


Participatory management of rangeland hydrology – a new socio-ecological technology to effectively adapt to and mitigate climate change: case from Morocco

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Abstract. Morocco’s drylands cover over 90% of the land area; low and irregular rainfall and high potential evaporation contribute to extremely high-water deficits in this area. These phenomena have significantly impacted rangeland hydrology and nomadic transhumant pastoralism. To adapt to this predominant water deficit, the inhabitants of these areas have developed two forms of lifestyles, which include household and livestock mobility: (i) a pendulum movement for seasonal transhumance between the mountains and their bordering plains; and (ii) random nomadic mobility regulated by the sporadic frequency of rains and thus water availability. In both cases, this mobility is controlled by the degree of the routes development, but also derives also from participatory governance of water access to livestock. For example, pastoral communities first use routes with ephemeral waters, while saving perennial or semi-perennial water sources for long lasting drought periods. To mitigate water scarcity, nomads and transhumant often reduce herd size, and switch temporarily to complementary activities such as trade, crafts, wage labor, and engagement in public services. However, the conservative practices of rangeland and water management have progressively declined following regional and global trends of sedentarism, urban extension, and the emergence of new activities such as intensive irrigation, industry, and tourism. Faced with this situation, various development organizations aim to recover local traditional conservation and participatory water management practices. Rainwater harvesting as well as hydraulic facilities, storage and tank services for isolated populations are being implemented at several points along nomadic routes. Besides, new schooling Opportunities have opened employment opportunities and additional income from farming activities. In this context, transdisciplinary monitoring of rangeland development through remote sensing in addition to biophysical and socio-economic indicators have been installed. In this work, we present an integrated analysis of hydrological management systems of Moroccan drylands in relation to pastoral adaptation to climate change.

Key words: Rangeland, arid zones, Climate change, water management, pastoralism, sustainability

1. Introduction

Morocco is one of the Mediterranean countries with a significant pastoral vocation. The agrosylvo-pastoral, pastoral and oasis lands cover more than 90% of Moroccan territory (MINISTRY OF AGRICULTURE, 2015). These lands offer necessary land support dedicated to extensive livestock farming, which plays a significant role in the income generation for peasant society and the rural economy’s functioning. Its production is about 1/3 of added-value in the agricultural sector, contributing to 30% of jobs. More importantly, it represents a source of income for 80% of rural households (QARRO et al. 2010).

Most of the rangelands, which represent 97% of the total (oasis 7 %), are located in arid and semi-arid environments where the chances of success of rain-fed cereal crops are closely related to the

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frequency of droughts (ARABA & BOUGHALMI, 2016; REED & DOUGILL, 2002). The North Africa drylands, including Moroccan ones, will face increasing temperatures with climate change. More importantly, they will experience disruptions to their hydrological cycles characterized by an increase of extreme events with a pronounced tendency of reduction of precipitation. This will exacerbate the already critical state of water scarcity and conflicts over water allocation and will have direct consequences for society (HSSAISOUNE et al., 2020; THOMAS, 2008).

Over centuries and decades, pastoralism in arid areas has been considered a crucial economic activity and a method of land exploitation. Under these conditions, the possession of even a small flock becomes a strategic way of ensuring the subsistence of human communities.

Nowadays, these large arid and semi-arid territories and their pastoral communities, after forming a civilization based on the management and control of natural resources scarcity, mainly water resources, are facing serious constraints related to the context of climate variability.

In this work, we will address the characterization of the socio-ecological frameworks for the exploitation of Moroccan pastoral territories. The objective is to re-examine the systems of mobilization and management of water resources related to traditional pastoral activities and analyze the technical ways for better mitigation and adaptation to climate change and variability.

