



Assessment of the Agricultural Intensification Impact on Groundwater Quality: a Case Study of the Triffa Plain

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Abstract Since the modernisation of the agricultural sector in Morocco, the Triffa plain has been experiencing the development of techniques and increased production. However, agricultural intensification, the uncontrolled use of fertilisers and pesticides, and the succession of years of drought have contributed to the overexploitation of water resources and the degradation of the groundwater quality in the plain. To study the impact of the poor quality of groundwater (nitric pollution and salinisation) on the health of vegetation, we examined the spatiotemporal evolution of nitrates and salinisation in the plain, as well as the chlorophyll activity of crops (NDVI) using the Google Earth Engine (GEE) associated with MOD13Q1 version 6 images, for the years 2007-2009-2016-2022. The main results show an increase of 174% of the chlorophyll activity ($NDVI \geq 0.6$) between 2007 and 2022, which make evidence of the significant intensification of the agricultural sector in the plain accompanied by a fast spread of nitric pollution regarding the groundwater. Hence, the area covered by the poor to very poor groundwater quality has almost doubled in a time interval of years ($S_{2007}^{N(\frac{ms}{T})} = 235.5 \text{ km}^2$, $S_{2022}^{N(\frac{ms}{T})} = 408.65 \text{ km}^2$). According to the analysis of the normalised difference vegetation

index maps calculated for the study periods: 2007-2009-2016-2022 and the Pearson correlation matrix between the different variables, we conclude that the degradation of groundwater quality negatively affects the chlorophyll activity, which will consequently have an impact on the crop yield. The results prove the excessive use of fertilisers and pesticides, which led to increased chlorophyll activity associated with fast degradation of the water's quality concerning nitrate concentrations.

Keywords Nitric pollution · NDVI · Groundwater · Chlorophyll activity · Google Earth Engine · Salinisation · Agricultural intensification

1 Introduction

As a part of its national socio-economic development strategy, Morocco has made enormous investments in the agricultural development sector, a pillar of the Moroccan economy.

Today, due to multiple programs and development projects aimed at securing food and improving the living and production conditions of farmers, according to World Bank national accounts data (IBRD, 2020), this sector accounts for 11.7% of PIB, with 38% of total employment at the national level and about 74% in rural areas.

However, agricultural development and excessive use of fertilisers and pesticides have significantly

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degraded the physical-chemical quality of groundwater in the Triffa plain, which is the focus of this research. Several academics have warned about this area's speed expansion of salt and nitric pollution. In 1996, groundwater contamination from fertilisers was not a significant issue because only 2 to 3% of the investigated wells showed nitrate contents higher than the European regulatory limit of 50 mg/l. On the other hand, 3/4 of the Triffa groundwater wells were deemed saline and unfit for irrigation. Recently, the analytical results of physicochemical parameters and metallic trace elements in most of the prospected wells indicated a concentration exceeding the WHO set thresholds. This illustrates the damage caused to groundwater resources and exposes us to severe environmental and human health hazards (Kadaoui et al., 2019).

Vegetation cover degradation is frequently observed where soil and groundwater suffer from

contamination (Opekunov et al., 2022). Groundwater pollution's impact on plants appears through interaction between contaminated water and the plant's root zone. As a result, the photosynthesis activity is negatively affected, and a significant modification in the spectral characteristics of the vegetation occurs.

In recent decades, NDVI has been considered a potentially powerful instrument in environmental monitoring applications because of its minimal price compared to hyperspectral data. NDVI provides a unique spectral characteristic to recognise vegetation stress (Rowland & Omonefe, 2022). This index has often been used as an indicator of vegetation health (greenness and growth) in response to environmental challenges (Jiang et al., 2022). The NDVI index was employed by Rowland and Omonefe (2022) to assess the vegetation response towards soil and groundwater contamination from leachate seepage; the obtained low NDVI values reflect the reaction of plants to

