harvesting structures, promotion of crop diversity and rotations, integration of agroforestry practices, improving irrigation efficiency, and soil conservation will be essential in the future. Additionally, education and awareness programs on climate change adaptation issues at the community level are also needed. These measures also have a significant role in improving food security and alleviating poverty in rural areas of Yemen.

Keywords: climate change; adaptation measures; traditional tools; water and agriculture resources; Yemen

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1. Introduction

Adaptation to climate change is a crucial topic that concerns many organizations and scientists at a national and international level [1]. Further, it is a complex political issue for many governments who cannot afford the required budget to implement the suggested mitigation measures that may return no benefit, at least in the short term [2,3]. In most developing countries, scarcity of resources and the need to focus on priority projects and infrastructures that have not yet been completed is a major issue facing decision makers [4]. Also, the difference between countries in the degree of wellbeing and understanding of global issues creates serious debate between the developed and developing world regarding the issue of climate change and the obligations required to implement the adaptation measures by nations that did not contribute to climate change [5,6]. On the other hand, projections based on global climate models (GCMs) are still uncertain in predicting what will certainly happen at local and regional levels [7–10]. The projected rise in global temperature, which is assured by GCMs, will impact the hydrological cycle and other variables of the climate [11].

To improve projections produced by global climate models (GCMs), several methods and models have been developed to produce more reliable and high-resolution projections to assess the potential impact of climate change at a local and regional level, such

downscaling and bias correction methods [12]. Dynamical downscaling (regional models (RCMs)) [13] and statistical downscaling (e.g., SDSM) [14], as well as hybrid downscaling [15], are being applied to improve the resolution of GCM outcomes through the use of ground data and the incorporation of physical information and terrain characteristics that affect local climate. As a result of several reasons and challenges, many countries and states are unable to collect climate records on a regular basis, such as data on temperature and precipitation [16,17], which will result in a persisting shortage of data. Therefore, this advanced application (downscaling), combined with satellite and re-analysis of datasets of long-term data, will definitely improve local studies and benefit many sectors such as water, agriculture, and hydrology [18–20].

Yemen covers an area of 555,000 km^2 and is situated between latitude 15.55° N and longitude 48.51° E. The population is approximately 29 million [21]. Most of Yemen's land is desert 57%, with a population density of less than 8%; the coastal areas is about 12% and a population density of 17%; and interior areas and highlands represent 31% with a population density of 75% [22]. Yemen is a fragile country in terms of economy and infrastructure, suffering from rapid population growth, ongoing political conflicts, and a severe degradation of environmental resources. Despite the oil boom in the 1980s and 1990s, which did not yield real development [23], Yemenis have relied on agriculture as a main source of income for many centuries. Further, Yemen is one of the most vulnerable countries to climate change based on its arid to semi-arid climate with an annual rainfall of less than 50 mm in desert and coastal areas, and up to 800 mm in the highlands and central plateau regions [24]. More than 70% of Yemen's agricultural lands rely on rainfed farming, while the remaining portion depends on irrigation from limited groundwater sources. Unfortunately, these groundwater sources are rapidly declining due to excessive extraction and insufficient recharge rates [25]. Farming in Yemen is considered ancient. Yemeni farmers still use simple old means and animals (donkeys and oxen) to furrow fields, which may not keep up with the rate of increasing demand for food in the future. Moreover, urban sprawl and the absence of appropriate planning have resulted in the loss of the agricultural fertile lands and blocked runoff streams and valleys. These factors could worsen the issue of food security and increase the frequency of flood events in the region [26,27].

Detailed studies related to climate change and natural resource management are also few in Yemen. This can be attributable to many factors, including lack of long-term observed data, shortage of budgets for field research, weak coordination between the government and research agencies, the absence of role of the private sector, and the frequent political and security unrests [28,29]. However, the few attempts to study Yemen climate using global models exhibit a high level of uncertainty in the future due to the location of the country, terrain heterogeneity (a desert range meets the highlands and then seawater from the west and south), the influence of Indian monsoon and the inter-tropical convergence zone, and, to a certain degree, the influence of the El Nino phenomenon that affects the average of tropical ocean temperatures [30–32]. Therefore, ideas for selecting and implementing the best methods to adapt or mitigate the potential impacts of climate change in Yemen are not assured and may differ from place to place and from one governorate to another.

Throughout ancient times, people were able to adapt to climatic variability and employed the natural elements to fulfill their essential needs, particularly for water and agriculture, which were integral to their way of life [33–35]. In many regions, such as Ethiopia [36], Nepal, Peru, China and the Mediterranean Sea countries, outstanding examples and measures have been built and practiced in agriculture, irrigation, and rainwater harvesting to cope with the frequent droughts, as well as to mitigate floods and prevent soil erosion [37–40]. In Yemen, the highland region offers a unique experience conducted by old Yemenis to minimize the intensity of droughts and reduce the effects of floods that hit the region from time to time. In addition, the Yemenis have managed the natural resources in a more efficient and effective manner [41]. For instance, people used to live high on the top of mountains to be safe from both invaders and floods, and most importantly

to keep the fertile agricultural lands for the family's livelihood. Drought-resistant crops such as sorghum, wheat, lentil, and barley were planted, as well as woody trees such as Acacia and Hyphaene for firewood and pastoralism. Livestock and poultry breeding were other key sources of income, utilizing farm residue to feed domestic animals. To allocate as much land as possible for agriculture, Yemenis built unique agricultural terraces on the slopes of rugged and complex mountains, utilizing the accumulated silt and clay that is usually transported by rainwater [42]. Cisterns and traditional storage that still stand today were extensively built of local materials to collect rainwater for domestic use and for supplementary irrigation during droughts [43]. Rotating crops, preserving native seeds, and refraining from cutting live trees for firewood are all longstanding farming traditions upheld by Yemeni farmers. At home, they rationalized water consumption by using utensils designed to measure the quantities of water available for bathing inside the house. They used cold water to prevent overconsumption. These practices are essential for addressing climate change and implementing adaptive measures.