2. Materials and method

The methodology used in this work focused on transdisciplinary, even multidisciplinary, collective action. We based our study mainly on the literature review of existing academic research and field observations, as well as various experiences of different researchers, including the different teams of authors involved in this paper through different research actions and projects. We focused on the scientific research carried out with the objectives of sustainable development but also of safeguarding and conserving the fragile ecosystems in situ. Therefore, we refer to: i) studies on the exploration and development of water supply systems for rural populations and their livestock, ii) establishment of National Parks and Biosphere Reserves for the conservation and rehabilitation of declining ecosystems, and iii) delimitation and characterization of pastoral and agro-sylvo-pastoral zones.

We also performed a qualitative analysis of available documents such as unpublished reports, books, and different research papers that constitute an added value to our contribution [AHLAFI 1999 ; FAO 2002, 2006 ; NEGGAR 2018 ; QARRO et al. 2010].

This theme is relevant for the sustainable development and exploitation of rangelands, as it constitutes a natural laboratory for observation and participatory analysis of socio-ecological systems. Therefore, it contributes to the monitoring of mitigation and adaptation aspects of climate change effects, particularly in:

- the amplification of the decrease tendencies of the production capacities in the arid and semi-arid ecosystems,
- the degradation, under the effect of massive migrations of young people, and the old systems of governance of scarce resources, thus producing a transmission break in the expertise between the different generations,
- the increasing actors' expression and partners interested in this theme, through the conciliation between development and the safeguard of the balance of arid and semi-arid ecosystems.

3. Results

Concerning its spatial spread between the Mediterranean and Saharan latitudes and its predominantly mountainous orographic character, Morocco is considered a territory with a pastoral vocation par excellence. The pastoral lands cover more than 87% of the national territory covering more than 71 million Ha (Fig. 1). Forest and scrub (matorral) areas constitute only 10%. In opposition, land classified as rangeland and uncultivated land covers more than 55 million Ha or 90% of the pastoral area. Without the forest rangeland, these grazing lands consist mainly of steppes at the rate of 94%; the rest concerns land covered with Alfa formations.
There are four main pastoral zones (Fig. 1):

**3.1. The nomadic pastoral system:**
It occupies the great Moroccan South, constituting the predominantly Saharan bioclimatic national territory with limited pastoral potential in terms of fern resources and watering water. This area is the seat of an exclusively nomadic pastoral system based on camel and goat breeding. Due to the geopolitical context with blocked borders and the modernization of pastoral activity, this system is in further declining.

![Figure 1: Major pastoral zones and movement of pastoralism in Morocco](image)

**3.2. The extensive agro-pastoral system:**
This system combines rain-fed cereal agriculture and extensive breeding with a local transhumant variant. This system is based on breeding mainly goats and sheep, and sometimes cattle. We distinguish two agro-pastoral sub-systems: first, the pre-Saharan zone, located between the Saharan area and the South Atlas Fault; second, the Atlantic plateaus and plains and Eastern Morocco.

**3.3. The agro-sylvo-pastoral system:**
Unlike the last system, goat-based cattle generally take advantage of the forest fodder resources offered by mountainous areas such as the Rif, the High Atlas and the Anti Atlas on their fronts open to the Atlantic Ocean, well as the Oriental Highlands.

**3.4. The sylvo-pastoral system:**
This system mainly concerns the high-altitude mountains represented by the High Atlas and the Middle Atlas and a few islets in the Central Plateau and the Oriental Highlands. These areas, characterized by their low temperatures and snowy accumulations in winter, offer precious pastures for the cattle of the transhumant tribes of
the pre-Saharan regions and the Atlantic and Oriental plains and plains (Fig. 1).