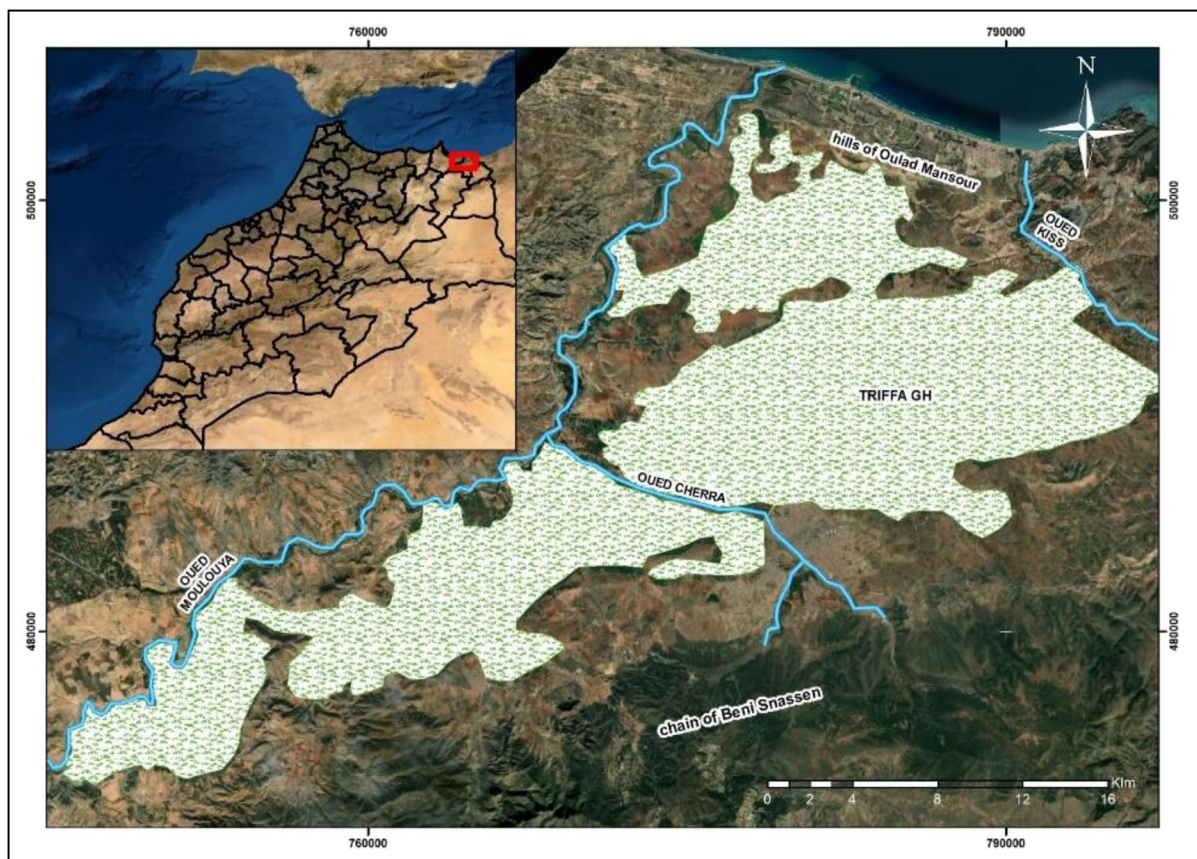


Fig. 1 Geographical location of the study area (Triffa plain)

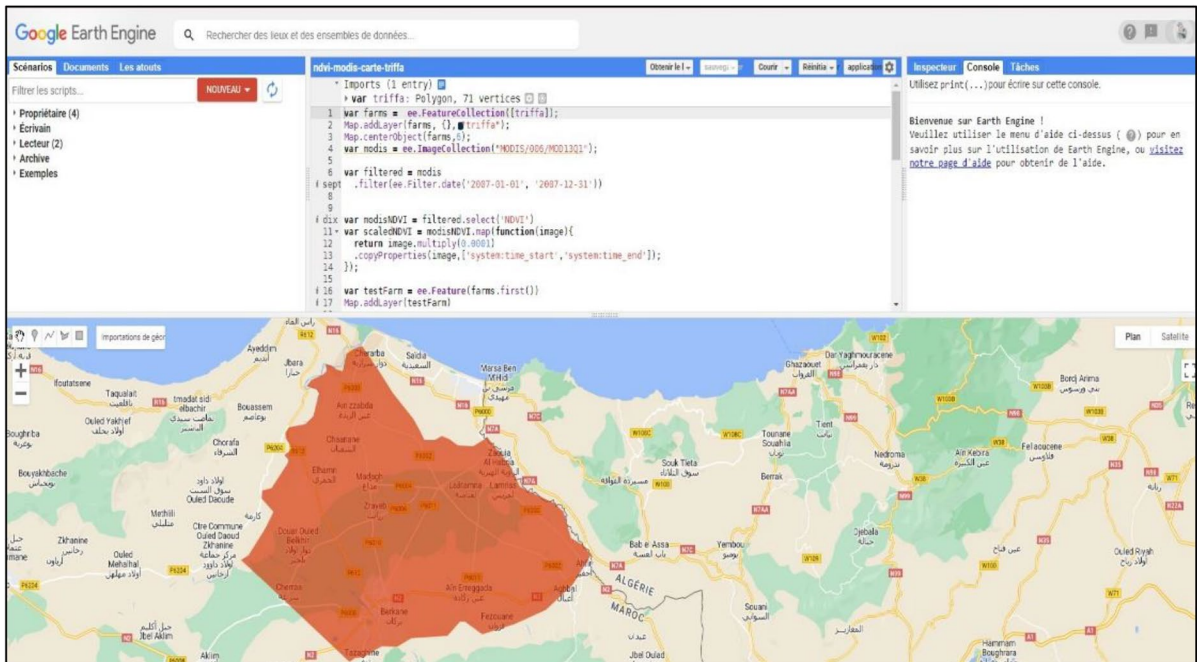


Fig. 2 The area view in the Earth Engine code editor

leachate contamination of soil and groundwater. Also, the NDVI index was used to analyse the drought response of different vegetation types; the results revealed the interaction between vegetation dynamics and climate change (Zhou et al., 2022). In the study presented by Prasood et al. (2021), the NDVI was used to produce the land use map, and the LST of the

basin were evaluated for the years 2001, 2011, and 2020 to model the impact of urbanisation on land use.

