Impacts and social implications of landuse-environment conflicts in a typical Mediterranean watershed

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Abstract

In coastal watersheds, services and landuse favour coastal tourism and urbanization, depriving rural upstream of infrastructure and attention. This unbalanced management leads to an intensification of socioeconomic changes that generate a structural heterogeneity of the landscape and a reduction in the livelihoods of the rural population. The incessant dissociation between the objectives of the stakeholders triggers landuse-environment-economy conflicts which threaten to mutate large-scale development programs. Here, we used multi-assessment techniques in a Mediterranean watershed from Morocco to evaluate the effects of landuse change on water, vegetation, and perception of the rural population towards environmental issues. We combined complementary vegetation indexes (NDVI and EVI) to study long-term landuse change and phenological statistical pixel-based trends. We assessed the exposure of rural households to the risk of groundwater pollution through a water analysis supplemented by the calculation of an Integrated Water Quality Index. Later, we contrasted the findings with the results of a social survey with a representative sample of 401 households from 7 villages. We found that rapid coastal linear urbanization has resulted in a 12-fold increase in construction over the past 35 years, to the detriment of natural spaces and the lack of equipment and means in rural areas upstream. We show that the worst water qualities are linked to the negative impact of anthropogenic activities on immediately accessible water points. We observe that rural households are aware of the existence and gravity of environmental issues but act confusedly because of their low education level which generates a weak capacity to understand cause and effect relationships. We anticipate the pressing need to improve the well-being and education of the population and synergistically correct management plans to target the watershed as a consolidated system. Broadly, stakeholders should restore lost territorial harmony and reallocate landuse according to a sustainable environment-socioeconomic vision.

Keywords: Watershed, landuse, vegetation, water, household's perception, Mediterranean

1. Introduction

Social, economic and ecological interactions in coastal landscapes generate exceptional 'Cultural Ecosystem Services', associated with intangible values (e.g. aesthetic, spiritual, cultural heritage, social relations and diversity) and with many tangible values, such as the access to local products, fishing and tourism development (Milcu et al., 2013; Zorrilla-Miras et al., 2014). However, these services are still poorly investigated in comparison to other ecosystem services categories (Fagerholm et al., 2016).

Definitely, focusing on provisioning or regulating services for tourism and urbanism and disregarding the cultural ecosystem services and their interactions carries consequences such as inequalities in infrastructure availability and access to natural resources (Hanaček and Rodríguez-Labajos, 2018). This results in mutations in close relationship with socio-economic and political drivers, leading to coupled environmental and cultural transformations, notably impacting upstream rural society (Ribeiro Palacios et al., 2013). These mutations are constantly intensified as a result of changes in landuse and management, which favour downstream (i.e. coastal) over-tourism and urbanization to generate, probably unintentionally, a structural heterogeneity of the landscape and a decrease in the livelihoods of the most vulnerable population (Hjalager, 2020; Ma et al., 2019).

This situation has triggered a range of conflicts regarding land allocation most of which can be basically defined as landuse-environment-economic conflicts, where there are contradictory objectives resulting from economic pressures and environmental goals (e.g. conservation of biodiversity, erosion control and preservation of water quality) (Cowell and Lennon, 2014; Hanaček and Rodríguez-Labajos, 2018; Hermoso et al., 2012). The incessant dissociation between the above-mentioned objectives makes resolving these conflicts a global challenge; decidedly, threats cause conflicts in adjacent places and alter overall landuse and planning agendas of other countries and regions (Carranza et al., 2020; Hanaček and Rodríguez-Labajos, 2018; Hjalager, 2020; Ide et al., 2020).

For this reason, related research has progressed over the past decade, but the results are biased, particularly due to the difficulties of integrating interdisciplinary scientific knowledge and the problem of choosing the appropriate scale (Carranza et al., 2020; Koubi, 2019; Stepanova and Bruckmeier, 2013). Fortunately, a significant improvement in the analysis of landuse-environment-economic conflicts was achieved with the advent of multi-assessment techniques (Lee, 2012; Li et al., 2020) and the increasing recognition of the importance of scale and cross-scale dynamics in understanding and addressing global environmental change (Cash and Moser, 2000).