4. Discussion

4.1. Pastoral area and socio-ecological framework of exploitation

Most of the rangelands, located in areas with extreme edapho-climatic conditions, have a water deficit due to a high seasonal and inter-annual frequency of drought periods (Table 1 & Fig. 2):

- **Saharan rangelands**: mainly cover the provinces of southern Morocco with an area of around 50 million ha, more than 4/5 of national rangelands. The hyperaridity of the environment contributes to the reduction of the rates of floristic richness and recovery of vegetation, and the regression of water resources. The possibilities of using the rangelands can only be sporadic during irregular rainfall events;

- **Pre-Saharan rangelands**: located further north where the improved bioclimatic conditions allow the development of steppe plant formations dominated by Saharan strains. This area is a modest extension of 10% of all rangelands, but it remains strategic for the maintenance of pastoral activity through its forage supply of perennial xerophyte shrubs and its potential for livestock watering;

- **Eastern rangelands**: these are steppe lands representing 8% of the total rangelands. These lands are dominated by a plant formation of alfa representing a species adapted to arid or semi-arid bioclimatic conditions.

![Figure 2: Map of the regional systems of water and soil conservation (WSC) and biosphere reserves in Morocco (KOUBA et al. 2018, modified).](image-url)
Table 1: Characterization of ecological zones in pastoral areas (QARRO et al. 2010)

<table>
<thead>
<tr>
<th>Types</th>
<th>Extension (%)</th>
<th>Plant formations</th>
<th>Water potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saharan area</td>
<td>82</td>
<td>- Saharan formations;</td>
<td>- Occasional surface water;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Very low floristic richness;</td>
<td>- Non-perennial groundwater;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Very low recovery rate;</td>
<td>- Deep aquifers with limited potential;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Occasional herbaceous plant.</td>
<td>- Degraded water quality</td>
</tr>
<tr>
<td>Pre-Saharan area</td>
<td>10</td>
<td>- Saharan Steppe;</td>
<td>- Seasonal surface flows;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Xerophytic shrub formations;</td>
<td>- Non-perennial groundwater;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Seasonal herbaceous plant.</td>
<td>- Moderate water quality</td>
</tr>
<tr>
<td>Eastern area</td>
<td>8</td>
<td>- Arid Steppe;</td>
<td>- Seasonal surface flows;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Alfa formations and floristic</td>
<td>- Semi-perennial groundwater;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>community;</td>
<td>- Deep aquifers with moderate potential;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Seasonal herbaceous plant.</td>
<td>- Moderate water quality</td>
</tr>
</tbody>
</table>

4.2. Socio-ecological systems of rangelands and water governance

Human presence in drylands has only become possible through the shaping of ingenious socio-ecological systems for the mobilization and management of natural resources. For example, in the case of nomads and transhumant, the guarantee of the livestock’s watering needs was based on the movements of the herds and their owning households to the water points (Table 2).

Generally, pastoral activity was practiced outside any significant hydraulic development. As a result, the most widely used surface waters are those of isolated ponds (Dayat, Graara) and receding ponds of wadis (Gueltas). At the same time, groundwater is limited to resurgences of underflows of wadis (Aayn). More often than not, to quench their thirst, livestock use the same water resources used by wild animals.

When the mobilization of more volumes of water becomes unavoidable to increase the duration of exploitation of the pastures, the communities pass to collective hydraulic installations mainly of dewatering and storage. The most adopted technique is the digging of wells (Bir, Hassi) for the extraction of water from the shallow aquifers generally attached to infra-flows of permeable alluvium. In pre-Saharan areas where the potential of underground resources becomes relatively scare, pastoral communities may have the possibility of benefiting from spring waters (Ayn) and underground drains with accumulation basins (Khettaras and Charij). On the other hand, for surface water, the most frequent developments consist in collecting rainwater and runoff: reservoirs covered with impluvium (Matfias) and open excavations (Ghdir).

The mobilization and use of water resources are subject to a rigorous and collective management system with the rights and obligations of individuals.

