Impacts of Climate Variability and agriculture on water Resources: Adaptation and Resilience, Case of the Irrigated Perimeter of Tadla, Morocco

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Abstract. Morocco's Socio-Ecological System has been highly impacted by the use of water resources. The decrease in annual volume of water collected and the increase caused by an increased rate of rates of Evapotranspiration result in the decrease of the Available Surface Water and Groundwater Repairs as a result of changes in the frequency and amount of precipitation throughout the year, is a process that produces significant Spatial and Temporal Water Disparities; this is known as Water Inequity. The irrigated perimeter of Tadla is facing a major environmental challenge. This issue is closely linked to climate change, which has generated a form of climatic and hydric imbalance. Its effects are visible through the decline in water levels, as indicated by piezometric measurements of groundwater, particularly the *Eocene* aquifer, which is non-renewable. A possible environmental crisis characterized by water scarcity that jeopardizes both agricultural productivity and the availability of drinking water is also indicated by the region's rising soil salinity.

1 Introduction

Climate variability and human influence are altering how water resources behave in arid and semi-arid regions more than ever before [1], [2]. Climate variability and human pressures will increase the constraints on water management due to social, economic, and agricultural demands within those areas [3]. As a result of these changes, Morocco has recorded some of the most profound environmental imbalances within its borders, and they are often described as environmentally unjust [4]. Unequally exposed to climate risks and having differing levels of control over and access to key natural resources such as water, these populations are experiencing the effects of both climate change and social inequalities [5]. Morocco's Socio-Ecological System has been highly impacted by the use of water resources [6]. The decrease in annual volume of water collected and the increase caused by an increased rate of rates of Evapotranspiration result in the decrease of the Available Surface Water and Groundwater repairs as a result of changes in the frequency and amount of precipitation throughout the year, is a process that produces significant Spatial and Temporal Water Disparities; this is known as Water Inequity [7]. The environment in the region of Tadla is undergoing very concerning degradation, manifested through general environmental injustice and, more

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specifically, the impacts of climate change. Several other resources that are part of the natural environment are also impacted by this situation as evidenced by growing scarcity of Water due to inequitable Spatio-temporal distribution; often referred to as "Aqua-Environmental Justice" and experienced predominantly in Arid or Semi-Arid regions [8]. The impacts of the phenomenon are widely apparent on Groundwater Resources which are experiencing severe shortfalls across the country, particularly in the irrigated perimeter area of "TADLA" and the aquifers contained within that perimeter [9]. Groundwater in "TADLA" is undergoing a dramatic reduction in piezometric levels in both the shallow and deep aquifers (the latter is non-renewable) presenting a serious concern for the capability to provide potable water and sustain agricultural practices associated with potable water supply [6], [10].
The research presented in this proposal will examine the effect of both climate change and the practices of agriculture on water resources within the Tadla region. The Tadla is an irrigated area located in Morocco's northern region. The second objective of this research is to identify how farmers are adapting to changes in climate and are working to adapt to the potential for climate variability. An improved understanding of how irrigation systems in semi-arid regions are affected by climate and how groundwater systems are affected by climate will also assist in identifying structural barriers to improving sustainable water management practices in semi-arid areas.

1.1 Study area

Covering 320,000 hectares, the Tadla region is mostly flat and located approximately 200 kilometres south east of Casablanca. Altitudinally, the area ranges from about 400 metres and is characterised by an elevation gradient of roughly one to three per million [9]. Hydrologically, the Oum Er-Rbia basin represents one of the largest river basins in Morocco, and includes the Tadla Irrigated Perimeter as part of its area. Most surface water resources in the Tadla region are now collected through some of Morocco's major hydraulic works, such as dams, built in the upper part of the Oum Er-Rbia to provide regulated river flows to the irrigation schemes. In recent years, increasing difficulties have made it harder to depend on surface water due to ongoing droughts. As a result, even less surface water has entered the system. Groundwater, therefore, has taken on much greater importance to support agriculture [3], [11].

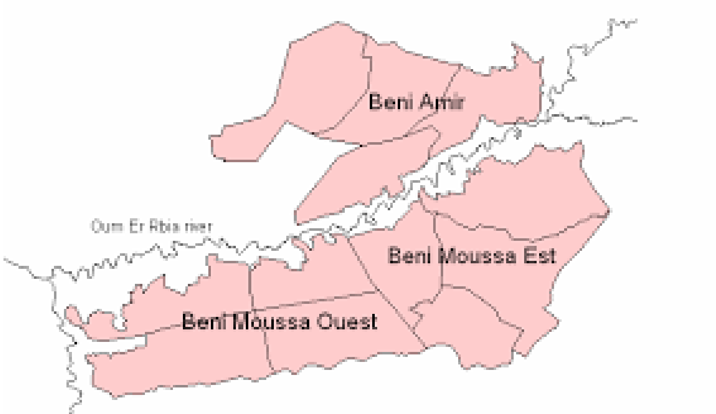

Fig. 1. Tadla irrigation boundary layout.

Beneath the Tadla Irrigated Perimeter lie two major aquifers: a shallow alluvial aquifer that can naturally recharge itself, but is highly dependent on climate and agricultural water use, and a deep aquifer that has very limited natural recharge and will ultimately be non-renewable in our lifetime because it is being pumped at rates greater than the natural recharge. The continual pumping out of both aquifers has caused them to continue to decline in elevation, which poses an ongoing threat to the continued ability of the basin to support agricultural activity [12].

2 Issues, objectives and methodology

2.1 Issues

Climate change is becoming a growing global concern among the developed and underdeveloped countries of the world, particularly in arid and semi-arid areas of the Earth such as Morocco. Morocco is being severely affected by the effects of climate change in terms of a growing and persistent imbalance and depletion of groundwater resources. Groundwater resource supplies at the national level are quite low, especially in the irrigated zones that are most susceptible to depletion. An example is the entire irrigated zone of the Tadla area, where water scarcity has increased to such a degree that it limits the ability to meet agricultural needs and maintain viable agricultural production levels. Currently, agriculture in this area is experiencing a severe water shortage that makes it impossible to sustain agricultural production both now and in the foreseeable future [13].
The present study will address the previously identified issues and focus upon the Issue "Effect of Climate Change and Agriculture on Water Resources: Adaptation and Resiliency Strategies" using "The Regulated Irrigation System in Tadla, Morocco" as an example.