The current research aims to document the multiple traditional measures practiced in the highlands of Yemen. These techniques can be considered for minimizing the impacts of climate change at the current time and in the future. The research further contains some examples and experiences that were conducted recently by the Yemeni government, focusing on shortcomings and lessons learned, which may be useful to be discussed in this research. To the best of our knowledge, this is the first study in Yemen that provides a detailed discussion of these practices, drawing from local knowledge. The author, having experienced most of these methods while working as a local farmer alongside his father, brings a unique perspective to this research.

2. Material and Methods

2.1. The Study Area

The study area is located in northwestern of Yemen, spanning from latitude 14.00° N to 16.75° N, and longitude from 43.25° E to 45.00° E. On account of its altitude (2500 m.a.s.l), the region enjoys a moderate climate in summer and is cold to semi-cold in winter. The study area includes five governorates with a population density of about 48% of the total Yemeni population. The region is an excellent agricultural site characterized by high mountain ranges in the west and southwest to flat and semi-flat areas in the east and northeast. Farming and cultivation methods vary by region, with some similarities in crop varieties, irrigation patterns, and agricultural heritages [44]. The area is also distinguished by the presence of ancient agricultural terraces and many unique rainwater harvesting methods that significantly contribute to reducing the impact of disasters such as droughts and floods. Figure 1 displays location of the study area and the administrative governorates within the region.

2.2. Data Collection

The study was conducted in AL-Sharqi, Hejrah (Hajjah), and Qarat Bani Swar in Bani Mattar villages (Sana'a). Around 450 individuals actively participated in the social meetings for this study. Our data collection approach and the comparative analysis involved the utilization of various quantitative methodologies such as questionnaires, semi-structured interviews, meeting minutes, individual interviews, and a scoring system. From all of the participants, 386 questionnaires were returned, while the remaining participants were interviewed individually or within a small group. Ideas and perspectives of the participants were evaluated across multiple groups of the different villages and within the specific group. Almost all society members took part in the public discussion, including Sheikhs, social council representatives, high-school students, and university graduates. Separate gatherings were also organized for women and teenage girls. During the preparation of the interviews and the questionnaire, questions were simplified and presented in a simple way to encourage people to participate. Based on the active involvement of community members in surveys and meetings, three different groups were identified for the comparison

analysis: women (homemakers and those involved in farming), male farmers, and the local council representatives. The term climate change was not explicitly introduced in its known scientific term, except when it was raised by the participants. Instead, the discussion was generally on agricultural and water resources management, climate variability, villagers' need for a water supply project, delay and variability of rainy seasons, and gathering information about historical experiences and the indigenous tools employed by the local people to manage water and agricultural resources. Narrative stories and inquiries of the old farmers were gathered in the same manner they were recounted. To quantify the existing mitigation measures conducted by the society and the degree of engagement in each activity, a set of criteria was established, including the role of women (RW), individual practice (IP), community participation (CP), cost burden (CR), degraded and subject to deterioration (DS), and implementation priority (MP). These roles and characterizations were evaluated against the existing traditional measures using a rating scale ranging from 1 (indicating low level) to 10 (indicating high level). Figure 2 below shows the methodology followed in this research.