In this regard, we take part in recent discussions about the scale-dependence in ecology, particularly as it has been applied to issues of environmental management and governance (Anderson, 2018; LaManna et al., 2017; O'Dwyer and Cornell, 2018). Our vehicle is a local case study of socioeconomic development, water resources, and environmental conflicts in North Africa. Our approach to scale issues responds to the concern for the 'local scale' assuming that local control of development produces more equitable and ecologically sustainable results than other development modalities (Beaugendre et al., 2017; Bolin et al., 2008; Brown and Purcell, 2005; Magoulick et al., 2017). Indeed, there is a growing interest in obtaining local-scale data that can increase the accuracy and predictive capabilities of global environmental models (Tang et al., 2019). Besides, scientists are also responding to the demand of policy-makers to assess potential local impacts of global environmental change and to produce policy-relevant information that can be used at regional and local scales (Cash and Moser, 2000; Ker Rault et al., 2019). Moreover, decision-makers from the local through global scales are attempting to understand how mitigative and adaptive actions at one scale might constrain or provide opportunities at other scales (Cash and Moser, 2000).

The contribution of the article lies in the fact that it examines a larger number of conflicts and establishes an understanding of the topics addressed. The analysis of conflicts uncovers upcoming planning issues and seeks to uncover systemic malaise. The aim was to assess the effects of landuse change on ecosystem services (water and vegetation) and to compare it to the perception of the rural population towards environmental issues.

Our specific objectives were (i) to investigate the pattern of cover changes based on the temporal landuse dynamic using long-term (1985-2019) high-resolution images and (ii) to identify the primary drivers and stages of landuse change in relation to the state and quality of vegetation; we provide quantitative measures of remote sensed phenological changes between 2001 and 2016 and a statistical Mann-Kendall trend evolution at pixel level to assess the spatiotemporal anthropogenic impact. Afterwards, (iii) on the basis of water sampling and analysis, and the calculation of an integrated water quality index according to the Moroccan water quality and the World Health Organization standards, we assessed the impact on the quality of groundwater to reveal the degree of exposure of the health of the local population, dependent on these exclusive source of drinking water. Later, (iv) we conducted a social survey with 401 of households, selected using stratified random sampling proportional to size, to analyse the perception of the rural population with regard to water and environmental issues.

Therefore, this study contributes to several Sustainable Development Goals (SDGs); concretely, it intends to ensure the availability of water to persons living in developing countries who encounter challenges in access to water (SDG 6), guarantee healthy lives and promoting well-being for all persons (SDG 3), ending poverty and hunger toward the achievement of disability-inclusive development (SDG 1) and reduce inequality within and among countries (SDG 10).

2. Study area

Mediterranean watersheds are known for their morphological, climatic, hydrological, biological and anthropogenic specificities: they are coastal, intramountain, restricted watersheds, influenced by the Mediterranean climate, with a dense, intermittent hydrographic network with rapid response, luxuriant with intercontinental biodiversity and land of the roots of deep human history (Abdelwahab et al., 2018; Brouziyne et al., 2018; Moresi et al., 2019; Ricci et al., 2018; Zema et al., 2016). True representative of this background, the Smir-Negro watershed originates in the Al Haouz mountains of the Rif belt south of the Strait of Gibraltar and is drained by two streams (Smir and Negro) which flow northeast toward the Mediterranean (**Fig. 1**). This northern Moroccan coastal watershed has a dense hydrographic network with a total length of 411 km and an area of 176.9 km² distributed between four upstream rural communes (Taghramt, Allyine, Saddina and Malalyine) and two coastal urban municipalities (Mdiq and Fnideq). Its climate is Mediterranean with long dry arid summers and moderately rainy mild winters, although precipitation can be spatiotemporally extremely abundant (Salhi et al., 2019). The average annual rainfall ranges between 600 mm downstream up to 1,000 mm upstream with a high intra-annual variability and a clear contrast between dry and rainy years (Salhi et al., 2019).

The watershed includes dozens of water springs throughout the contact zone between the mountain karst ridge (Dorsale Calcaire) and the impermeable hills (Ghomarides), two coastal marsh areas and a dam at the foothills of the mountain ridge. The hydrographic network is mainly fed by these karst springs, often permanent, which have drawn many rural villages linearly to the contact area. It is also fed through precipitation and phreatic groundwater, occasional discharges from the Smir Dam, wastewater, and the salty water reaching coastal marshes. The hydrogeological context is dominated by the calcareous-dolomitic karst aquifer of the Al Haouz mountains which extends over a total area of 92.4 km² along a North-South axis over a length of 42.9 km (between Tetouan and the Strait of Gibraltar) and a maximum width of 4 km. Downstream are identified the two small coastal aquifers of Smir (25.5 km²) and Negro (23.9 km²) formed of quaternary alluviums and separated by accentuated reliefs. The thickness of the alluvial deposits hardly exceeds twenty meters. Upstream, a semi-permeable, thin (3 m at most), discontinuous roof of gravelly clays is identified, while downstream the permeable deposits outcrops to create extensive marshes (3 and 1 km² for Smir and Negro, respectively). The substrate consists of Plio-quaternary marls.

