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THE IMPACT OF INTENSIVE AGRICULTURAL EXPLOITATION ON GROUNDWATER RESOURCES IN ARID AND SEMI-ARID AREAS: THE CASE OF THE TAFRATA PLAIN IN NORTHEASTERN MOROCCO

Groundwater is a major source of water supply for domestic and agricultural purposes, especially in arid and semi-arid regions. In this study, changes in groundwater levels in the Tafrata Plain in the Guercif Basin, located in eastern Morocco, were tracked by measuring and analyzing the evolution of the water depths of wells and boreholes through official statistics and fieldwork. The results showed a significant and continuous decline in groundwater levels throughout the study area, with varying degrees of variation.

The agricultural transformations and the annual increase in irrigated areas at the expense of fallow and pasture lands, along with the accompanying well-drilling campaigns to pump water, reflect an unprecedented trend toward irrigated agricultural investment. However, the negative impact of agricultural modernization operations in the Tafrata Plain on water resources quickly became apparent.

This alarming situation is the result of the ongoing overexploitation and unsustainable management of limited vital water resources, particularly by the agricultural sector. This critical situation has also pushed the region into a water crisis. To mitigate the effects of groundwater depletion, it is recommended to rationalize groundwater use through effective measures, primarily related to promoting sustainable development in agricultural activity. Future research should focus on developing integrated water management strategies and adaptive agricultural practices tailored to the Tafrata Plain.

Keywords: *water table, intensive agricultural exploitation, Tafrata Plain, sustainable development, arid and semi-arid areas.*

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1. Introduction. The world is also becoming increasingly aware of the human impact on Earth. Organizations, both national and international, are taking action to try to halt the coming climate change catastrophe. Efforts to address climate change and consider the future of Earth in terms of sustainable consumption are focusing on the areas of water, energy, and food [1]. The growth of the global population, combined with agricultural activities, rapid urban expansion, and climate change, has intensified pressureon foodd production food production due to high demand and water scarcity [2].

Water is a vital and renewable resource, but its availability varies and is limited by region [3]. The scarcity of water resources has become a critical challenge in many regions, affecting not only economic and social development and the delicate balance of ecosystems [4]. Specific to arid and semi-arid areas of North Africa. In Morocco, the semi-arid to arid zones cover about 85% of the country [5]. Climate change projections are likely to result in severe climatic, hydrological and agricultural droughts, with warming trends in most regions of Morocco [6].

Agriculture worldwide is responsible for many environmental threats, including land degradation and depletion of water resources [7]. The problem of intensive water exploitation is primarily linked to climate change and human activities. It has become clear that the governance problem in water management cannot be limited to institutional structures alone. Rather, water management is deeply rooted in established social and political relations at the national and local levels [8].

In recent decades, Moroccan rural areas have witnessed significant spatial transformations, particularly in the agricultural sector. Guercif Plain has undergone rapid transformations, which manifested in the formation of irrigated spaces spontaneously in different areas of the plain, accompanied by significant changes in the morphology of the geographical landscape of the plain [9].

The Tafrata plain is considered one of the components of this basin located in the eastern region of Morocco, which witnessed a great dynamism and transformation, through which the traditional local rural economy, which was based on pastoral activity, was transformed into a traditional and modern agricultural economy [10].

These profound transformations in the region have been accompanied by a negative environmental trend due to the overexploitation of natural resources, particularly water, which is a fundamental component of territorial development in the region.

The problems facing the region with successive years of drought are further complicated by irrational human interventions due to poor management. All these factors contribute to the pressure on groundwater resources.

The primary objective of this research is to analyze and emphasize the critical importance of addressing key environmental challenges, particularly water scarcity, the effects of climate change, and human pressures on water resources in agricultural exploitation. This research aims to highlight the urgent need to take proactive measures to achieve sustainable development in Morocco's arid and semi-arid regions by mitigating the challenges of water scarcity, combating the effects of climate change, promoting sustainable agricultural practices, and effectively managing human pressures.