2.2 Objectives

The article will address the need to raise Awareness regarding the Immediate Need for individuals and communities to be aware that water resources are being Over utilized and, therefore, that their Future Availability Requires the Preventative Action(s) of Limitations to be placed upon individuals' use, which in turn allows Each Community to access its Own Sustainable Water Resource Systems. The discussion shall be centered around three primary Themes of Awareness and will provide Supporting Information regarding Each of Those Three Themes:

- Examples of groundwater availability and lack thereof.
- Causes for depletion of groundwater resources from the area.
- How to better manage groundwater use in this area due to changes in climate conditions.

2.3 Methodology

We will use a scientific methodology, with a territorial approach supported by field surveys, to examine the problem and conduct the analysis. Data collection will take place via a simple, probabilistic sampling method, using 660 surveys of farmers located within the irrigated area of the Tadla region.
All data from the climate and piezometric datasets will be statistically analysed and graphically represented using either Microsoft Excel or SPSS. The piezometric level distribution will be visually displayed on maps using ArcGIS with kriging as a form of spatial interpolation; so that piezometric levels are accurately represented and illustrate the geographic location.
Using an understanding of agricultural impact and Climate Change on Groundwater Resources; including a Multi-Phase Process in delayed development of the Methodological

Approach used in developing our work is what we did as we developed all aspects of our Methodological Approach:
* Documentary research phase on the subject, aimed at defining water problem and establishing a typology, analyzing how this problem manifests itself at the national and local levels, how it is addressed, and how it can be prevented.
* Field visit phase, notably to ORMVAT, ABHOER, and DPA, with the objective of meeting officials from environmental observatories and relevant institutions.
* Compilation and analysis of both ancient and recent data on climatic parameters and evolution of piezometric level, along with an evaluation of the actions implemented by ORMVAT for the monitoring and safeguarding of water resources within the irrigated perimeter.
* .Phase of map and graph development: this stage involved the production of graphs and thematic maps of precipitation and piezometric levels using spatial interpolation techniques. Universal kriging was adopted, as it demonstrated the best fit to field conditions and produced the most accurate and representative models.
* Territorial survey phase: The main objective of this stage is to collect information and data that are not available in the existing documents and references. This phase is primarily based on field surveys, and in order to achieve reliable and robust results, it follows a scientific approach carried out through several successive stages.
- Determination of the sample size: The population size refers to the total number of individuals forming the subject of the study. When working on a wide-ranging project, you should utilize estimated values rather than exact figures. The smaller the group, the higher the importance you will place on statistical accuracy. In the situation you are working with, the overall size of the target audience is large, and is around 30,000 farmers, with one third of them located in the Beni Amir region. Thus, it makes sense to use a large or unknown population formula.

n = [t2*p(1-p)] / e2
n = 2.5752 *0.5(1.0.5) /0.052
= 6.63(0.5*0.5) /0.0025
n = 663

- (n): sample size
- (E): confidence level, which determines the representativeness of the sample
- (e): accepted margin of error (1%, 2%, 3%, 4%, 5%, etc.)
- (p): homogeneity of the population in its responses (p = 0.5)

The value of t always depends on the confidence level E.

Confidence level (E) — t value

95 %	1.96
99%	2.575
90%	1.645

We used a 99% confidence level and a 5% margin of error to calculate a representative sample size, allowing the results to be generalized. After applying the above rule, we determined a sample size of 663 farmers. This sample was distributed across the two sectors to maintain representativeness: one-third for Beni Amir (221) and two-thirds for Beni Moussa (442), as the latter accounts for two-thirds of the total number of farmers in the Irrigated Perimeter of Tadla [14].

Sampling Techniques: After completing the determination of sample size, we then selected the relevant approach for our study. We opted for the use of a probabilistic sampling technique. More specifically, simple random sampling was employed since we have access to a sampling frame or parent population made up of farmers located in Irrigated Perimeter of Tadla (IPT).

Survey Design

We adhered to a number of important guidelines when creating the survey questions:

- Employing clear and easily understandable concepts
- Incorporating both open-ended and closed-ended questions
- Structuring the questions in a logical and sequential order

*** Survey Administration Phase**

This phase of administering the surveys to farmers lasted over six months, as data collection began in early December 2018 and continued until early June of the same year.

*** Data Analysis and Transcription Phase**

This phase involved analyzing and transcribing the collected data.

*** Computer Application Phase**

This phase involved using computer applications to enhance the presentation and ensure wide dissemination of the results related to the piezometric levels in the Irrigated Perimeter of Tadla. We decided to use several software programs, each serving a specific purpose, including:

- **ARCGIS** to present thematic maps and perform spatial interpolation
- **Excel** to simplify calculations related to piezometric levels and to create graphical representations
- **SPSS** to process the survey data and generate graphical representations

3 Results and discussions

3.1 Reduction in piezometric levels in the irrigated perimeter of Tadla

The main phases in the evolution of groundwater in the irrigated perimeter of Tadla can be interpreted through the changes in the piezometric level shown in the figure above. Overall, six distinct periods can be identified in the temporal evolution of this groundwater system [15].