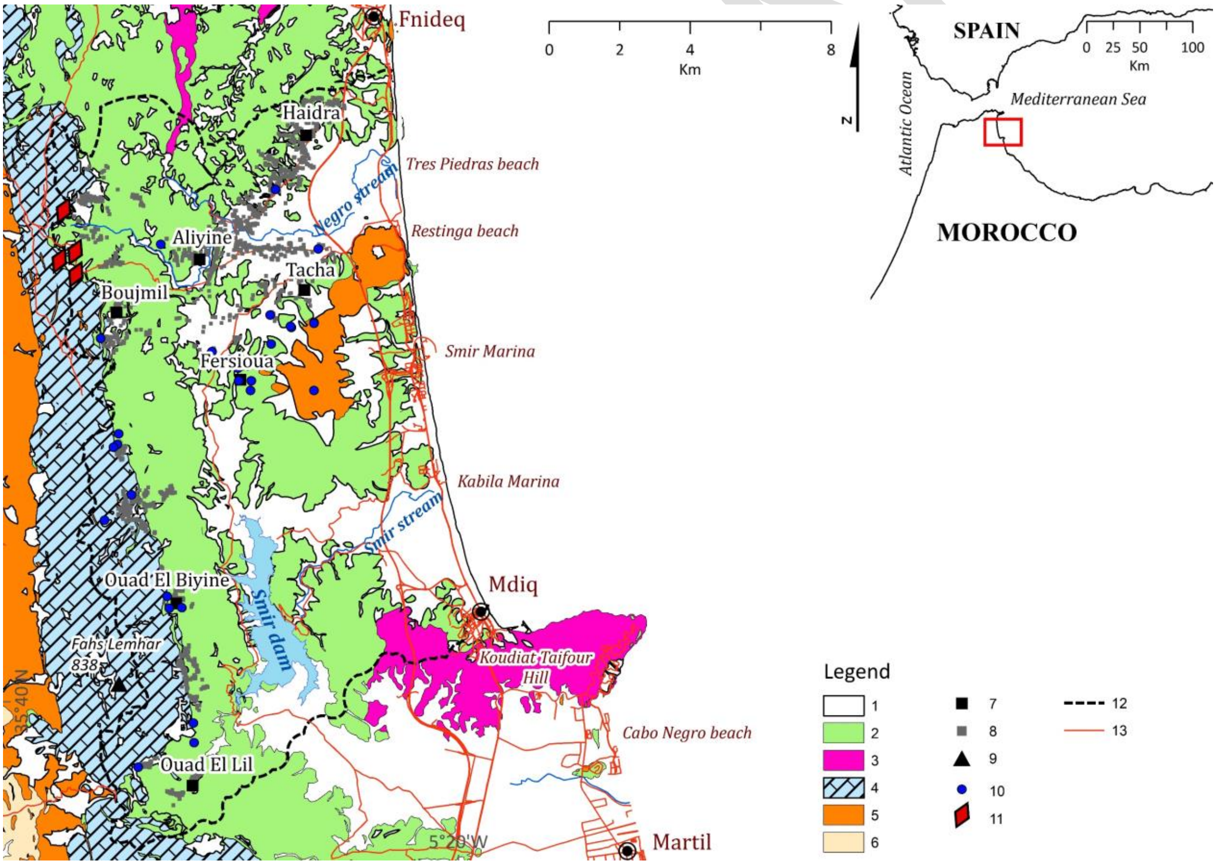

Fig. 1: Geographic location of the Smir-Negro watershed, geological setting (modified from Kornprobst and Durand-Delga, 1985a,b), and position of wells and springs used in the assessment of water quality. 1: Foreland; 2: Ghomarides; 3: Sebtides; 4: Dorsale Calcaire (chain of Al Haouz); Flysch nappes; 6: Intrarif; 7: Villages; 8: Spatial distribution of habitats; 9: Mountain peak; 10: Springs and wells; 11: Quarries; 12: Drainage divide; 13: Road network.