2. Research Problem. The accelerated agricultural development and demographic growth in the Tafrata Plain basin are intensifying groundwater depletion in an area already characterized by limited and climate-sensitive water resources. This situation raises a fundamental research problem: to what extent are current agricultural water-use practices sustainable? And how can the region reconcile its growing agricultural water demand with its limited and climate-sensitive water resources?

3. Study area. The Tafrata Plain administratively comprises four Moroccan territorial communities in the eastern region: Houara Ouled Rahou, Lmarija, in the Guercif Province, and Kteter, and Sidi Ali Belkacem, in the Taourirt Province. The Tafrata Plain is located on the right bank of the Moulouya River, between Guercif and Oued Za. The Tafrata Plain is considered one of the most important plains in the Guercif Basin. It forms a vast area characterized by a topographic gradient towards the north, interspersed with a series of dry, dense seasonal valleys. It extends eastward to Jebel Ouled Aamrou and the Oued El Abed Basin. It is bordered to the south by the Debdou Massif and the Sidi Lahcen Mountains, to the southwest by the Maarouf Plain, and to the north by the Moulouya River [11].

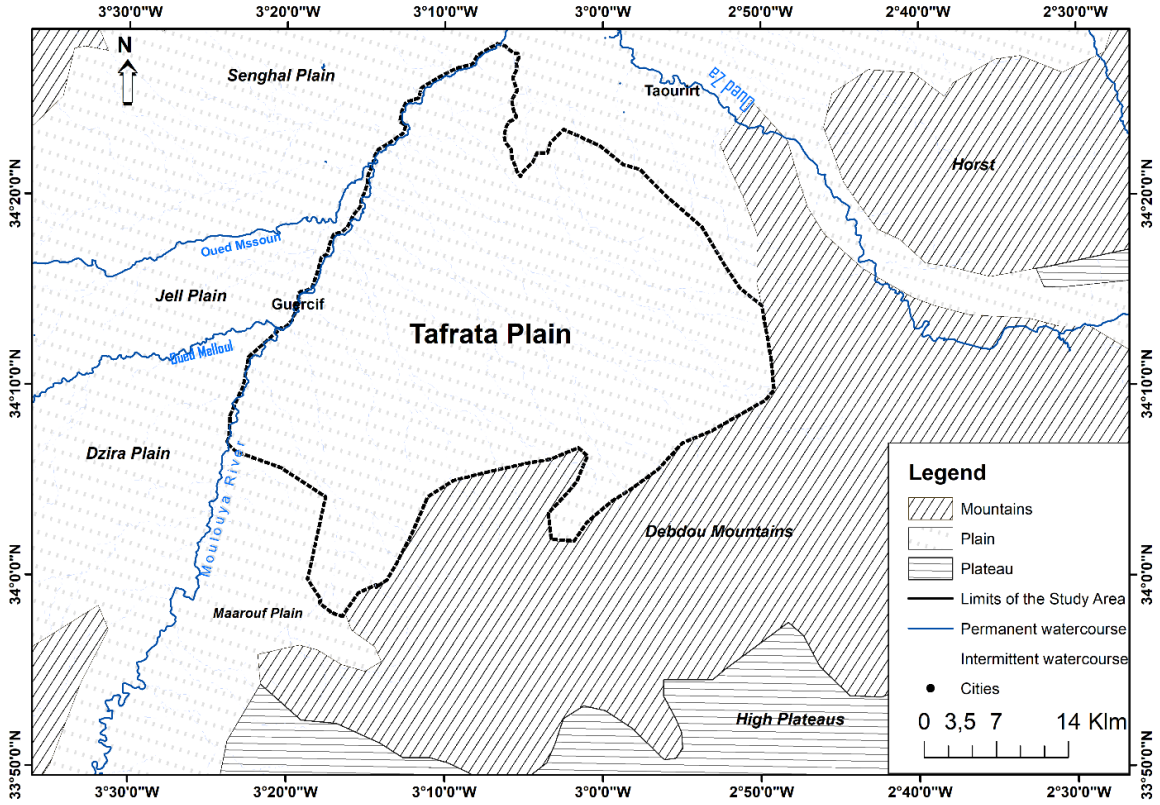

Fig. 1. Localisation of the study area

The Tafrata Plain basin is in northeastern Morocco and boasts significant economic potential based on its natural resources and agricultural sectors. The agricultural sector, which has witnessed tremendous development over the past decades, is a major source of social, economic, and social support for the region's population. Water resources in the Guercif Basin are limited in terms of quantity and quality and are impacted by climate

risks.