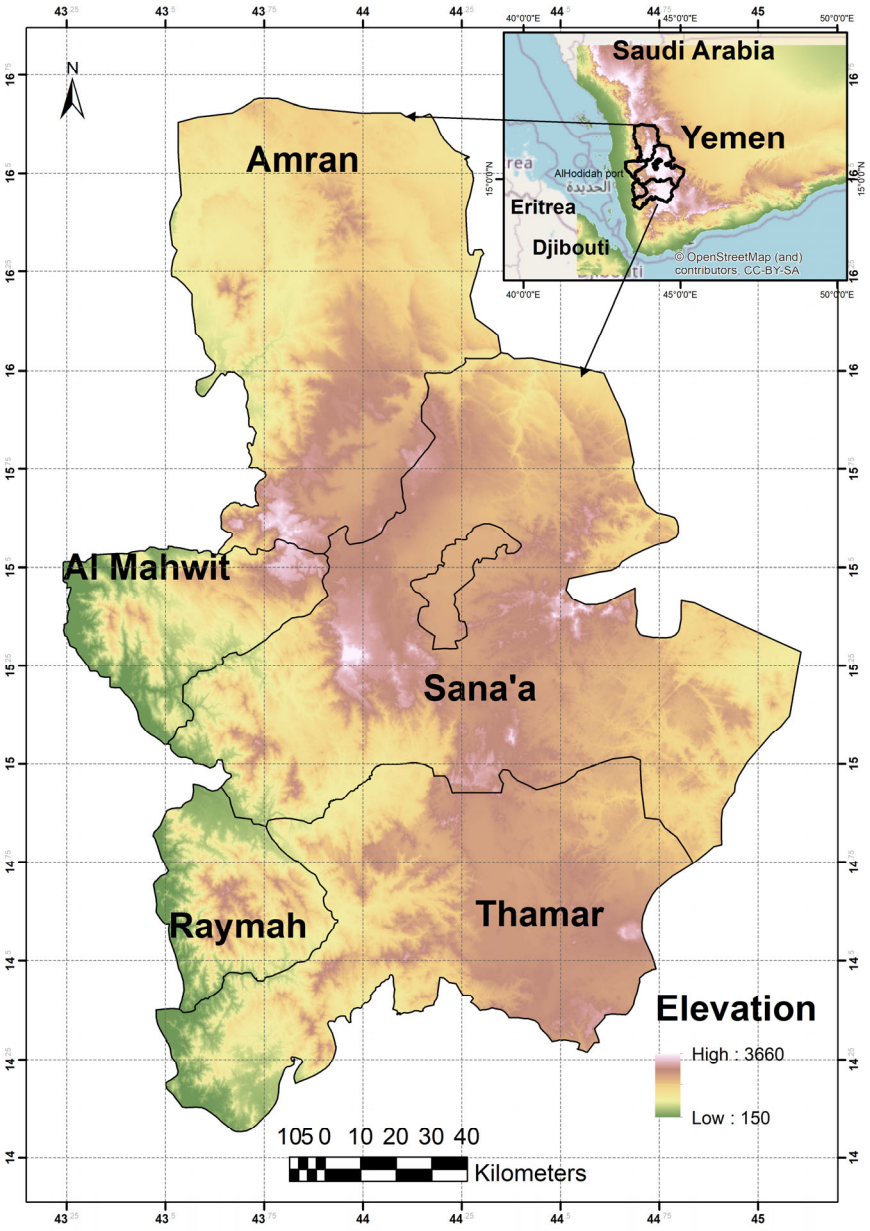

Figure 1. Location of the study area in the Yemeni map and names of the administrative governorates.

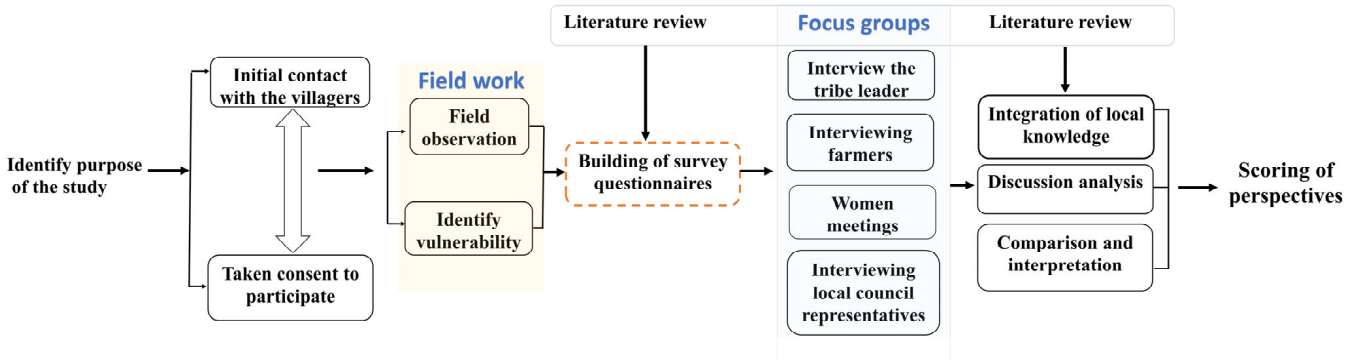

Figure 2. Methodology overall steps.

3. Result and Discussion

The current chapter contains a number of traditional practices, which may slightly vary due to the topographic nature and local heritage. The social perspectives and results from individual interviews are further discussed to provide an insight into the potential and restrictions of adaptation measures for future policy across the region.

3.1. Agricultural Water Management

3.1.1. Collection of Rainwater

The tradition of rainwater harvesting is an ancient practice in many lands, but it is more evident in water-scarce regions, such as the Arabian Peninsula [45]. According to Vogel [46], the collection of rainwater in Yemen dates back more than 4000 years. In the highlands of Yemen, rainwater harvesting is community-based work. Maintenance of storage, distribution, and use of water is coordinated by a local committee, typically led by Al Aqel, who serves as the wise person nominated by the community. Further, the techniques and types of rainwater harvesting structures varied according to the purpose of use. For example, there were primary reservoirs for domestic use. Another traditional type of storage was used for washing and cleaning of agricultural tools, as well as for sheep washing [47]. For worship purposes, a collection storage was built attached or close to the prayer place. Traditional ponds for supplementary irrigation during the dry season were widely constructed on terraced lands and in the sites above fields. All of the tanks were built from local materials and the storage walls were cemented using slacked lime that is still held in place today [48]. Such practices have proven their efficiency in adapting to the scarcity of rainwater during droughts, as well as for storing excess water during the rainy season that could turn into devastating floods [49]. However, most tanks that were designated for agricultural use, which are still stand today, lack bottom drainage outlets, are exposed to pollutants, and promote evaporation under the direct effect of sunlight. Therefore, only a small amount of the collected water is drained during or after heavy rain, while the majority of water remains in the storage. The only way to obtain the stored water is manually, either with the assistance of animals or directly using a water bucket. However, future considerations could include constructing drainage exits to facilitate water drainage and covering the storage with a roof made from local materials (e.g., stones) to reduce evaporation (Figure 3). Building more of this storage is a positive step towards coping with climate change.