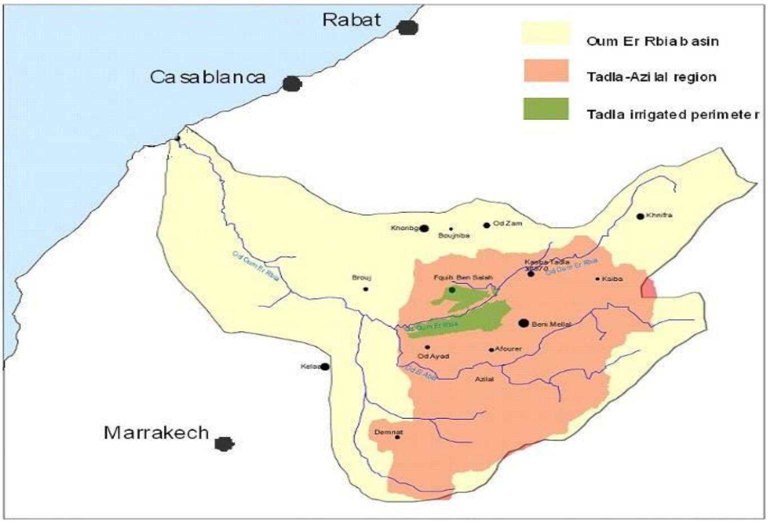

Fig. 2. Tadla irrigation perimeter, Morocco.

- **Between 1975 and 1980**, the lack of modernization of the main irrigation canals led to considerable water losses, which in turn caused a rise in the piezometric level and generated drainage problems within the plots. During this period, the average depth to groundwater ranged between 0 and 4 m.
- **The period from 1981 to 1985** was marked by severe drought, with annual rainfall not exceeding 100 mm. When there were insufficient surface water supplies to provide adequate crop irrigation, there was an increase in groundwater extraction; the resultant increase in groundwater extraction has caused significant reductions in the piezometric levels.
- **From 1986 to 1991**, groundwater levels in the two monitored wells increased once more as a result of a return to more typical weather.

From 1991 to 1996, during this time, climate adversity resulted in decreased annual rainfall and limited surface water availability. Farmers began utilizing groundwater wells more frequently for irrigation since they had access to use whatever amount of ground that ORMVAT allocated for irrigation on demand instead of relying solely on scheduled water deliveries. Consequently, as a direct result of this increased usage of groundwater wells, the number of borehole drills in the Beni Moussa Est region rose significantly because boreholes provide a greater yield of water when compared to most conventional well systems; however, the expenses associated with drilling boreholes are significantly greater than those associated with traditional well drilling.

Between 1997 and 1999, groundwater recovered as a result of improving hydrological and climatic conditions. The increase in piezometric levels noted in the two wells under observation during this time period reflects this.

After 1999, groundwater levels indicate a significant downward trend and several contributing causes have been identified as to why this is occurring including; well defined and readily identifiable pumping stations and lack of a consistent and reliable means of determining how much water is being pumped from the aquifer have yet to be established. Further complicating matters is the increasing need for new pumping installations, as noted by the nearly 6630 active wells and boreholes in the Beni Moussa region alone, raising serious concerns regarding the potential longer-term viability of groundwater supplies in the Tadla plain.

Groundwater protection requires the implementation of specific actions. One important action is the regulation of the drilling of new wells that access deep aquifers used for a variety of purposes (both agricultural and municipal) in many towns and rural areas within the region.

Between 1995 and 2016, the piezometric levels within the total area of irrigated land throughout Tadla varied from a low of 6.5 m to a high of 16.2 m. These levels are represented visually in the chart above

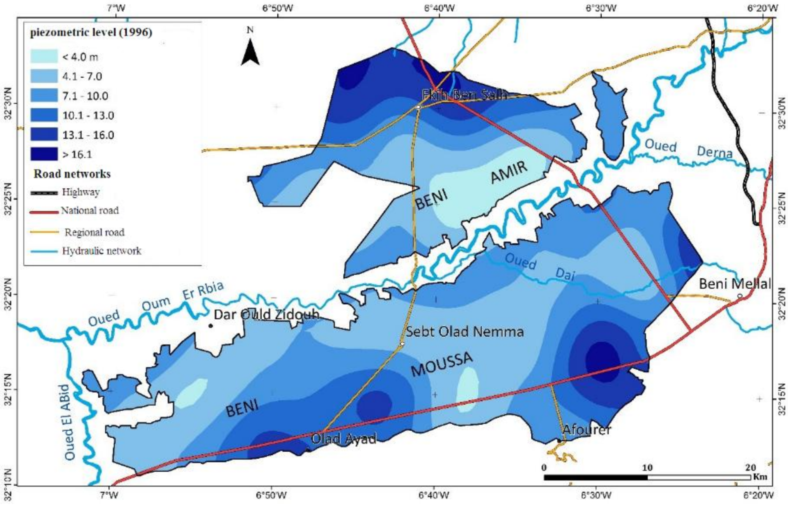

Fig. 3. Average piezometric level of the groundwater of the Irrigated Perimeter of Tadla in 1996.
Source : travail personnel

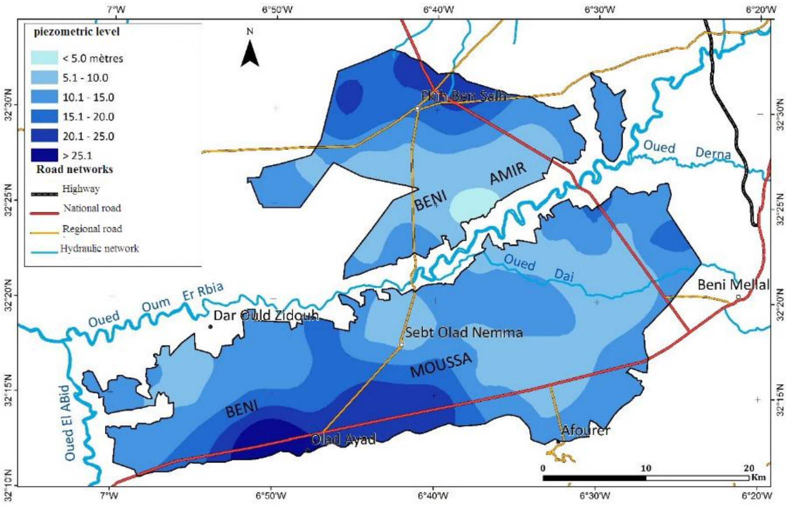

Fig. 4. Average piezometric level of the groundwater of the Irrigated Perimeter of Tadla in 2006.
Source : Personal work