Substantial pressure is being placed on the region's groundwater resources because of transformations in the agricultural sector and population growth. Climate change projections are likely to result in severe droughts in the region, widening the gap between water supply and demand. Hence, the need to find ways and means to bridge these gaps.

4. Materials and Methods. The nature of the problematic that forms the core of the research topic warrants a geographical perspective based on a scientific approach capable of bridging the gap between the interconnected relationships and interactions between the various components of the field. This approach is based on a series of interconnected scientific and practical processes, beginning with the collection of raw scientific material and ending with its analysis.

- The descriptive approach aims to accurately identify the phenomenon by describing the manifestations of agricultural dynamism and its relationship to the exploitation of water resources.

-The statistical approach aims to quantitatively compile the scientific material in mathematical form, using numbers and graphs, to arrive at more accurate, certain, and scientific results regarding the geographical phenomenon under study. Data and information related to well measurements and groundwater aquifer fluctuations were classified.

-Fieldwork is defined in the geographical field as a qualitative method for collecting data in the field. Field research included a variety of research methods, including direct observation, interviews, and questionnaires. The latter attempted to identify the transformations experienced by the agricultural sector, water exploitation methods, and the depth of wells in the field.

5. Results and Discussion. Spatial transformations and agricultural exploitation in the Tafrata Plain have accelerated over the past two decades. This dynamic has taken on negative dimensions due to recent economic trends that have negatively impacted groundwater resources. These resources must be exploited in a manner that maintains their economic profitability and sustainability, especially with the growing demand for food in the face of demographic pressure. Agricultural activities in the area, along with the associated equipment, tools, and technologies, have increased pressure on water resources.

The qualitative leap and modernization of water exploitation methods in this arid environment have led to numerous environmental imbalances. The necessity of intensive water exploitation, given the significant economic benefits this sector provides and the number of job opportunities it creates for the region's population, should not make us overlook the importance of preserving environmental balance and the sustainability of this vital resource.

Table 1

Volume of Water Withdrawn from Wells in Tafrata Plain in2017

The territorial community	Pumped Volume (m^3/an)	Dynamic Recharge (m^3/an)	Crop Balance Recharge (m^3/an)	Gross Recharge (m^3/an)
Houara Oulad Raho	24,174,371	14,719,333	34,146,060	31,837,795
Lmrija	14,424,914	5,518,114	12,951,635	22,852,572
Gteter	11,593,714	3,233,455	13,160,550	4,529,993
Total	50,192,999	23,470,902	60,258,245	59,220,360

Source: Moulouya River Basin Agency, 2017

The total volume of agricultural irrigation water consumption through wells and boreholes in the rural communities of the Tafrata Plain covered by the study was 50,192,999 cubic meters per year, corresponding to a total flow rate of 1,591.60 liters per second.

The total annual volume collected using the volumetric method is estimated at 59,220,360 cubic meters. The crop-balanced approach yields a total volume of approximately 60,258,245 cubic meters, while the energy method yields a total annual withdrawal of 23,470,902 cubic meters. The difference between the three methods is (Moulouya Hydraulic Basin Agency. 2017):

- The energy method assumes pump set characteristics (engine power), which is irregular in most cases. Therefore, the calculated flow rate is often overestimated.

- The crop-needs approach uses needs assessments and does not subtract direct rainfall from the calculated needs, on the one hand, and assumes that crop needs are fully satisfied (available resources). The volumetric method based on on-site flow measurements and pump set run times assumes a constant daily pumping time and does not consider climatic conditions.