The NDVI has demonstrated its unique spectral potential to perceive vegetation stress. This index uses a combination of red (R) and near-infrared (NIR) bands to assess plant photosynthetic activity. The red band was sensitive to variations in chlorophyll

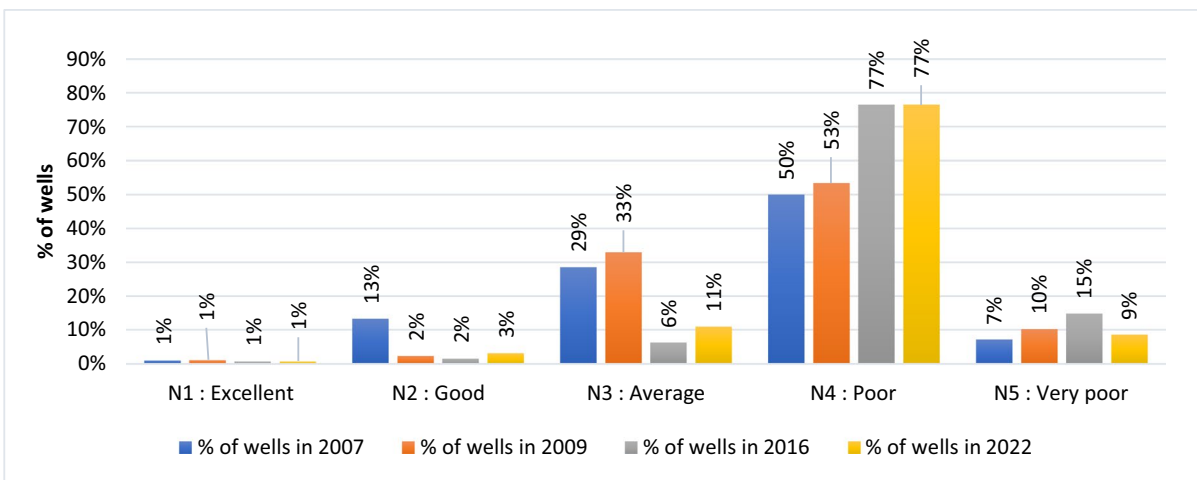


Fig. 3 Presentation of the percentages of wells according to the degree of nitrate contamination

concentration in the visible spectrum, whereas the NIR can characterise different plant kinds and conditions. A high NDVI near +1.0 indicates a favourable environment for plant development and high photosynthetic activity. Low photosynthetic activity, or when there is very little near-infrared light, is characterised by a low NDVI (close to -1.0) (e.g., dead or stressed vegetation). Healthy vegetation generally has an index of 0.20 to 0.90 (Taufik et al., 2016).

Saline stress decreases the chlorophyll content of crops, affecting plant growth and consequently decreasing crop yields (Mouhdi et al., 2022). The occurrence of high nitrate concentrations in groundwater is even more severe. They are considered unsafe for human consumption, especially for infants. In this paper, the issue is to study the impact of groundwater salinisation and nitrate pollution on vegetation health, using the means offered by remote sensing, particularly the normalised difference vegetation index (NDVI).

2 Data and Methods

2.1 Description of the Study Area

The study area is located in the northeast of Morocco (Fig. 1), part of the hydraulic basin of the lower Moulouya, an agricultural area classified as the most fertile and productive of the eastern region (Lazaar et al., 2021). It covers an area of about 750 km² and an average altitude of 75 m, bounded by the hills of

Oulad Mansour in the North (about 15 km), the chain of Beni Snassen in the South (about 65 km), Oued Moulouya in the West (about 50 km), and Oued Kiss in the East (Algerian-Moroccan border, over 20 km). The average rainfall is 327 mm, mainly distributed from September to May with a strong inter-annual variability. The average annual temperatures recorded during 27 years vary between 10 and 25 °C (ORMVAM).

The occurrence of two aquifers characterised this area: a free aquifer overexploited, hosted in formations from the secondary to the quaternary, and a confined liasic aquifer held in the dolomitic limestone of the Lias inferior, which presents a significant water supply potential and hydrothermal purposes (Boughriba & Jilali, 2018; Sardinha et al., 2012). The main crops practised in the region are arboriculture, cereals, legumes, and industrial crops. The Triffa plain suffers greatly from ignorance of farmers and producers about the correct agricultural practices; a survey established in 2020 (Bouterfas et al., 2020) shows the abusive and systemic use of pesticides, exceeding the dose recommended by farmers to protect their crops against pests and to stabilise their yields, neglect of the pre-harvest period. This practice negatively affects the environment, consumers, and crop health.

2.2 Choice of the Perimeter and Methods

In order to follow the spatiotemporal evolution of nitrate pollution and salinity of the groundwater of