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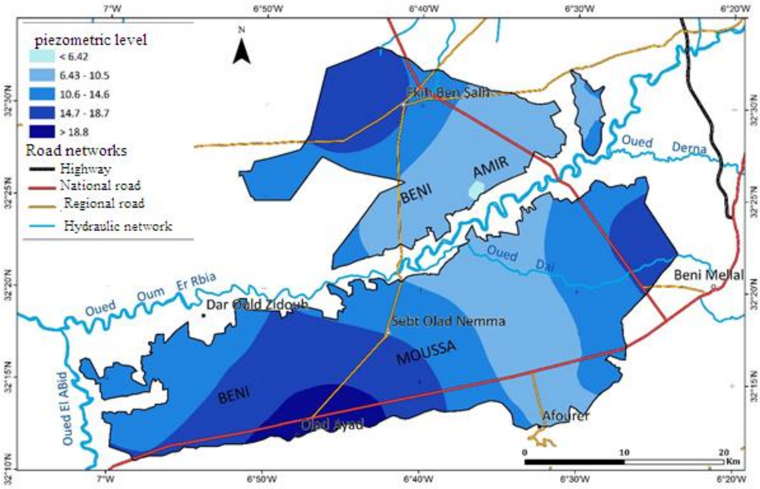

Fig. 5. Average piezometric level of the groundwater of the Irrigated Perimeter of Tadla in 2016.
Source : Personal work

The analysis of the above maps confirms that the trend of declining piezometric levels of the groundwater within the irrigated perimeter of Tadla continues to increase steadily and progressively across the three sectors, following a highly alarming pattern. This decline is particularly pronounced in Beni Amir (BA) and Beni Moussa East (BME), where drawdown levels exceeded 19 m in 2016 compared to about 25 m in 2006. Conversely, areas experiencing only slight drawdown have shrunk rapidly between 1996 and 2016.
This drawdown is generally due to the expansion of private pumping stations. The decline in the groundwater has intensified over time with the increase in the number of wells and boreholes. In addition, the succession of drought years has further aggravated the situation. These two factors are the main causes of the significant drawdown of the Mio-Plio-Quaternary aquifer in the irrigated perimeter of Tadla.

3.2 The impact of climate change on the irrigated perimeter of Tadla

The plain of Tadla is characterized by a semi-arid Mediterranean climate with a marked continental influence. It experiences a cold and wet winter extending from November to March, and a hot, dry summer from April to October, while the autumn season is practically indistinct. The climatic characteristics presented in this study are derived from data recorded at the Ouled Sidi Driss agro-meteorological station—one of the oldest stations in the region, located in Beni Amir within the irrigated perimeter—as well as the more recent Beni Mellal station situated to the southeast of the perimeter, in addition to other complementary meteorological stations [16].

- **Rainfall**

The average annual rainfall in the plain of Tadla over the past five years has been approximately 300 mm, with a highly irregular distribution both temporally and spatially. During the 2016/2017 hydrological year, average annual rainfall ranged from 414 mm at the Beni Mellal station, to 318 mm at Mchrar Dahk, and 176 mm at Ouled Sidi Driss. Most of the precipitation occurs between October and April, typically concentrated in a few days each month, and rarely exceeding sixty days per year. In 2016/2017, rainfall was limited to just 30 days. Summer is generally dry, with occasional sudden showers in the foothills. The annual rainfall trend is presented below, and the distribution of monthly rainfall is illustrated in the accompanying diagram [17].

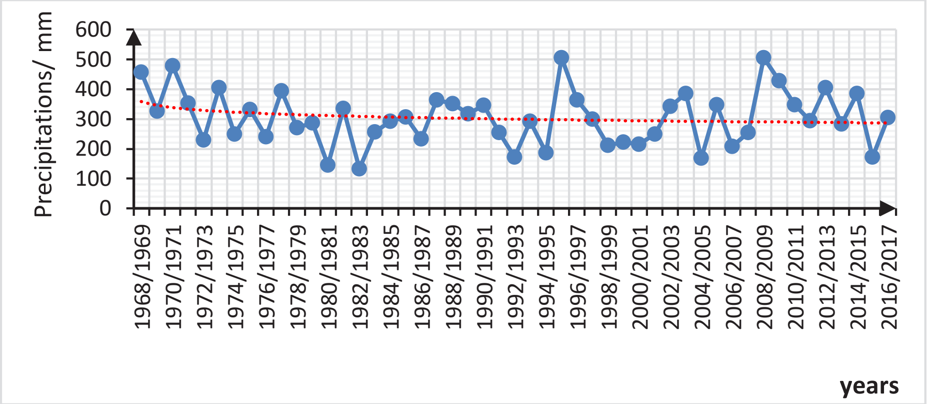

Fig. 6. Evolution of average rainfall at Irrigated Perimeter of Talla (1968/2017).
Source: ABHOER (reproduced and adapted)

3.3 Overexploitation of groundwater

Groundwater resources play a strategic role in supplying drinking water and supporting irrigation, particularly during periods of drought. However, due to decreased rainfall and, more importantly, the overexploitation of groundwater, piezometric levels are declining at a rate of 1 to 3 meters per year. This trend is likely to result in the drying up of wells and boreholes used for drinking water and irrigation, especially in the peripheral areas of the Tadla aquifer [10], [12], [18].

The decline in water levels is illustrated below through maps and the figure above. The findings of our research showed a marked increase in the total number of abandoned boreholes and wells compared to the total number that are functional. There has been an increase in the abandonment rate from the early 1990s until 2018, with 56% of the Beni Amir farmers abandoning their wells, and 44% of the Beni Moussa farmers having abandoned theirs. The main cause of this trend is the complete de-mining of the groundwater due to over-pumping, evidenced by the situation experienced during field work in 2018, which forced farmers to drill additional boreholes or deepen their existing wells to access remaining groundwater [19].