The quantities of water withdrawn by groundwater users were assessed by the Moulouya Water Basin Agency's reports for population and livestock needs, based on the needs of the population and livestock. Table (2) shows the calculated volumes for each community, with the annual volume withdrawn for livestock amounting to 40,057 cubic meters, corresponding to a quantitative flow rate of 1.27 liters/second per year.

The total amount of water withdrawn for livestock consumption and drinking water consumption combined amounted to 169,413 cubic meters, while drinking water consumption alone for the rural world amounted to 129,356 cubic meters, which exceeds livestock consumption by several times. The table shows the clear disparity between rural communities in terms of water consumption.

Table 2

Withdrawn Water Quantities, Livestock Consumption, and Potable Water in Rural Municipalities

The territorial community	Available Quantity (m³/an)	%	Livestock Consumption (m³/a)	%	Potable Water for Rural Areas (m³/an)	%
Houara Oulad Raho	13,412	7.9	1,221	3	12,191	9.42
Lmrrija	132,265	78.07	30,065	75	102,2	79
Gteter	23,736	14.02	8,771	21	14,965	11.58
Total	169,413	100	40,057	100	129,356	100

Source: Moulouya River Basin Agency, 2017

Table 3

Annual Water Quantities Exploited in All Sectors and Fields of Study

The territorial community	Agriculture (Irrigation) (m³/an)	Potable Water for Rural Areas (m³/an)	Industries (m³/an)	Urban Sector (m³/an)
Houara Oulad Rahou	24,371,174	13,412	5,081	3,758,776
Lmrrija	14,914,424	132,265	1,166	-
Gteter	11,714,593	23,736	-	-
Total	50,192,999	169,413	6,247	3,758,776

Source: Moulouya River Basin Agency, 2017

The total volume of groundwater drawn from the Tafrata aquifer for irrigation, drinking water supply in urban and rural areas, and industrial units, from various water points (wells, boreholes, springs), according to available data, totals 56,456,069 cubic meters per year. Agriculture accounts for a significant proportion of this, with an annual exploitation of 50,192,999 cubic meters and a flow rate of 1,591.60 liters per second. This significant figure indicates a significant consumption of water resources in agriculture. Despite the adoption of localized irrigation, the expansion of agricultural areas has contributed to an increase in agricultural water consumption. Water springs constitute 2,328,634 cubic meters, most of which are in the rural commune of Lmridja. Industrial consumption totals 6,247 cubic meters per year, which is the amount of water used annually by agricultural industrial units, including medicinal plants, oils and aromatic products units, and olive processing and packaging units.

The variation in agricultural water consumption values according to the rural communities (Houara Ouled Rahou 24,174,371 m3, Lemrija 14,424,914 m3 Gteter 11,593,714 m3) indicates the differences in the level of agricultural dynamism according to these rural communities. The rural community of Houara Ouled Rahou has the largest agricultural irrigated area and in terms of the number of wells, boreholes and technologies related to the exploitation of water resources and agricultural modernization. The community of Lemrija occupies the second place and finally the rural community of Gteter. The Contribution of Excessive Agricultural Exploitation to the Decline of the Water Table. The number of licensed wells has been steadily increasing in both the communities of Lamrija and Houara Ouled Rahou. The total number of wells and boreholes increased from 85 in 2011 to 482 in 2014, and then to 720 in 2016. This demonstrates the strength and speed of the drilling activity for agricultural purposes in the communities of the Tafrata Plain, particularly in Houara Ouled Rahou. Furthermore, an analysis of the depth categories of licensed wells reveals an increasing demand for drilling at greater depths, along with increased license applications, an indicator of pressure on the water table. The depth of wells during this period ranged between 10 and 250 meters, while wells drilled in the Lamrija community in 2016 recorded depths ranging from 45 to 180 meters, while in the Houara Ouled Rahou community in the same year, depths ranging from 10 to 200 meters were recorded.

- Well drilling has fluctuated in terms of the number of licenses, especially in the rural community of Mrija, where 27 water wells were drilled in 2011, then decreased to 15 water holes in 2014, then increased in 2015 (41 wells), while in the community of Houara Ouled Rahou, the number of wells continued to increase, rising from 58 in 2011 to 147 water wells in 2014, which was accompanied by the equipment of agricultural farms and the support allocated for this through the Green Morocco Plan.