From the geologic point of view, the study area belongs to the Internal Rif domain which extends from Sebta (North) to Jebha (East) and consists of continental units displaced westward over several hundreds of kilometres, thus representing a genuine exotic terrane (Chalouan et al., 2008). It does not exceed 10 km wide in the study area and it constitutes, from bottom to top, three superimposed structural complexes named the ‘Sebtide’, ‘Dorsale Calcaire’ and ‘Ghomaride’ Complexes, respectively (**Fig. 1**) (Kornprobst and Durand-Delga, 1985a; Kornprobst and Durand-Delga, 1985b; Suter, 1980). The Sebtide Complex is affected by a strong polyphasic Alpine metamorphism which is absent or poorly developed in the Dorsale Calcaire and Ghomaride Nappes (Zaghloul et al., 2010). The lower plate corresponds to the Sebtide, shown in the two capes of 'Cabo Negro' (M'diq) and 'Monte Hacho' (Ceuta) which surround the bay limiting the study area to the east. It is dominantly consisting of relatively deep crustal rocks overlayed by the Ghomaride through a regional detachment. These last constitutes a low mountain belt with rounded peaks which include Palaeozoic rocks affected by a Variscan metamorphism superimposed by weak Alpine recrystallization, and relicts of their Mesozoic-Cenozoic cover; the Dorsale Calcaire which is a complex of thrust sheets dominated by Triassic-Liassic carbonates (Azzouz, 1992; Wildi, 1983), locally called here the chain of Al Haouz, taking shape of a meridian structure of altitudes up to 838 m which constitutes the western limit of the study area with a system of asymmetric ridges. This geological landscape continues towards the Mediterranean with two alluvial plains which end in a low foreshore, a few tens of meters wide and having in places sandy accumulations of back beach. These two plains (i.e. Smir and Negro) are separated by the Numidian sandstone massif of 'Jbel Zemzem' resulting from a back-thrust to the west of the Dorsale Calcaire.

The watershed shows a stepped landscape starting from limestone mountain ridges which provide most of the water resources flowing through the impermeable hills before converging on the marshes and coastal plains. The latter receive intense pressure from anthropogenic activities linked to the population growth of the town of Mdiq and coastal tourism, unlike the mountains and hills where the hinterland settlements mainly take the form of small villages and scattered rural houses. The anthropogenic pressure on the coast is the consequence of a significant increase in the population which rose between 1960 and 2020 from 14.5 to 189.7 thousand inhabitants (HCP, 2004; HCP, 2014b), alongside with the exceptional tourism attractiveness of this area considered the preferred summer destination in Morocco (Aderghal, 2016; HCP, 2008). Indeed, the proliferation of hydraulic, tourist and urban activities in this coastal zone has mutated its physicochemical, hydrological and biological components, especially in the humid ecological complex of Smir (175 hectares). This mutation started with the construction of the Smir dam (1991) which reduced the arrival of fresh water, then with the development of the 'Kabila' marina and tourist complexes which have altered the natural settings, stopped the regulatory role of the coastal dune, and favoured the salinization of the lagoon and marshes (Bayed and Chaouti, 2005). Recently, the installation of a new luxury seaside resort and the expansion of the marina is putting an end to the regulating role of this natural landscape.

3. Material and methods

3.1. Long-term landuse monitoring

The analysis of landuse changes was conducted on the basis of a cloud service (called ‘Landviewer’) developed by ‘Earth Observing System (EOS) Data Analytics’ which provides access to satellite data and fast-paced analytics. It offers an abundance of long-term data (such as weekly updated Sentinel-2 imagery and historical Landsat data) to enable advanced zone analytics through the clustering of satellite data-based classification and enhanced spectral indices to allow scalable analysis on landuse.

In this study, ready to use Sentinel-2 L2A scenes (10 m spatial resolution bands) were used for the period between 2015 and 2019 together with historical Landsat 5 Thematic Mapper (TM) series (30 m spatial resolution bands of Level L1T orthorectified scenes, using the computed Top-of-Atmosphere (TOA) reflectance) to monitor the spatiotemporal change of landuse between 1985 and 2010 (Table 1). The availability of scenes was an influencing factor; even if other Landsat scenes are available during some periods (i.e. Landsat ETM+ scenes are reachable since 1999 while Landsat OLI are only available from 2013), but the scenes are unfortunately useless either for the wide cloud cover (blocked by the mountain belt) characteristic of the study area (Salhi et al., 2019) or for the known Landsat ETM+ SLC-off data issue (since June 2003, the sensor has acquired and delivered scenes with data gaps caused by the Scan Line Corrector ‘SLC’ failure).