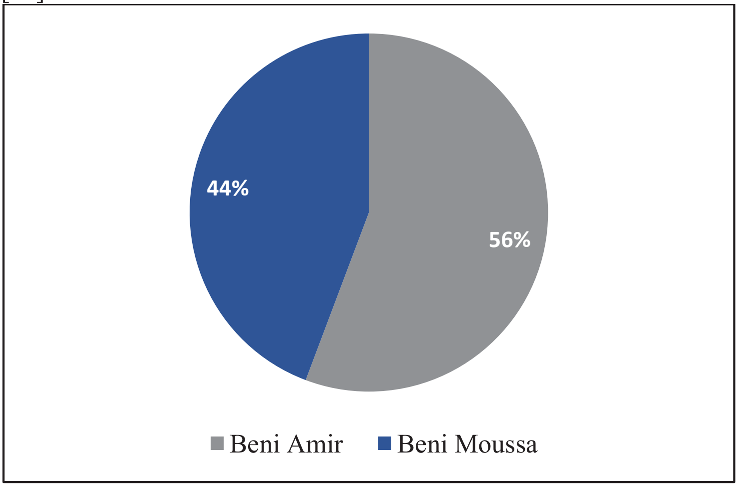

Fig. 7. Comparison between the Beni Amir (BA) and Beni Moussa (BM) sectors regarding abandoned wells according to farmers.

Source : Field work 2018

Wells run dry when groundwater is significantly lower than natural levels due to the overuse and unsustainable practices of farmers. Because of this, farmers found ways around the depletion of wells by obtaining enough water to supply their crops. Over half (53%) of farmers interviewed drilled new wells to supply their crops with the water they needed [20].

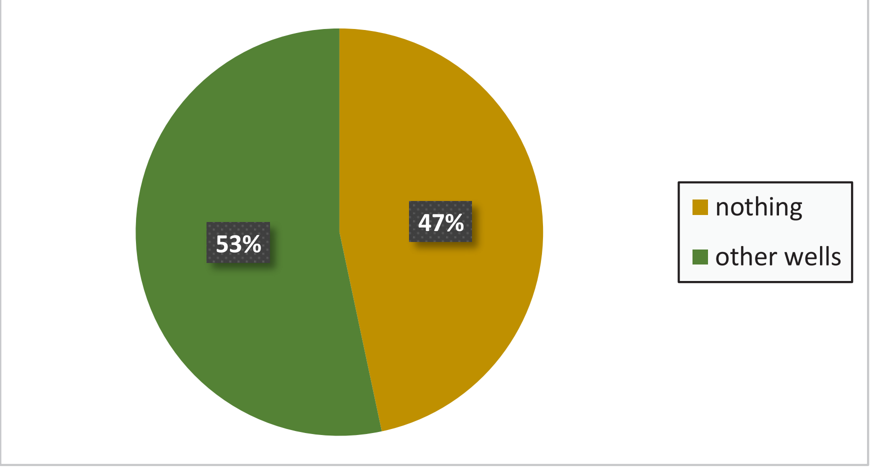

Fig. 8. Solutions adopted by farmers after the abandonment of their wells.

Source : Field work 2018

3.4 Non-rational use of water

At present, 89% of all irrigated surfaces in the country depend entirely upon gravity-fed systems; therefore, considerable amounts of water are wasted and economic productivity lost from them, as well as from the overall quality of water supplied. Additionally, irrigation networks suffer similar losses; approximately 53% of farmers have more than two wells to supply their crops with sufficient water, while 47% only have one well [21]. However, the most significant cause of increased water uses and lowered groundwater levels is the random, unplanned method by which farmers utilise their available water resources. In excess of 96% of farmers do not know what their various crops and soils precise water needs are [22].

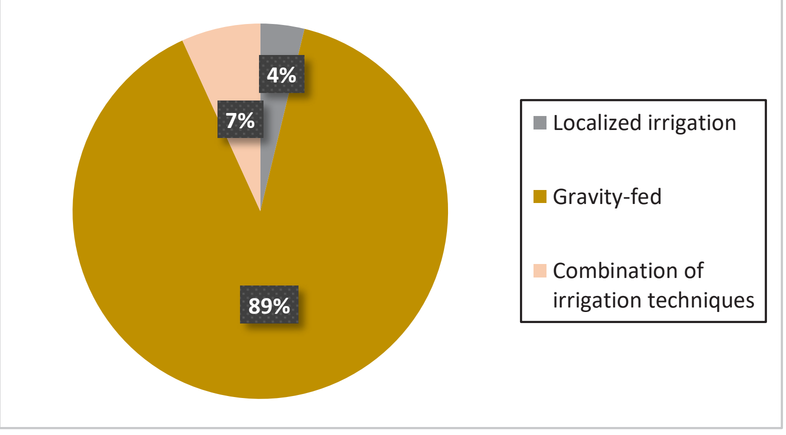

Fig. 9. Distribution of irrigation methods in the Tadla irrigated perimeter.

Source : Field work 2018

3.5 Tips for rationalizing the use of groundwater with the challenge of climate change in the irrigated perimeter of Tadla

Due to the misuse of water and droughts, there is an alarming and increasing level of depletion of non-renewable deep aquifers (e.g., Eocene and Turonian aquifers), with declines in water levels of more than 50 meters. To help protect against this serious issue and limit the negative effects of overextraction of groundwater, many alternative methods can be employed:

- Encouraging localized irrigation to minimize water losses and ensure that water reaches crops more efficiently.
- Changing Cultivation Practices: Modifying farming practices can help conserve groundwater through several approaches:
- Increasing fallow land: Leaving portions of land uncultivated allows more rainwater to infiltrate and recharge the groundwater.
- Adopting water-efficient crops: Switching to crops that require less water reduces the demand on groundwater for irrigation.

Encouraging Localized Irrigation through State Support:

Farmers should be trained on the Benefits of Localized Irrigation, so they gain knowledge of the types of localized irrigation systems available to them. There are currently 78 percent of farmers who do not have enough information or are not aware of any active projects in the communities where they are working. The IPT also found that only 68 percent of these farmers are technically trained on how to install and maintain localized irrigation systems and only 12 percent were aware of localized irrigation methods [23].