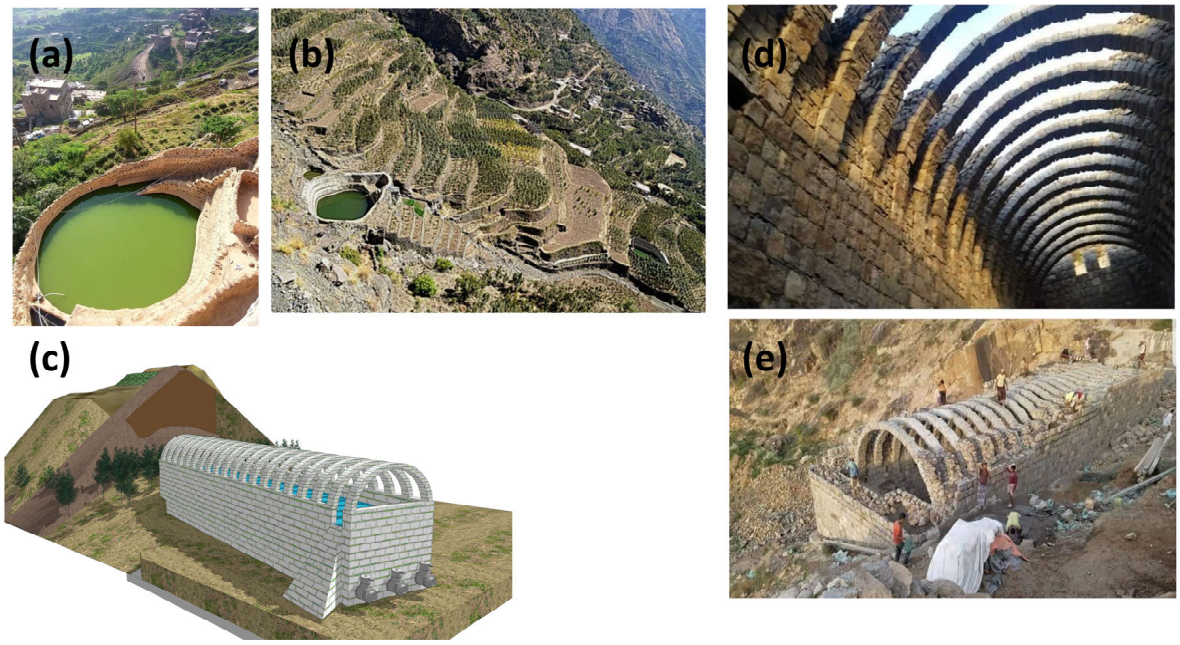

Figure 3. Collection of photos showing an example of rainwater harvesting in the study area: (**a**,**b**) existing traditional storage, (**c**) drawing of outlets at the bottom which can be incorporated into the newly built storage to facilitate complete drainage of the collected water such as the example shown in (**d**,**e**). (**a**,**b**,**d**,**e**) Obtained from https://www.facebook.com/IWHP.Yemen/ (accessed on 1 October 2023). (**c**) Belongs to the author.

3.1.2. Distribution of Rainwater (Outside and Inside Fields)

The distribution of rainwater between and within the agricultural fields has long been well-established in Yemen [50]. An earth-direct canal or a network of small streams is constructed to transport rainwater from the upper lands directly to the lowland fields [48]. Typically, these canals are jointly maintained and used by several farmers. To ensure the fair distribution of water among the fields, traditional divides made of flat stones are placed along the stream path before the water reaches the fields [51]. Another technique, which is typical on terraced lands, is the overflow from the upper terrace to the lower. In the field, the vertical and horizontal movement of water at the same shared field is well organized. Activities taking place in the section close to the water canal should not restrict water flowing horizontally into the adjacent part of the field. Given the issue of climate change, we are unsure this tradition of water distribution will continue in the same manner in the future. Is it appropriate to raise this issue at the current time and listen to new ideas that might be applicable in the future without creating problems among the people?

3.1.3. Introduction of Modern Irrigation Systems

Based on a number of experimental fields and irrigation programs conducted by the Ministry of Agriculture, drip irrigation, particularly in narrow agricultural terraces, were not successful for several reasons. Frequent floods that destroy irrigation networks, differences in soil surface levels, maintenance requirement (e.g., for distribution tank and the network), operation cost, and small agricultural holdings were all the main challenges. Improved irrigation (drip and sprinkler) was more successful in flat fields that exclusively depend on groundwater, such as in grape farms in the north and east of the capital, Sana'a. Despite the establishment of water user groups (WUGs), from the community members, an assessment conducted a few years later showed that the biggest beneficiaries of the subsidized irrigation system were the wealthy, who own an independent groundwater well (e.g., the Sheikh). For poor farmers, the scenario was different. The farmers were required to supply between 20–40 L diesel to the well owner and pay an additional fee

ranging from 10$ to 30$ for each irrigation hour. Following irrigation, the farmers felt deceived by the well owner as the amount of irrigation water they received was less than what they had previously obtained through the traditional spate irrigation, which typically reached a depth of 10–15 cm. Even with government efforts to provide education and training programs, it seems that the farmers remained attached to the traditional irrigation regime. One farmer also pointed out that drip irrigation only goes beneath the tree, leaving nothing to irrigate grass between trees, which can subsequently be utilized for cattle grazing. Additionally, there was difficulty furrowing the field using conventional tillage as the pipes were in the way. Although it was uncertain how productive the field was when using drip irrigation, it is worth mentioning that drip irrigation resulted in a considerable saving of water, fuel, time, and labor. Some farmers, however, reported the same productivity as before under spate irrigation, while others claimed a decline, and some reported a small rise in the total output. Figure 4 shows some of the social interviews conducted in the targeted villages.