- The number of wells and water holes licensed for irrigating agricultural lands during this period in the rural community of Lamrija reached 133 wells, representing 8.5%, and 587 wells and holes in the rural community of Houara Ouled Rahou, representing 81.5%. Thus, the Houara Ouled Rahou community holds the largest number of drilling licenses, which has contributed to creating

an important irrigated agricultural dynamic in this rural community, which varies through the methods and techniques of its exploitation with other rural communities belonging to the Tafrata plain**.**

Analysis of the survey results shows that the depths of water points in the Tafrata Plain range from 3.5 to 260 meters in the Guercif Basin, of which the Tafrata Plain constitutes a significant portion. Analyzing the distribution of well and borehole depths revealed the following:

- The number of wells and boreholes varies among territorial communities, with the Houara Ouled Rahou community accounting for the largest number, with 1,644 boreholes and water wells (57.90%). The rural community of Lmrija accounts for 25.95%, with 737 water wells.

The community of Gteter, meanwhile, represents a smaller percentage, with 458 wells and boreholes (16.15%).

- The clear dominance of well depths greater than 50 meters, with 2,216 wells, indicates extensive exploitation of the groundwater aquifer in varying forms across the plain. - Recording low numbers in short and medium depths: 105 wells in the ≤ 10 category, 59 in the > 10 to 20 category, and 459 wells and holes in the > 20 to 50 category, which constitutes a gradation linking the relationship between the number of wells and holes and depth categories, such that the deeper the categories, the greater the number of wells and holes, which is an indicator of the continued increase in the depth of wells and holes with the strength of agricultural exploitation, which raises the problem of the sustainability of groundwater resources in the area.

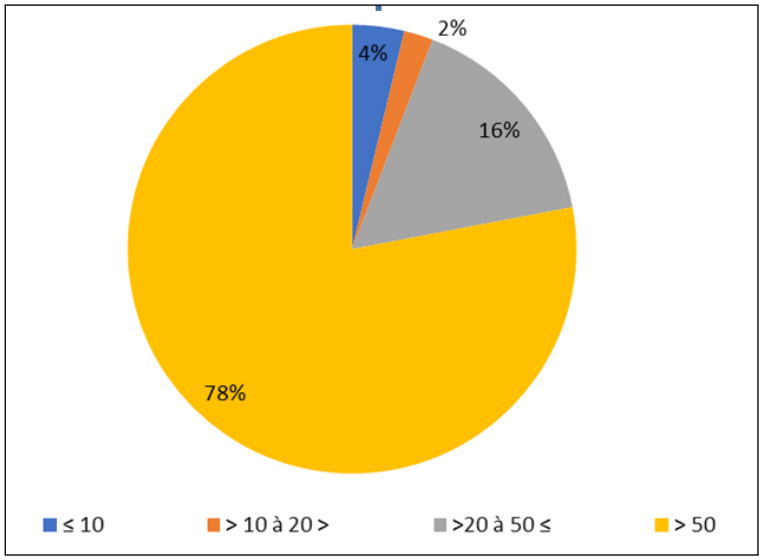

Fig. 2. Distribution of Depth Categories of Wells and Boreholes in the Tafrata Plain
Source: Data from the Water Basin Agency, 2017

The analysis of the distribution of depth categories for wells and boreholes in the Tafrata Plain shows a clear variation among these categories, with the category of depths greater than 50 meters forming a significant percentage. The main findings are as follows:

- 3.75% of the wells and boreholes in the Tafrata Plain have depths less than or equal to 10 meters, which constitutes a small percentage in the plain.
- 1.2% of the depths range between 10 and 20 meters, which is also a small percentage.
- 16.15% of the water points have depths ranging between 20 and 50 meters.
- 78% of the wells and boreholes have depths exceeding 50 meters, a percentage that exceeds that recorded in the Guercif basin, where 7% of the water points have depths greater than 50 meters.