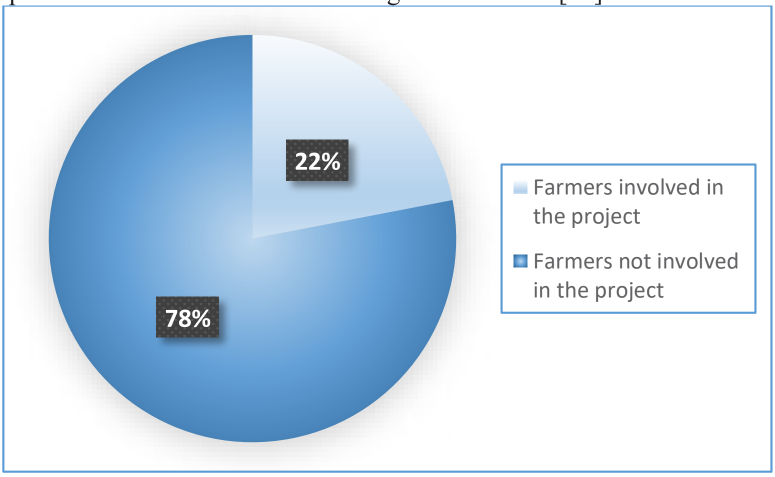

Fig. 10. Farmers are insufficiently aware or involved in local irrigation projects.

Source : Field work 2018

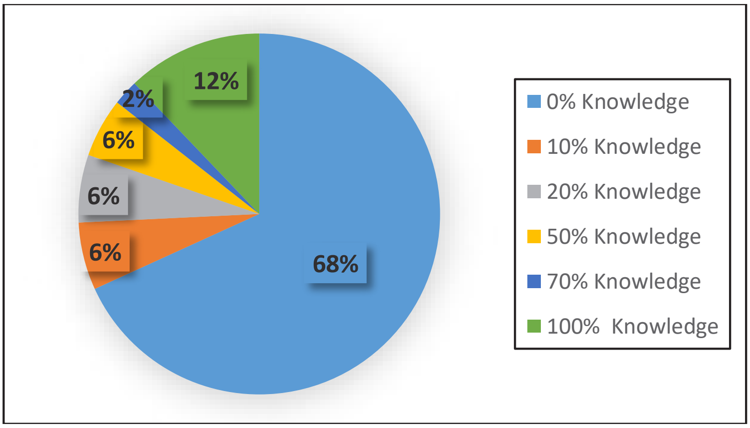

Fig. 11. Technical knowledge of localized irrigation among farmers.

Source: Field work 2018

Farmer Training and Support for Localized Irrigation:

In 2018, Fieldwork reported that 80% of farmers do not have adequate knowledge of the types of tools and equipment they require to implement localized irrigation on their farms; therefore, it is vital that these farmers receive the appropriate training. The other issue is convincing farmers of the advantages of localized irrigation systems. Approximately 43% of farmers do not believe in the value of these types of irrigation systems [24].

Financial Support for Farmers: Farmers need assistance to fund the cost of buying or installing localised irrigation systems. Currently, nearly 55% of farmers lack the financial ability to either purchase or build a genie system. Additionally, most farmers lack sufficient funds to keep their genie systems operating.

Inadequate Legal and Infrastructure Support: Farmers require the use of wells to access their aquifers; therefore, there needs to be appropriate legislative action. Currently, more than two-thirds of their farms do not possess a permit to construct a well. Maintaining the irrigation canals will reduce water loss and the amount of underground water used [23], [25].

Pic. 1. Gravity Irrigation of Cereals at the irrigated perimeter of Tadla.

Photo by N. Akhal, March 29, 2018"

4 Conclusion

Climate change and the intensive farming methods are both directly and indirectly affecting the desertification of the irrigated areas, especially in an area called 'Tadla' which is located in a semi-arid environment. The reason for this desertification is due to both poor climatological conditions which produce low amounts of intermittent rainfall, high temperatures and high rates of evapotranspiration combined with the pressure that intensive agriculture places on natural resources. These two factors work together to create a synergy between them creating an acceleration of land degradation processes and an increase in the amount of pressure on water resources.

Decreasing groundwater piezometric levels is the most significant reflection of groundwater degradation due to continued demands for irrigation supplies that exceed what the aquifers can naturally recharge. Groundwater extraction in Tadla has occurred at rates that exceed aquifer recharge, causing both shallow and deep aquifers to decline significantly, with deep aquifers typically being non-renewable. The depletion of aquifers in Tadla threatens to provide an adequate supply of water for agricultural uses in the future, while at the same time, there is an increased risk of soils becoming saline, becoming less fertile, and having a decreased yield from crop production. If current trends continue, the region will be facing not only an environmental crisis within years, but also a potential socio-economic disaster, resulting in loss of sustainable agriculture and extensive rural poverty.

Integrated and sustainable approaches are needed to restore and protect aquifers from depletion. Highest priority should be given to implementing water-saving irrigation practices such as localized irrigation systems (drip irrigation) which reduce evaporation and percolation and improve the efficiency of water use. Also, the timing and schedule of irrigation should be rationalized based on crop water requirements and climate in order to maximize the benefits achieved from water used.

Adaptable to dry climatic conditions is an important component to changing modern agricultural practices in relation to the changing climate. Incorporating different types of crops into production; utilizing newer, improved drought-tolerant varieties; and changing planting season practices will all lessen the amount of pressure on groundwater. Supporting these three avenues will be through the same methods currently utilized to govern the use of water, provide farmers with educational resources, and allow for greater accountability of groundwater resources. The combined effects of all three actions will be beneficial to the future of water resources in the irrigated areas of Tadla, and to the efforts to limit the degradation of cropland due to desertification and develop sustainable agricultural practices.