Table 2: Livestock watering mobilization

<table>
<thead>
<tr>
<th>Planning types</th>
<th>Water resources</th>
<th>Techniques of mobilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploitation without planning</td>
<td>- Ponds with acceptable quality:</td>
<td>- Dayat, graara, gueltas.</td>
</tr>
<tr>
<td></td>
<td>- Underflows resurgences:</td>
<td>- Aayne, Aayoune.</td>
</tr>
<tr>
<td>Traditional planning</td>
<td>- Storage of rainwater and runoff:</td>
<td>- Ghdir, notfiass.</td>
</tr>
<tr>
<td></td>
<td>- Exhaure of water from local aquifers:</td>
<td>- Wells, Hassi.</td>
</tr>
<tr>
<td></td>
<td>- Use of underground oasis drains:</td>
<td>- Khettaras, charii.</td>
</tr>
<tr>
<td>Stakeholders intervention</td>
<td>- Wadi with perennial or semi-perennial flows</td>
<td>- Dams, Small dams.</td>
</tr>
<tr>
<td></td>
<td>- Exploitation of deep aquifers:</td>
<td>- Boreholes.</td>
</tr>
<tr>
<td></td>
<td>- Water transfer to places of consumption:</td>
<td>- Towed citterns.</td>
</tr>
</tbody>
</table>
4.3. Rehabilitation attempts and experiences of stakeholder participation

The pastoral areas in Morocco are more than ever subject to pronounced stresses due to overexploitation of rangelands combined with water shortage (DEL BARIO et al. 2016; KOUBA et al. 2018).

In the face of declining dynamics, these areas are underway to rehabilitate the pastoral socio-ecological framework. They include various decisions, such as national range development strategies; emergency drought response programs; the range and livestock development project, biodiversity conservation project through transhumance in the High Atlas, projects to install national parks and biosphere reserves (Fig. 2). Currently, the ministry in charge has just launched a study of differentiation, inventory, and characterization of the rangelands to create pastoral and sylvopastoral spaces in the twelve regions of the country. The figure 3 shows an example of pastoral and transhumance within Southeastern Morocco including the movement axes between plain and Mountains in one hand and between water points and feeds areas in other hand. These movements are done according the different seasons.

Figure 3: Case of pastoral and transhumance from Southeastern Morocco

The development and implementation processes of the various programs and projects have provided precious opportunities for adopting horizontal approaches favoring the principles of
consultation and citizen participation and all stakeholders. This new approach places the people concerned at the center of the development process. It has been relatively successful in improving pastoralists' living conditions and supporting their activities. To this end, more efficient hydraulic equipment has been installed, but this has not been able to halt the trend towards the disappearance of nomadic and transhumant lifestyles.

5. Conclusion

Even though the water supply systems used for livestock may appear to have poor to moderate yields, they are recognized by their high capacity to adapt to the fragility and irregularities of local water potential. For the community of scientists engaged in the processes of finding the best practices facing mitigation and adaptation to the effects of climate change, the traditional pastoral systems developed in the past by nomadic and transhumant societies engaged in the processes of finding the best practices facing mitigation and adaptation to the effects of climate change, the traditional pastoral systems developed in the past by nomadic and transhumant societies, which ends in the exhaustion of the regeneration capacities of pastures and consequently by increasing the risk of speeding up the desertification process.

However, these legacy systems seem to be in a phase of regression and loss of expertise expressed by an increasingly intense settlement. Complex factors have contributed to this trend towards spatial fixation, and intensification of this mobile pastoral activity.

Far away from the ecological characteristics, the factors of change in these pastoral systems have economic, social and even political dimensions. This includes the closure of international borders, the urbanization spread, the desire to improve livestock farmers' standards, the growth of the population and food needs, and finally, the shift to intensifying livestock farming.

In this context, we remind that all the development activities of arid and semi-arid pastoral areas, carried out by the State and pastoral partners, are mainly oriented towards pastoral hydraulics to improve the water supply. However, such actions only facilitate the fixation of nomadic and transhumant societies, which ends in the exhaustion of the regeneration capacities of pastures and consequently by increasing the risk of speeding up the desertification process.

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