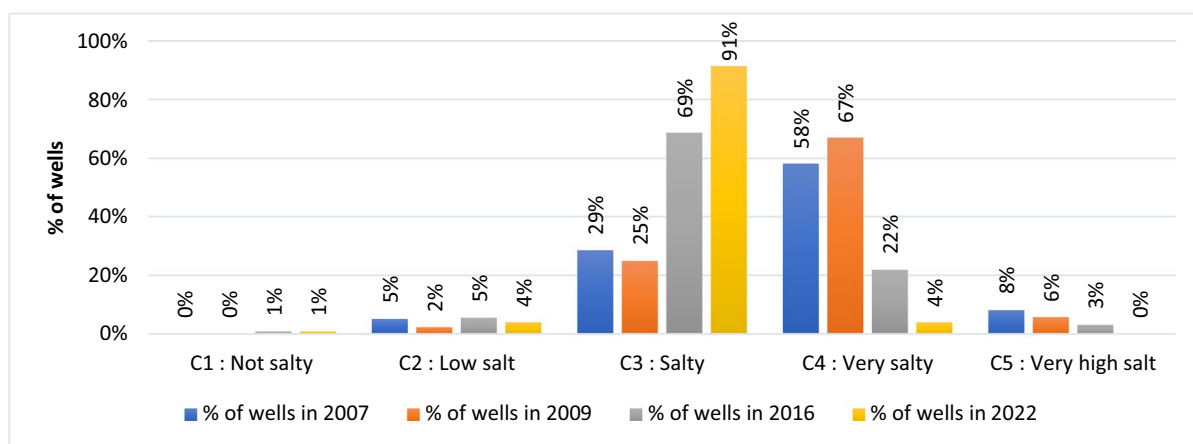


Fig. 4 Presentation of the well's percentages according to the salinity degree

the Triffa plain, we studied the evolution of nitrates and electrical conductivity during each of the following years 2007-2009-2016-2022. The choice is to cross the available data to follow the same perimeter for the same years.

- 2007, nitrate and electrical conductivity analysis results were subtracted from the work of Fekkoul (2012) for 98 wells.
- 2009, we used the data from the analysis of 88 wells carried out by the AGRINTER S.A.R.L. for the benefit of the Directorate of Development and Management of Irrigation (DDGI).
- In 2022, 128 wells were distributed throughout the study area; these same wells were analysed

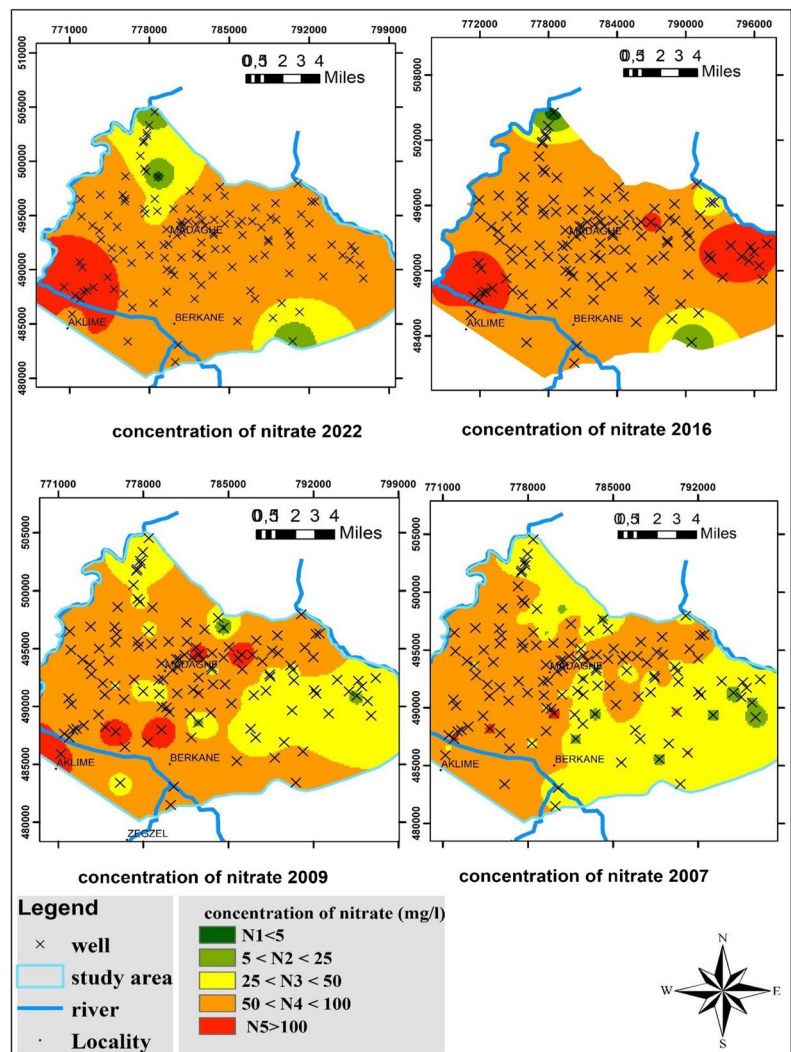
in 2016 by the Hydraulic Basin Agency of Mou-louya (AHBM).

The realisation, processing, and analysis of nitrate and salinity distribution maps are developed using the software ArcGIS version 10.3.

2.3 Normalised Difference Vegetation Index

Because of its low cost relative to hyperspectral data, NDVI has been regarded as a potentially strong sensor in environmental monitoring applications. This index evaluates the photosynthetic activity of plants using a mix of red (R) NIR bands that are typically

Fig. 5 Spatial distributions of nitrate pollution in the Triffa plain for the years 2007-2009-2016 and 2022