Figure 4. Photo collection of social meetings with villagers in the study area.

3.1.4. Use of Groundwater in Irrigation

Compared with rainwater, groundwater ownership and use rights have not been regulated in Yemen since the exploration of groundwater in the late 1960s. Even though some laws exist, they are not updated and most critically not implemented [50,52]. In general, the local governorate is responsible for conducting field surveys and issuing permission for groundwater drilling, while the drilling operations are conducted by contracting firms. However, the situation on the ground is complicated by the uncontrolled illegal drilling conducted by unauthorized rig owners, particularly in rural areas. This illegal work benefits the wealthy and some agricultural associations, allowing them to establish their own wells. Therefore, irrigation from the groundwater is managed by assigning specific irrigation

timeframes (measured in hours) in return for a certain fee collected from the farmers. To improve the efficient use of irrigation water, some farmers use closed conduits (e.g., plastic or polyethylene pipes) to convey irrigation water from the well to the field. This approach has been proven to reduce water loss and evaporation. However, this irrigation technique is still not widely applied. At the same time, using closed conduits will deprive women and children from access to water for clothes washing. When a well is operated, women are gathered along the water flow canal to make use of some water for clothes washing. Sheep and domestic animals also drink from the waterway. Principally, improving the existing irrigation systems in order to save the limited groundwater is essential, but other sides and alternatives should be considered such as building further rainwater storage for washing purposes.

3.2. Farming Measures

3.2.1. Agroforestry

The locals used to plant trees alongside the farms in order to avoid erosion, increase shade, and feed cattle. For instance, perennial trees like Sidr nabak and Acacia are widely planted for purposes such as fuel, honey production, and cattle fodder. Fruit trees such as apple, fig, Indian fig, peach, and pomegranate, as well as woody trees like the Cordia, are often planted in combination with coffee and qat trees. In the current time, this tradition is not practiced in the same way it was followed before. To mitigate the potential impact of future climate change and to diversify income sources, agroforestry will be essential in the future.

3.2.2. Inter-Cropping

Another outstanding custom practiced by the local farmers is growing legumes in conjunction with sorghum, taking advantage of the available spaces between the planting lines and the shade provided by sorghum leaves (Figure 5). This farming habit increases the farm net benefit and provides additional food for the family. Sorghum can benefit from the nitrogen-fixed bacteria available in the legume's roots [53]. Further, planting a single crop can create an ideal condition for specific pests to thrive, while a more diverse ecosystem within the field can disrupt the lifecycle of diseases and pests [54,55]. This practice is useful to mitigate the effects of climate change.

Figure 5. Intercropping practice: legumes planted with sorghum.

3.2.3. Crops Rotation

The rotation of crops has a positive effect on soil fertility and increases field productivity. Crops with a short-growing season and drought-resistant crops such as barley and wheat are planted alternately in the area. This practice will improve food security and

mitigate climate change, especially under the projected increase in average rainfall rates in the future.

3.2.4. Supporting Walls and Fields Boundaries

Experience and fieldwork have shown that field edges that contain soil with grass are more resistant to necrosis and carving caused by fast flowing water. The longer the edges have been compacted, the more resistant they are to erosion (Figure 6). Further, trees are often planted above the field and opposite the inflow direction to reduce water velocity and to support field walls.

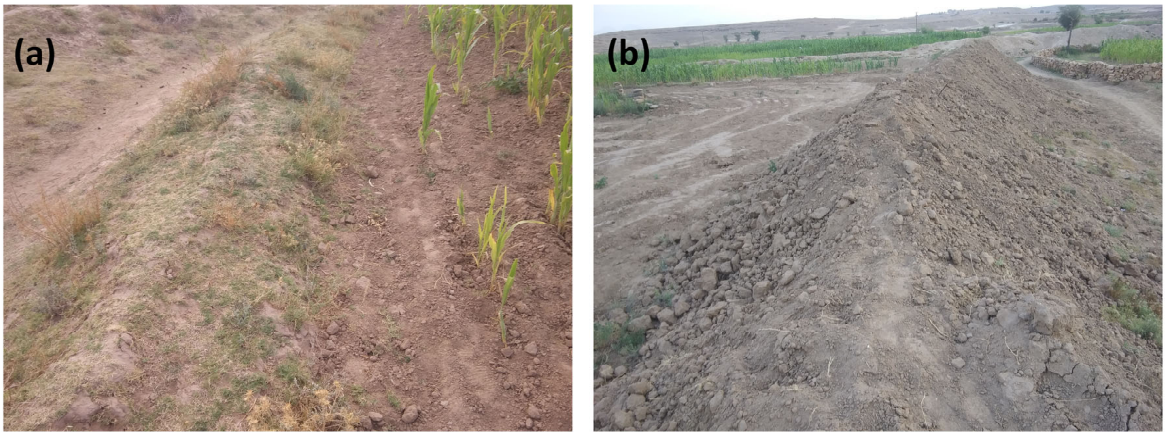

Figure 6. Boundaries of two fields cultivated with sorghum: (**a**) a compacted and more cohesive soil with grass and (**b**) soil loss and bare of grass and weeds, making it more susceptible to soil erosion.