If today's climate patterns do not change and current agriculture practices are maintained or remain the same, it is likely that future decades will result in additional worsening of desertification within Tadla's irrigated lands. Current climate outlooks indicate an increase in overall temperatures, continued reductions in actual precipitation, and an increase in variability between the amount of precipitation received each year (interannual variability), thus, leading to increased demand for irrigation water. At the same time, it is anticipated that continuing to rely on groundwater to replace depleted surface waters will continue to cause groundwater quantity reductions and ultimately very possibly cause aquifers to reach critical levels that will make it extremely difficult or impossible for an aquifer to recover after depletion. If this scenario develops, it can lead to depleted wells, increased costs associated with pumping, decreased available irrigated land, and abandonment of agricultural land, thereby increasing rural community vulnerability to socio-economic issues.

On the other hand, the implementation of sustainable water and agricultural management practices might fundamentally alter this trend. For example, providing localized irrigation systems (such as drip systems) across a wide area will result in less water withdrawal from the ground and, thus, a slower rate of decline in groundwater levels. An increase in the usage

of crops requiring less water and with greater drought resistance, supported by adaptive agriculture planning, could provide additional resiliency against climate change. If these practices are adopted, groundwater levels in some locations will stabilize; soil degradation will be constrained; and food production will occur at sustainable levels.
Ultimately, it is clear that the future of the irrigated perimeter of Tadla can be determined by what actions we take now. Predictive analyses indicate that absent of any form of intervention, the negative effects on our environment will worsen and the availability of fresh water will continue to decline. Conversely, By utilizing Integrated Water Resource Management Techniques combined with Agriculture Adapted to Climate Change and Sound Governance, it may be feasible to prevent excessive depletion of groundwater, mitigate or eliminate the threat of desertification, and maintain viable agricultural activities in this region for the foreseeable future.

References

[1] F. B. Silatsa et F. Kebede, « A quarter century experience in soil salinity mapping and its contribution to sustainable soil management and food security in Morocco », *Geoderma Reg.*, vol. 34, p. e00695, 2023, Consulté le: 23 janvier 2026. [En ligne]. Disponible sur: https://www.sciencedirect.com/science/article/pii/S2352009423000913

[2] A. Soltani, L. Djabri, C. Fehdi, H. Bouguerra, et E. T. Salah, « Hydrochemical and isotopic methods of identifying the impact of irrigation on the quality of groundwater: a case study from the guelma-bouchegouf region, ne Algeria », *Geomat. Landmanagement Landsc.*, nº 4, p. 211-233, 2023, Consulté le: 23 janvier 2026. [En ligne]. Disponible sur: https://bibliotekanauki.pl/articles/59123517.pdf

[3] A. Benmoussa, A. Wafik, N. Abdsamad, et S. Khrmouch, « Nouvelle approche d'étude de la vulnérabilité à la pollution des eaux souterraines: Cas de la nappe Mio-Plio-Quaternaire du bassin du Tadla (Maroc) », *ESI Prepr.*, vol. 22, p. 512-512, 2023, Consulté le: 22 janvier 2026. [En ligne]. Disponible sur: https://www.academia.edu/download/107499564/17214.pdf

[4] A. Boundi et Z. Ait Yacine, « Variability of rainfall regime in an agricultural region with a semi-arid climate: Case of Tadla irrigated perimeter (continental Morocco) », *Casp. J. Environ. Sci.*, vol. 19, nº 1, p. 31-45, 2021, Consulté le: 23 janvier 2026. [En ligne]. Disponible sur: https://www.researchgate.net/profile/Boundi-Abdelhaq/publication/379833182_Variability_of_rainfall_regime_in_an_agricultural_region_with_a_semi-arid_climate_Case_of_Tadla_irrigated_perimeter_continental_Morocco/links/661db6e839e7641c0bcad6d2/Variability-of-rainfall-regime-in-an-agricultural-region-with-a-semi-arid-climate-Case-of-Tadla-irrigated-perimeter-continental-Morocco.pdf

[5] F. Z. Hafiane *et al.*, « Assessment of spatial and seasonal nitrate variation of groundwater in the irrigated perimeter (Tadla Plain-Morocco). », *Agric. For. Šumarstv*, vol. 66, nº 1, 2020, Consulté le: 23 janvier 2026. [En ligne]. Disponible sur: http://www.agricultforest.ac.me/data/20200401-19%20HAFIANE.pdf

[6] N. AKHAL, « Les eaux souterraines au périmètre irrigué de Tadla entre le risque du réchauffement climatique et la demande en eau d'irrigation », *Espace Géographique Société Marocaine*, vol. 1, nº 63, 2022, Consulté le: 22 janvier 2026. [En ligne]. Disponible sur: https://revues.imist.ma/index.php/EGSM/article/download/34784/17787

[7] M. El-Hamdouny, A. Midaoui, M. Goumih, et A. Lahrach, « EVALUATION DE LA VULNERABILITE ET DELIMITATION DES PERIMETRES DE PROTECTION A L'AIDE DU MODELE DRASTIC BASE SUR LES SIG: CAS DE LA SOURCE