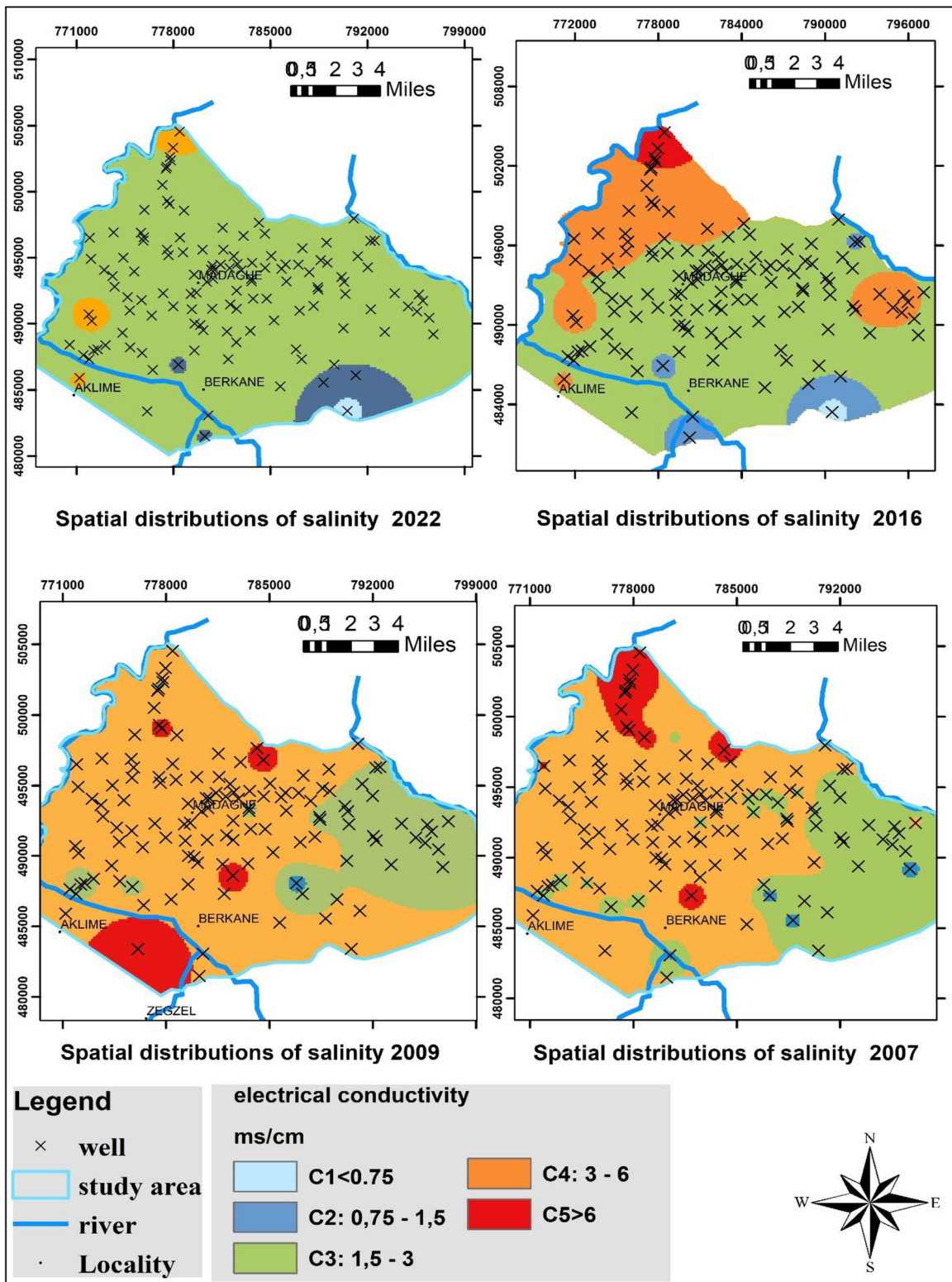


Fig. 6 Spatial distributions of salinity at the Triffa plain for the years 2007-2009-2016 and 2022

conditioned by the presence of chlorophyll. The NDVI defied as $NDVI = \frac{(IR-R)}{(IR+R)}$

where *IR* = infrared channel pixel values. *R* = pixel values in the red channel.

To calculate the annual NDVI for our study area, we used Google Earth Engine (GEE), a cloud-based online data processing platform that can immediately collect and batch process massive amounts of remote sensing data (Güzel et al., 2021; Jiang et al., 2022). Via Earth Engine code editor (code.earthengine.google.com), a script was generated to assess the images of the distribution of the annual NDVI index for the periods 2007-2009-2016-2022 for the study area (Fig. 2). The processing and analysis of the images (NDVI) are carried out by the ArcGIS software version 10.3.

3 Results and Discussion

3.1 Spatiotemporal Evolution of Groundwater Pollution

The examination of the results of the percentages of wells affected by nitric pollution and salinisation, presented in Figs. 3 and 4, reveals that:

- The quality of groundwater in the Triffa plain is poor concerning salinity. From 2007 to 2021, there has been a slight increase in the number of wells unaffected by salinisation or with low salinity and a decrease in wells with high salinity. Currently, the EC varies between 0.65 and 3.65 ms/cm, with 95.3% of the wells surveyed being salted to strongly salted. The high values are recorded at the source Ain Zebda and Ain Chebek and the source Ain Tifert, as well as private wells with multiple uses whose coordinates: Well N°2 (*X* = 772100 / *Y* = 490200), Well N°18 (*X* = 771875 / *Y* = 490700).
- The results of the analyses carried out in 2022 show that the groundwater of the plain is the poor quality; the nitrate contents vary between 1.4 and 143 mg/l with an average of 70.75 mg/l. The highest concentrations are recorded upstream and downstream of the STEP of the city of Berkane, as well as the wells N°2 and N°18. In 2007, 57.14% of the wells had nitrate concentrations that

Table 1 Area in km² of perimeters affected by salinisation and nitric pollution in the Triffa plain (2007-2009-2016-2022)