3.2.5. Control of Pests and Plant Diseases

Spraying extremely fine soil on the leaves and sprouts is a simple and ancient custom for controlling various plant diseases and pests. This method has been used to treat pests on qat, grape, and sorghum, and has proven its efficiency in controlling plant diseases and fungal growth. This strategy will be useful in the future too.

3.3. Soil Protection Measures

3.3.1. Fertilizers and Improvement of Soil Fertility

As commonly practiced in many worldwide rural areas, Yemeni farmers takes advantage of house animals' manure to improve soil fertility. Further, ash is periodically collected from inside the kitchens to fertilize the soil and to reduce evaporation from the surface soil. Adding ash to the fields is the conventional way to clean the traditional mud oven and dispose of ash waste accumulated inside the kitchen. Another useful method to improve soil fertility is to leave sorghum roots for a sufficient period of time, about one or two months, after harvesting the grains and fodder. This practice provides more time for the roots to decompose in the soil and to remove moisture in the root, which will be used later as a firewood. Like other plant residues, sorghum roots contain organic matter. The decomposition of sorghum roots adds organic carbon to the soil, which enhances soil fertility, improves the water-holding capacity, and increases nutrient retention [56,57]. In addition, Yemeni farmers bring new soil from outside the field and practice soil fermentation to improve soil fertility, especially when the soil shows a high deficiency of nutrients or if manure is not in sufficient quantity. Some farmers indicate that the interaction between rainwater and stones is expected to bring a good amount of silt and stone-tiny debris that enhances soil fertility. Growing alfalfa is occasionally practiced to improve soil fertility and decrease salinity. Alfalfa is either planted along with crops or in the period of crop rotation.

3.3.2. Field Preparation and Soil Tillage

Surface tillage and soil mixing in Yemen is an old practice and do not result in significant loss of moisture content in the soil. Maintaining this practice is another wise step to mitigate the impact of climate change on soil water.

3.3.3. Control of Soil Compaction

Inside the field, frequent walking on the soil by pedestrians is completely prohibited and upsets farmers. In fact, this behavior is considered a violence against field sanctity. The reason for this is to protect soil texture, as well as to avoid any damage to the planted crops. Respecting this tradition will protect the soil and enhance field productivity.

3.4. Conservation of Natural Resources

3.4.1. Expanding the Agricultural Area

To secure food, old Yemenis did incredible work by utilizing any available space on the mountain slopes and converting it into arable land. Silt and clay that are often carried by rainwater encouraged local people to establish small fields along the mountain slopes in beautiful contour lines locally known as *Al Jedals* (Figure 7). In addition to serving as agricultural land, these terraced systems are regarded as one of the most remarkable techniques to harvest rainwater and to reduce the quantities that flow into the valleys, thus mitigating floods. Future attention to the role of terrace cultivation and the maintenance requirements of these systems is necessary to adapt to climatic changes and improve food security.

Figure 7. An overview of agricultural terraces from the study area. The pictures are obtained from Maxey Information Services (https://www.maxey.info/yemen{-}{-}-agriculture-project{-}{-}-clp (accessed on 1 October 2023)).

3.4.2. Protection of Runoff Catchment Area

The wadis, from which rainwaters flow straight into the fields, are considered a protected area and a common property of the society. Housing and other barriers that can block the free flow of rainwater to the fields are forbidden by custom. Protection of these areas will ensure sustainable farming in the future.

3.4.3. Preserving Original Seeds

In the past, the only option to sustain cereal cultivation is to store quantities of wheat, sorghum, or corn in its spikes for planting in the coming years. Despite experience and recent studies highlighting the need for preserving native seeds, in particular seeds connected to sorghum, wheat, barley, and lentils, this practice has started to disappear. For

many years, grains were stored in manholes dug into impermeable rock. Perhaps the same work will be needed in isolated rural areas to prepare for climate change.

3.4.4. Conversion of the Agricultural Land into Residential Areas

One of the major mistakes that Yemeni have recently made is the conversion of agricultural land, especially those located near cities, into residential and industrial areas. Urban sprawl at the expense of agricultural land will exacerbate the effects of climate change. Across most of Yemen, agricultural lands adjacent to buildings have shown rapid degradation and are more vulnerable to the impact of climate change.

3.4.5. Firewood Collection

When gathering firewood, the inhabitants have established a traditional rule of avoiding cutting living trees and bushes and only collecting firewood from dry trees. Maintaining this habit will help to feed sheep and camels, as well as improve expansion of the grazing space. Encouraging such practice is beneficial for adaption to future climate change.