This situation can be explained by two main reasons: the first is the depth of the aquifer in the area, and the second is the intensive use of water resources, particularly those linked to pumping water for agricultural irrigation.

Table 4

Evolution of the depths of wells and water holes in the Tafrata Plain between 1985 and 2022

Aquifer	Year	Depth Range
Tafrata plain	1985	30 to 40 meters
Tafrata plain	2017	18 to 165 meters
Tafrata plain	2022	30 to 200 meters

*Source: Fieldwork + Water Basin Agency data. 2022***,** *Diaboun T. 1985. Research on climatic and agro-climatic water balances in the corridor plains of Taza/Oujda (Eastern Morocco). 2 volumes. Third cycle thesis, Paris*

The increase in the depths of wells and boreholes has been accompanied by pressure and intensification of agricultural exploitation. Despite the severe drought of the 1980s, the groundwater table depth was low (30 to 40 meters) from the main sources of supply (Kaadat Debdou - Oued Moulouya), which is consistent with the weak exploitation of the groundwater table during this period. Meanwhile, 2017 saw an increase in the depths of the groundwater table, ranging from 18 to 165 meters. Human pressure on the groundwater table in the plains increased with subsequent drought years, recording high values ranging from 30 to 200 meters in 2022, with the increase in irrigated agricultural areas, which constituted a general trend in agricultural dynamism in the face of weak renewable capacity. Based on available groundwater measurements and old bibliographic data, it was found that the groundwater table level in Tafrata in general, and the Maarouf plain in particular, is experiencing a significant decline, because of the current dynamics [12].

The size and average depth of wells and boreholes vary in the Guercif plains, highlighting the strength of human exploitation and the strength of agricultural dynamism linked to the exploitation of the water table, the pressure of demographic growth, and the degree of aquifer renewal in each plain separately. The Tafrata plain, the subject of the study, represents the largest group in terms of depth categories and average depth, which reached 95 meters, while the depth of wells ranged from 18 to 165 meters.

The depths and averages of wells are lower in the Jel plain, with an average well depth of 51 meters, and in the Maarouf plain, with an average well depth of 46 meters. Most of the groundwater aquifers in the Guercif basin are fed by the surrounding highlands, such as**(** Kaada Debdou, Jebel Arsheida, and El Heloua**)**, in addition to the Moulouya Valley, Oued Messoun, and Mellou**)**. However, the importance of water resources remains limited due to the intensification of drought in recent years, coupled with a climate characterised by high temperatures, strong evaporation and strong winds, which reduces the amount of water available in the region, in addition to excessive exploitation for irrigation, which has begun to expand due to the recent transformations taking place in the regio[13].

This major water crisis that the Tafrata Plain has experienced, perhaps the most significant manifestation of which reflects the agricultural dynamism that the plain has experienced, is the significant decline in groundwater, which constitutes the last reserve of water used in agriculture and drinking water. The increasing rate of well drilling and boreholes in the Tafrata Plain warns of increased pressure on groundwater resources.