Classification year	Surface in km ² of perimeters affected by nitric pollution					Cover in km ² of perimeters affected by salinisation				
	N1: Excellent	N2: Good	N3: Average	N4: Poor	N5: Very poor	C1: Not salty	C2: Low salt	C3: Salty	C4: Very salty	C5: Very high salt
2007	0.10	39.50	207.29	233.32	2.18	0.00	6.38	183.70	248.62	43.69
2009	0.04	1.35	171.44	295.39	16.39	0.00	0.75	133.42	321.83	26.39
2016	0.34	4.54	29.18	356.42	91.91	0.67	14.34	345.68	107.30	14.40
2022	0.07	8.60	64.96	358.25	50.40	0.71	20.22	453.94	7.52	0.00

exceeded the threshold set by the WHO, which is 50 mg/l; in 2009, 36.4% of the wells had nitric contamination below 50 mg/l, and 63.6% were the poor to very poor quality. In 2016, we noticed an increase in nitric pollution since 91.4% of the wells exceeded the threshold.

The monitoring of the spatial distribution of nitrates and electrical conductivity is carried out using ArcGIS software. All the wells were geo-referenced (*x* and *y*), and the results were used to generate maps of nitrate pollution and salinity distribution for the years 2007-2009-2016 and 2022 (Figs. 5 and 6).

The analysis of spatial distribution maps of nitric pollution and salinity of groundwater in the Triffa plain allowed us to delimit the perimeters according to their degrees of contamination and to quantify the spread of contamination (Table 1).

3.2 Examination of the Results in Table 1

Examination of the results in Table 1 shows a rapid spread of nitric pollution at the groundwater level of the plain of Triffa. In 2007, the surface covered

by groundwater, whose quality is terrible to awful, was 235.5 km². In 2022, the surface almost doubled (408.65 km²) in a time interval of 15 years.

In terms of salinity, there has been an improvement. The area covered by the groundwater with low salinity levels has increased. Indeed, in 2007, the total surface was 6.83 km². Currently, the surface covered by the groundwater, whose quality is good, is 20.93 km². At the same time, the surface of the very to very high salted areas has decreased.

The results confirmed the increased degradation of the Triffa plain groundwater in terms of quality and quantity. This is due to the increased multiplication of sources of pollution, in particular the excessive spreading of fertilisers and pesticides. These domestic discharges are channelled to surface water and groundwater without prior treatment (Fig. 7).

3.3 Normalised Difference Vegetation Index

In this study, the vegetation index dataset is derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) from the NASA Earth Observation System (EOS) data gateway. The product used