3.5. Household Measures

3.5.1. Poultry and Livestock Breeding

Livestock raising, poultry, and beekeeping have been practiced for a long time as a source of income for most families in Yemen, benefiting from the fodder and farm residue. Today, factors such as moving to cities for jobs and migration abroad for a better life are contributing to the neglect of this activity [58]. Returning to poultry and livestock breeding will certainly increase family income and minimize the potential effects of climate change. The production of honey, which is still practiced in many areas today, also helps enhance family income.

3.5.2. Training Children on Water Consumption

Yemeni families are known for rationalizing water consumption by training children to use specific amounts of water on a daily basis. Before eating, hand washing is poured on the hands or hands are maybe washed in the same pot. For ablution and body washing, the water quantity is between 3–10 L. This amount of water might not be sufficient for many people in other countries, but this is the way the local people used to adapt to the water scarcity issue.

3.5.3. Improving Water Quality in Traditional Ponds

When collecting rainwater, especially at the beginning of the rainy season, the initial runoff is prevented from entering the storage, in particular the storage designed for domestic use. By adopting this approach, water contamination is controlled to a large degree.

3.5.4. Construction of Medium and Small Dams

In addition to the governmental efforts of building massive dams, the expansion of traditional storage and ponds close to homes and at a close distance from the fields is a prerequisite for irrigation and domestic use. Across the region, traditional ponds and storage are commonly observed, indicating the role of these structures in the past.

3.5.5. Tillage Machinery Exchange

The exchange of tillage tools, including animals, is common among rural households. This pleasing tradition substantially lowers the cost of agricultural input, but future work may require rethinking alternatives, especially with the declining number of oxen and donkeys, as well as the need to improve productivity using modern equipment (e.g., two-wheel tractors) over traditional options. Table 1 contains information about the location of the traditional measures and recommendations for improvement.

Table 1. Types of local activities, location, current status, and recommendations.

Activity	Location	Topography	Current status	Recommendation
Terraces	East and north districts of Al Mahwit, west of the Sana'a capital, and in the eastern districts of Raymah governorate	Complex, and steep topography	30–35% of terraced lands are degraded	Maintenance, and rehabilitation of terraces is urgently needed. More storages above terraces can be built to reduce water velocity
Modern irrigation	North and east of Sana'a capital, in Amran, and northeastern districts of Thamar governorate	Flat to semi-flat area	Not widely applied,	Experiment fields are recommended, education programs to save groundwater use in irrigation is urgently needed
Rainwater harvesting	Common practice across the region	In complex and flat topography zones	Subject to deterioration	Maintenance is needed, expansion in building storages is highly recommended
Soil protection measures	Common practice	In complex and flat topography zones	Subject to neglect, dependency in manufactured fertilizers	Supporting of fields wall is regularly needed, manure and ash supply to field should continue
Tillage machine exchange	Common practice across the region	In flat and terraced fields	Widely practiced	New and modern machine (e.g., two-wheel tractor) is recommended
Original seed preservation	Common in all districts	In complex and flat topography zones	Degraded	Education programs, and new approaches along with the old practices are recommended
Soil fertilization	Common practice	In complex and flat topography zones of the region	Subject to deterioration	Livestock breeding, soil fermentation should continue as in the past
Inter-cropping	Common farming	Common in all rural areas	Subject to deterioration	Awareness program and saving of legumes original seed will assure practicing inter-cropping
Agroforestry	West of Sana'a capital, east of Al Mahwit and in the eastern districts of Thamar and Raymah governorate	In complex topography zone	Degraded	Awareness program in plantation is recommended
Groundwater management	Critical issue all over the region	Flat and complex topography area	Highly degraded	Prevention of illegal drilling, establishment of water use rights will improve the situation of groundwater management
Control of pests and plant diseases	Common farming practice	Flat and semi-flat areas	Subject to deterioration	Import of hazardous pesticides should be regulated, awareness program on the importance of old practice should be encouraged

3.6. Social Aspects and Challenges

Climate change in its scientific terms is not comprehended by most farmers and rural families. Most of the traditional practices that contribute to the conservation of natural resources, including water and agricultural resources, are inherited and still practiced to a large extent, regardless of people's unawareness of climate change and its potential impact. In areas with a difficult topography such as Al-Mahwit, the western zone of Sana'a, and the Raymah governorate, the maintenance of agricultural terraces, which is considered the most effective measure to mitigate climate change impacts, also stands as a difficult task

for farmers. Terraces are frequently subject to runoff and erosion, which require additional costs that most poor families cannot afford. Also, splitting the agricultural small lands into even smaller holdings for inheritors and between the large family members has resulted in agriculture deterioration, and the agriculture is no longer the main income source for many people. Men, particularly young people, prefer to travel and work outside the field, leaving agricultural work to the women and children. Interestingly, women do not complain about working in the fields, on the condition that men should look for another source of income, whether through jobs in cities or travel abroad. Moreover, agricultural work in Yemen tends to be individual, except for the exchange of agricultural tools and participation in harvesting work, while the conservation of natural resources is characterized by community collaboration. Priority of agricultural work and type of cultivation is restricted to short-term and field-level returns. Further, the orientation of the local market plays a key role in local agriculture. For example, while there are calls to control qat cultivation (stimulant evergreen plant), many farmers are still growing qat because of its faster and more profitable returns. Further, some farmers show no strong objection to the conversion of agricultural lands into residential areas, especially around cities, as long as there is a need for housing and the land sale price is profitable, which indicates the dominance of the perception of short-term benefits over the scope of long-term benefits. According to the social discussion, most adaptation measures are practiced individually. The maintenance of terraces, rainwater collection, inter-cropping, and soil protection stand as the highly important actions to be considered at the current time and in the future in order to cope with climate change. Further, the maintenance of terraces followed by rainwater harvesting and soil protection measures is the most expensive action at an individual and the community level. As a result of the complex topography of the area and the nature of Yemen's rain, which is characterized by its intensity and occurrence within a short period of time (often less than 40 min), floods and peaks are rapidly generated, causing erosion and destructive damage to field walls. Therefore, soil protection measures and field support barriers are the most wasteful activities that farmers should bear, almost every year. Further, the most degraded practices and those subject to deterioration are agricultural terraces, soil, groundwater, and rainwater harvesting structures. The role of women (RW) is significant in the fertilization of soil, household water rationalization, and farming practices. Figure 8 displays the results of individual interviews and the opinions about maintaining existing practices, which may hold true in the future too.