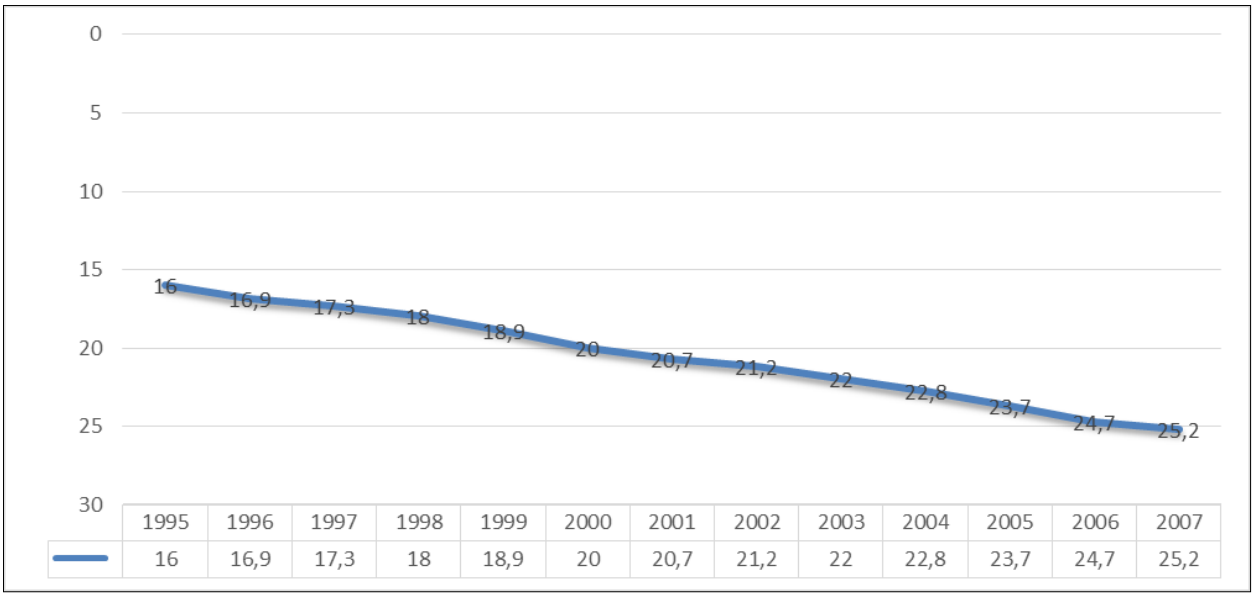

Fig. 3. Decline in groundwater level in meters in the Tafrata Plain between 1995 and 2007
Source: Moulouya Water Basin Agency data

The average groundwater level in the Tafrata plain decreased from 16 meters in January 1995 to 2.25 meters in January 2007, which represents a sharp decline, especially in the late 1990s, with a level of 7 meters over a period of ten years. At 1.5 km from the point of the first measurement, it was found that the groundwater level decreased by only 2 meters. This situation is explained by the varying intensity of pressure on the groundwater from one area to another and the supply situation, which varies from one region to another. The groundwater layers of the Guercif basin experienced a decline in their levels during the hydrological year (2011-2012); the water level in the plain decreased by 0.30 to 0.95 meters due to drought and intensive exploitation, while the Maarouf plain experienced a decline in groundwater levels, ranging from 0.74 to 2.44 meters, while the center experienced an increase of 3 meters (Moulouya Water Basin Agency, 2012).

Conclusion. The agricultural transformations and the annual increase in irrigated areas at the expense of fallow and pasture lands, along with the accompanying well-drilling campaigns to pump water, reflect an un-

precedented trend toward irrigated agricultural investment. However, the negative impact of agricultural modernization operations in the Tafrata Plain on water resources quickly became apparent.

- A study of a sample of wells revealed that the average depth of wells in the plain reached 100 meters, the highest average depth of wells in the plains of the Guercif Basin. This pressure in a semi-arid area has produced an agricultural landscape (in favorable topographic locations) based on a multiplicity of large and medium-sized agricultural lands, both traditional and modern, with a well-planned and well-organized landscape.

- The agricultural dynamism experienced in the study area, in relation to its natural fragility, has negatively impacted most of the lands in the area, whose soils are very poorly protected from erosion, particularly fallow areas and areas devoid of vegetation cover. In contrast, wooded areas or areas with vegetation cover are characterized by medium and high levels of protection.

The economic and social growth of the plains region has resulted in a significant demand for water resources, particularly with the entry of investors into the area, the transformation of irrigation methods, and the significant increase in well drilling, which has become widespread. The use of water is no longer limited to extracting it using traditional methods. Mechanical pumps are now widely used, and these wells have become particularly important after the drying up of some valleys and springs on which the population relied.

Although the plain still experiences weak water resources, it is characterized by rapid transformation and increased pressure on water resources in an arid environment that suffers from recurring drought years. This is particularly true with the land development experienced by the plain, which is based on the distribution of collective lands and the mechanization of the sector.