AIN KAICHER AU NORDEST DE LA NAPPE TURONIENNE DE TADLA », *Espaces*, nº 11-12_Fr, p. 47-53, sept. 2024, doi: 10.34874/PRSM/espaces-2261.
[8] E. Zerouali, A. Wafik, A. Najine, F. Radouani, et S. Chlahbi, « Vulnerability Study by DRASTIC Method for Eocene and Turonian Aquifers in the Tadla Plain », *J. ISSN*, vol. 2766, p. 2276, 2023, Consulté le: 23 janvier 2026. [En ligne]. Disponible sur: https://www.jelsciences.com/articles/jbres1822.pdf
[9] E. Bouyzillan, A. Azdod, A. Lagni, H. Ouakhir, et M. El Ghachi, « Contribution of hydrometric measurements to the analysis of hydrological functioning in an ungauged watershed in the context of climate variability: The case of the Oued M'Hasser springs (2022-2023) », *BIO Web Conf.*, vol. 211, p. 01004, 2026, doi: 10.1051/bioconf/202621101004.
[10] S. Didi *et al.*, « Groundwater quality mapping in the Northern Tadla Plain, Morocco, using GIS and combined physico-chemical and bacteriological analysis », *Euro-Mediterr. J. Environ. Integr.*, vol. 10, nº 4, p. 2377-2399, août 2025, doi: 10.1007/s41207-024-00731-9.
[11] S. Khoali, Z. Lakhyar, A. Laamari, et H. Faris, « Analyse de la performance et de l'efficience des exploitations agricoles de la région Tadla », *Afr. Mediterr. Agric. J. - Al Awamia*, nº 140, p. 75-94, oct. 2023, doi: 10.34874/IMIST.PRSM/afrimed-i140.43740.
[12] M. Achbah, A. Khattabi, D. Pruneau, et T. Boumeaza, « Évaluation de la vulnérabilité des communautés de montagne face au changement climatique. Région Beni-Mellal-Khénifra, Maroc », *VertigO Rev. Int. En Sci. Environ.*, nº 24-2, sept. 2024, doi: 10.4000/12pp9.
[13] K. NOUREDDINE, « Le patrimoine architectural des médinas de Demnate et de Ksbat Tadla: caractérisation, dégradation et perception (Région Beni Mellal-Khénifra, Maroc) », 2022, Consulté le: 22 janvier 2026. [En ligne]. Disponible sur: https://toubkal.imist.ma/handle/123456789/25401
[14] B. Tarik, *Using remote sensing (optical and radar) and modeling to support the irrigation management of cereals in a semi-arid region: a case study of the Tadla irrigated perimeter in Morocco*. Universite de Liege (Belgium), 2016. Consulté le: 22 janvier 2026. [En ligne]. Disponible sur: https://search.proquest.com/openview/95cca285229547975a0ebfeecd1170ca/1?pq-origsite=gscholar&cbl=2026366&diss=y
[15] W. Baite, A. Boukdir, et M. Baite, « Integrated management of irrigation water in the irrigated perimeter of Tadla (Morocco) and involvement of farmers in the aquifer contract », in *AIP Conference Proceedings*, AIP Publishing LLC, 2021, p. 020043. Consulté le: 22 janvier 2026. [En ligne]. Disponible sur: https://pubs.aip.org/aip/acp/article-abstract/2345/1/020043/652437
[16] J. Mabrouki, M.Azrour, A.Boubekraoui, S. El Hajjaji, (2022). Simulation and optimization of solar domestic hot water systems. International Journal of Social Ecology and Sustainable Development (IJSESD), 13(1), 1-11.
[17] K. Azoulay, I. Bencheikh, J. Mabrouki, (2024). Wastewater as a Valuable Resource: Implications for Human Health and Ecosystems. In Integrated Solutions for Smart and Sustainable Environmental Conservation (pp. 79-94). Cham: Springer Nature Switzerland.
[18] B. I. Kamaguru, A. M. Djamba, A. M. Kankolongo, et M. N. Luwawa, « Les Perceptions Des Riziculteurs Sur Les Contraintes De Rendement Du Riz Dans Les Conditions Agro-Ecologiques Des Périmètres Irrigués Insécurisés De La Plaine De La Ruzizi. », *Int. J. Agric. Policy Res.*, vol. 8, nº 1, p. 17-36, 2025, Consulté le: 22 janvier 2026. [En ligne]. Disponible sur: https://hal.science/hal-04922192/

[19] A. Chaaou *et al.*, « Mapping soil salinity risk using the approach of soil salinity index and land cover: a case study from Tadla plain, Morocco », *Arab. J. Geosci.*, vol. 15, nº 8, p. 722, avr. 2022, doi: 10.1007/s12517-022-10009-5.
[20] K. D. Vecchio et M. Kuper, « La mise en visibilité des eaux souterraines au Maroc: un processus historiquement lié aux politiques de développement de l’irrigation », *Dév. Durable Territ. Économie Géographie Polit. Droit Sociol.*, vol. 12, nº 3, Art. nº 3, 2022.
[21] S. Oussaoui *et al.*, « Mapping drought severity impact on arboriculture systems over Tadla and lower Tassaout plains in Morocco using Sentinel-2 data and machine learning approaches », *Geocarto Int.*, vol. 40, nº 1, p. 2471104, déc. 2025, doi: 10.1080/10106049.2025.2471104.
[22] Y. Hrour, « Évaluation de l’impact du changement climatique sur la disponibilité des ressources en eau dans un bassin méditerranéen agricole: cas du bassin du Bas-Loukkos », PhD Thesis, Institut agronomique et vétérinaire Hassan II (Maroc), 2023. Consulté le: 22 janvier 2026. [En ligne]. Disponible sur: https://theses.hal.science/tel-04505930/
[23] Y. Khardi, « Analyse des innovations de mobilisation des ressources hydriques pour faire face à la pénurie d’eau dans les oasis: cas du bassin de Todgha (Maroc) », PhD Thesis, Montpellier SupAgro; Institut agronomique et vétérinaire Hassan II (Maroc), 2023. Consulté le: 22 janvier 2026. [En ligne]. Disponible sur: https://theses.hal.science/tel-04448135/
[24] C. Iharzi *et al.*, « Compilation and mapping of hydrogeological data for the Tadla irrigation perimeter », in *E3S Web of Conferences*, EDP Sciences, 2025, p. 02004. Consulté le: 22 janvier 2026. [En ligne]. Disponible sur: https://www.e3s-conferences.org/articles/e3sconf/abs/2025/07/e3sconf_errachidia2024_02004/e3sconf_errachidia2024_02004.html
[25] H. Nassah, A. Zitouni, O. Tibssirte, L. Daghor, H. Chattoui, et L. Midhat, « Irrigation water needs analysis and management strategies in the Tadla irrigation zone: A case study of sugar beet plots. », *Ecol. Eng. Environ. Technol. EEET*, vol. 26, nº 4, 2025, Consulté le: 22 janvier 2026. [En ligne]. Disponible sur: https://www.ecoeet.com/pdf-200563-122918?filename=Irrigation%20water%20needs.pdf