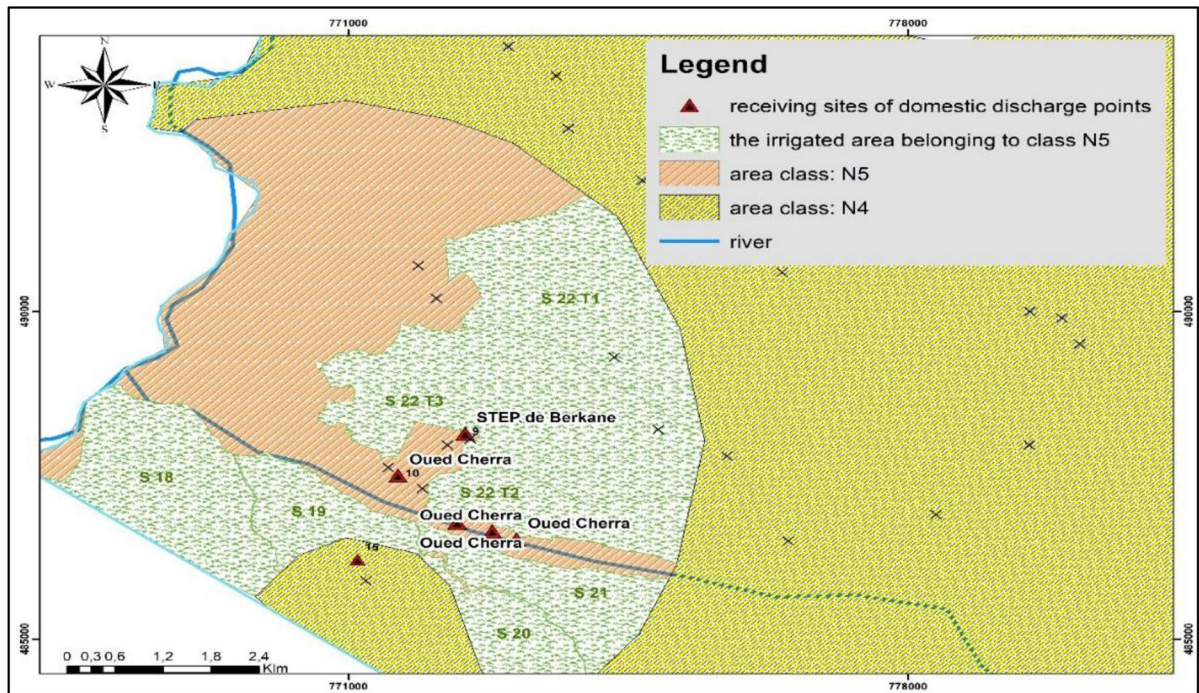
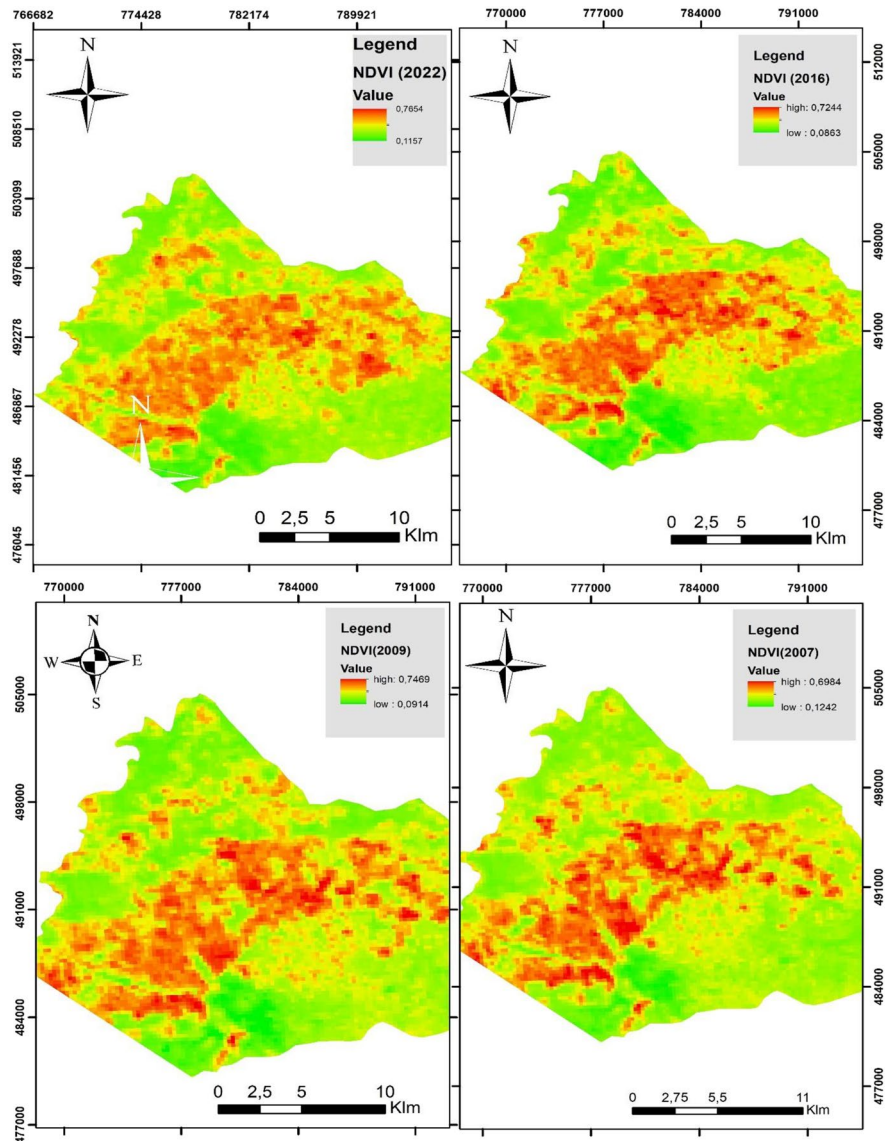


Fig. 7 The distribution of pollution sources in the very poor area concerning nitrate concentration (2022 situation)

Fig. 8 The distribution of the NDVI index for the periods 2007-2009-2016-2022



is MOD13Q1 version 6, which has the advantage of using the best available pixel value, which has low clouds, low viewing angle, and the highest NDVI/EVI value of all the acquisitions every 16 days with a spatial resolution of 250 m (Didan, 2015).

The realisation of the annual average NDVI distribution images for the years (2007-2009-2016-2022) for the study area is executed using a script generated in the Google Earth Engine platform. The processing and analysis of the images are done in ArcGIS version 10.3 (Fig. 8).

The NDVI values vary between -1 and +1, the vegetation cover is generally between the values

of 0.10 and 0.90, the values < 0.20 correspond to a low chlorophyll activity, a 0.2 < NDVI < 0.5 means a moderate activity, and a matter of NDVI > 0.5

Table 2 The area in km² was occupied by each NDVI class during the study periods 2007-2009-2016-2022

Years	Low activity NDVI < 0.20	Moderate activity 0.2 < NDVI < 0.5	High activity NDVI > 0.5
2007	16.44	397.669	68.209
2009	16.32	374.639	91.356
2016	37.996	349.539	94.78
2022	23.7	340.085	118.536

Table 3 Statistical analysis by CCP between the chlorophyll activity, the concentration of nitrates, and the salinity in the groundwater of the Triffa plain

		C5 Very high salt	N4 Poor	N5 Very poor
Low activity	Corrélation de Pearson	-.528	.732	.975*
	Sig. (bilatérale)	.472	.268	.025
Moderate activity	Corrélation de Pearson	.984*	-.989*	-.812
	Sig. (bilatérale)	.016	.011	.188
High activity	Corrélation de Pearson	-.979*	.883	.540
	Sig. (bilatérale)	.021	.117	.460

represents a high chlorophyll activity (Taufik et al., 2016).