- The importance of groundwater resources has increased in intensifying agricultural activity, especially since the region lacks surface resources that can be mobilized for agricultural use, apart from the Moulouya Valley and the Za Valley, which remain remote from a significant area of the plain's lands. The water resource needs of agricultural land are not met. Therefore, exploiting groundwater has been a way to provide the region with water for irrigating agricultural lands to increase agricultural production. This has led to increased pressure on groundwater, given the limited potential for water resources in the face of intense human pressure.

- The natural transformation of agricultural activity has negatively impacted water resources and the expansion of pastoral lands, with poor agricultural yields in fallow lands dominated by cereals, while agricultural yields have improved in irrigated areas, which rely on fodder, vegetables, and olive trees.

-This over-exploitation of the groundwater table could push the plain into a water crisis zone if repeated droughts persist.

- This will weaken the groundwater's replenishment capacity unless accompanied by technological innovations. Focus should be placed on preserving the natural environment and its resources, as well as on crops that do not require large quantities of water, while deepening the drip irrigation technology and monitoring its application on the land.

In conclusion, this study has examined the interplay between agricultural development and the limited water resources in the Tafrata Plain basin. The results highlight the challenges posed by water scarcity on sustainable agriculture and rural livelihoods, emphasizing the urgent need for integrated water management strategies to ensure the long-term socio-economic and environmental stability of the region. Despite numerous studies on agricultural development in northeastern Morocco, the specific impacts of water scarcity on the sustainability of agricultural practices in the Tafrata Plain remain insufficiently investigated. Existing research often overlooks the integrated assessment of water resource limitations, land-use changes, and their socio-economic consequences, leaving a critical gap in understanding how to balance agricultural growth with environmental sustainability in the region. Future research should focus on developing integrated water management strategies and adaptive agricultural practices tailored to the Tafrata Plain.

The application of modern tools such as remote sensing, GIS, and predictive modeling could enhance planning and decision-making, ensuring the long-term sustainability of both water resources and agricultural productivity in the region.

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ВПЛИВ ІНТЕНСИВНОГО СІЛЬСЬКОГОСПОДАРСЬКОГО ВИКОРИСТАННЯ НА ПІДЗЕМНІ ВОДНІ РЕСУРСИ В АРИДНИХ ТА НАПІВАРИДНИХ РАЙОНАХ: КЕЙС РІВНИНИ ТАФРАТА НА ПІВДЕННОМУ СХОДІ МАРОККО

Підземні води є основним джерелом водопостачання для побутових та сільськогосподарських потреб, особливо в аридних та напіваридних регіонах. У цьому дослідженні відстежувалися зміни рівнів підземних вод на рівнині Тафрата в басейні Герсіф, розташованій на сході Марокко, шляхом вимірювання та аналізу динаміки глибин води в колодязях та свердловинах на основі офіційної статистики та польових робіт. Результати показали значне та безперервне зниження рівнів підземних вод по всій території дослідження, з різними ступенями варіацій. Ця тривожна ситуація є наслідком постійного надмірного використання та нестійкого управління обмеженими життєво важливими водними ресурсами, особливо у сільському господарстві.

Сільськогосподарські перетворення та щорічне збільшення зрошуваних площ за рахунок перелогових земель та пасовищ, а також супутні кампанії з буріння свердловин для відкачування води відображають тенденцію до зростання інвестицій у зрошуване сільське господарство. Однак негативний вплив модернізації сільського господарства на рівнині Тафрата на водні ресурси швидко став очевидним.

Ця критична ситуація призвела регіон до водної кризи. Для пом'якшення наслідків виснаження підземних вод рекомендується раціоналізувати їх використання за допомогою ефективних заходів, головним чином спрямованих на сприяння сталому розвитку сільськогосподарської діяльності. Майбутні дослідження повинні бути зосереджені на розробці комплексних стратегій управління водними ресурсами та сільськогосподарських практик, адаптованих до рівнини Тафрата.

Ключові слова: *рівень ґрунтових вод, інтенсивне сільськогосподарське використання, рівнина Тафрата, сталий розвиток, аридні та напіваридні райони*.

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