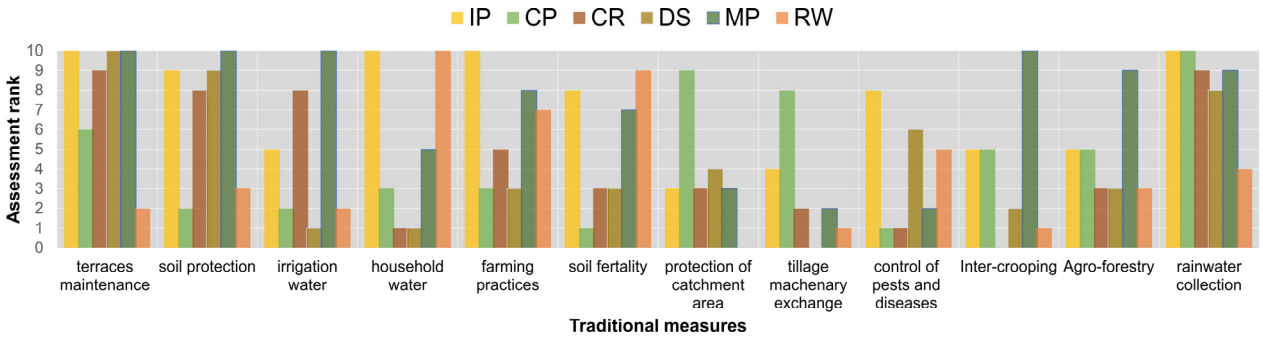

Figure 8. Assessment scores used to quantify each mitigation activity and engagement of people in each action. These scores are based on the feedback received during the public meetings. Individual practice is denoted as IP, while CP, CR, and DS represent the community participation, cost burden, and degraded or subject to deterioration, respectively. MP and RW are the implementation priority and role of women, respectively.

4. Conclusions

Climate change adaptation measures may differ from one region to another. Although there is no one universal technique that can be generalized in all regions to mitigate the impact of climate change, many researchers and organizations working on climate change

and climate-change-related studies emphasize the significant role of local knowledge and traditional techniques in minimizing the potential impacts of climate change, based on the long history of these practices in reducing the severe consequences of several natural disasters (e.g., flood and droughts) and the ease of application by local communities. With advancements in the adaptation concept such as the incorporation of sustainability and socio-economic aspects, these conventional methods are consistent with this approach based on their longtime standing and their significance in societal solidarity. The recent research focuses on the historical traditions of Yemen's highlands, which have served for millennia and have proven to be very efficient in managing natural resources and reducing hazards that occasionally occur in the region. The study area is characterized by annual rainfall averages of around 500 mm and an average moderate temperature of 22 °C, as well as the existence of a good fertile soil, making the region one of the best agricultural areas in the Arabian Peninsula, historically known as "the Yemeni Felix". People have converted a vast area of complex topography into fertile agricultural lands (mainly terraces) and built many reservoirs and ponds to collect rainwater.

Many other methods and practices have evolved in response to the fluctuation and variability of rainfall, starting from the management of water inside the home and harvesting rainwater for supplementary irrigation and domestic use. Inside the farm, practices such as adding new soil to the field or using municipal manure and ash waste from kitchens to improve soil fertility, and mulching the topsoil to minimize the effect of evaporation are extensively practiced. Strengthening the walls of agricultural fields, the maintenance of agricultural terraces, living high on the top of mountains, and keeping the fertile land for only agriculture have been practiced by local farmers for centuries. The distribution of rainwater among farms has evolved and a set of traditional rules to properly manage natural resources are followed and highly respected by all members of society. The native seeds are saved in a remote storage, usually underground in a solid rock, for use in the next agricultural season to assure a sustainable agriculture. Crops are often cultivated in combination with trees, and two to three crops can be cultivated in the same field. Soil salinity is controlled through a traditional but a sophisticated drainage system. Allowing sufficient time for sorghum roots to decompose in the soil and using simple methods to control pests are among the impressive traditional farming practices of Yemen.

All of the discussed methods can be practiced in the future to mitigate the potential impact of climate change on natural resources, mainly water and agricultural resources. Such measures are easily adopted by society members, including women and children, and can still be implemented in the future. Even though the measures may appear ancient and simple, they have been proven to function properly and sustainably, better than any other measures that may demand higher cost and complicated processes to be handled, whereas the government cannot offer support to these types of projects. The measures will last forever, as long as people are encouraged to use them.

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