Spatial analysis of the areas occupied by each NDVI class during the study years (Table 2) shows a significant increase of 174% in the high chlorophyll activity class between the years 2007 and 2022, which corresponds to the development and intensification of the agricultural sector in the region (Bentekhici et al., 2018). Excessive use of fertilisers and pesticides increases crops; they produce a diffuse source of pollution that affects groundwater quality.

To investigate the relationship between the spatial extensions of nitric pollution and salinisation with the chlorophyll activity of crops, we used bivariate correlation statistical analysis. This analysis allowed us to determine the consistency between the different variables.

The Pearson correlation coefficient (PCC) analysis showed a strong positive relationship between chlorophyll activity (low to moderate activity), very poor nitric groundwater quality (class N5 > 100 mg/l), and salinisation (class C5 > 6 ms/cm). On the reverse, the relation is negatively strong between low to moderate chlorophyll activity and poor nitric groundwater quality (50 < N4 < 100), as well as very high salinisation (class C5) (Table 3).

From the results of the statistical analysis by CCP, we concluded that the degradation of the groundwater quality negatively affects the crop’s chlorophyll activity. The spatial extension of the areas covered by the very poor groundwater quality leads to a decrease in chlorophyll activity in the latter.

Despite the location of the irrigated area on the surface covered by groundwater with poor quality,

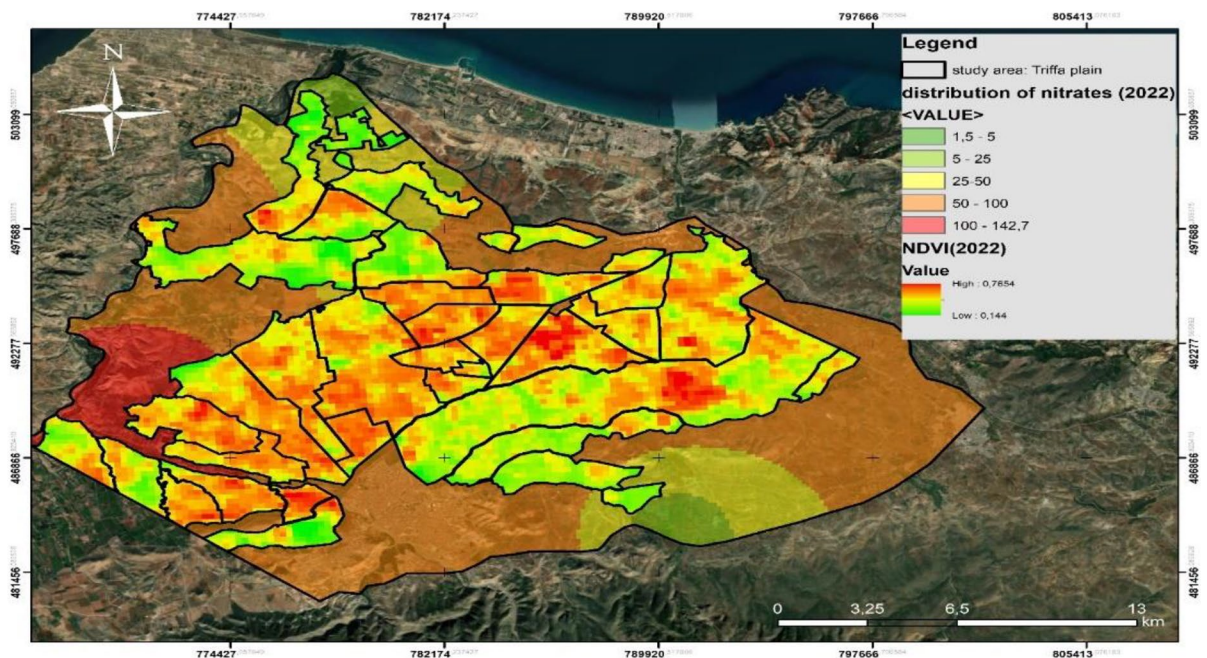


Fig. 9 Distribution of the NDVI index at the level of the irrigated perimeter for the year 2022

high chlorophyll activity is observed (Fig. 9), which suggests the possibility of excessive use of fertilisers and pesticides, which led to an increase in chlorophyll activity associated with rapid degradation of the quality of the water of the groundwater.

4 Conclusions

This paper summarises the most relevant observational and experimental evidence confirming the presence of intensive agriculture in the Triffa plain, as well as excessive, unregulated, and irresponsible fertiliser and pesticide usage. The groundwater in the Triffa plain has high nitrate concentrations and salinisation, resulting in adverse crop health effects, as demonstrated by the NDVI index calculated by GEE using MOD13Q1 version 6 images, as well as a bivariate statistical analysis (CCP) comparing the spatial extent of groundwater pollution and chlorophyll activity in the research region.

The spatial and temporal evolution of nitric pollution in the plain reveals a significant increase in the region occupied by groundwater with concentrations over the threshold (50 mg/l). Furthermore, the electrical conductivity measurement suggests that the aquifer is heavily mineralised. Also, between 2007 and 2022, there was a 174% increase in the class with high chlorophyll activity. These findings point to strong chlorophyll activity on the surface of places impacted by low-quality groundwater. This is usually related to the unregulated and excessive use of fertilisers and pesticides.

Consequently, we can claim that remote sensing technologies and geospatial processing services (GEE) are excellent techniques for assessing surface activities and groundwater interaction. The findings can help decision-makers and management develop specific solutions to persistent concerns.

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Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

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