Table 1: Characteristics of the scenes used to monitor the spatiotemporal landuse change

Sensor	Landsat 5 TM	Landsat 5 TM	Landsat 5 TM	Landsat 5 TM	Landsat 5 TM	Landsat 5 TM	Sentinel-2 L2A	Sentinel-2 L2A
Date	17 May 1985	18 May 1991	10 May 1994	11 May /2000	08 May 2005	07 June 2010	26 June 2016	08 June 2019
Cloudiness (%)	1	26	15	63	62		4	0
Sun elevation (°)	61	59	58	60	61	59	71	70

We focused especially on the growth of urban land and its spatial change trend. Therefore, it was evaluated the Enhanced Vegetation Index (EVI) at pixel size for the entire watershed during the growing season (May-June) at a five years’ time-scale. The values of spatial coverage were extracted based on land cover types with a special focus in two of them (to avoid confusions): vegetation and not-vegetated soil (which includes urban and bare lands). Landsat and Sentinel EVI can be compared even though the models may be affected by the change of the infrared band during different generations of Landsat (Bolton et al., 2020; Griffiths et al., 2019; HAO et al., 2019;

Kowalski et al., 2020). This methodological limitation should not affect our study since it relates in particular to the growth of urban land and its spatial change trend, and because we had frequent recourse to local documents and territorial reports.

The enhanced vegetation index (EVI) is an optimized vegetation index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences (Jiang et al., 2008; Mondal, 2011; Obata et al., 2013). It was developed to be less sensitive to both soil background and atmospheric disturbances (Jiang et al., 2008). It allows monitoring spatial differences in landuse and land cover in greater detail than other indexes (da Silva et al., 2019; Mondal, 2011; Scarpare et al., 2016). It uses the Red (R), Near infrared (NIR) and Blue (B) bands where the latter is used to correct atmospheric scattering. It is computed following this equation:

$$\mathrm{EVI} = \frac{2.5 \cdot (NIR - R)}{NIR + 6 \cdot R - 7.5 \cdot +1} \qquad (1)$$

The resulting value ranges between 0 and 1 to reflect the intensity of greenness at the pixel level. From one EVI image we can differentiate between not-vegetated soil (values between 0 and 0.3) and vegetation (values between 0.3 and 1) (Glenn et al., 2008). The pattern of different land covers and management systems differ over time so that significant changes in the pattern of time series indicate the point in time and the type of the landuse change (Guerschman et al., 2009).

3.2. Phenological dynamics and trend assessment

The phenological dynamics of terrestrial ecosystems reflect the response of Earth's biosphere to inter and intrannual dynamics of the Earth's climate and hydrologic regimes (Zhang et al., 2003). Further, shifts in phenological dynamics are among the most indicative biotic responses to global environmental change caused by human-altered landscapes (Leong et al., 2016; Oliver et al., 2018). The products of growing anthropogenic pressure have accelerated rates of land conversion to the point that they can drive localized ecological systems to shift abruptly and irreversibly from one state to another when they are forced across critical thresholds (Barnosky et al., 2012). Consequently, understanding phenological dynamics and trends in these ecological systems is necessary to evaluate their conservation potential and opportunities for restoration and management (Driscoll et al., 2013).

In this context, it was used the 'Moderate Resolution Imaging Spectro-radiometer' (MODIS) to assess the spatiotemporal dynamics of phenological parameters, based on a set of 368 images of MOD13Q1 16-day composites product at 250 m resolution for 16 years between 2001 and 2016 (23 acquisitions per year). MOD13Q1 product is calculated from the Level-2G daily surface reflectance gridded data (MOD09 and MYD09 8-day composites series) using the Constrained View angle-Maximum Value Composite method (CV-MVC) (Didan, 2015). Actually, MODIS-Terra is a near-polar orbiting satellite operated by NASA and has many spectral bands and quality bands (Didan, 2015). All the images have been downloaded from the United States Geological Survey (USGS) reverb tool (NASA LP DAAC).

The normalized difference vegetation index (NDVI) layers were used to produce NDVI time series for each season to assess its signal and extract the phenological parameters using the Timesat software for smoothing time series data and estimating seasonal phenological metrics (Benabdelouahab et al., 2019; Salhi et al., 2020). The software characterizes many statistical parameters of adjustment and offers different smoothing methods based on different algorithms. The GA filter was selected for its high ability to process data series and because it is less sensitive to noise than other methods (Jönsson and Eklundh, 2004). Phenological profiles were extracted based on representative regions of interest from the study area and the phenological metrics were computed based on the GA function for the sixteen cropping seasons. These metrics are the Great and the Small integrals defined, respectively, as the canopy photosynthetic activity across the entire growing season and its activity between the function describing the season and the base level; both metrics allow the discrimination between different phenological areas (Eklundh and Jönsson, 2015; Reed et al., 1994). The extraction of the difference in the phenological profiles per pixel is possible during the constitution of the time series of the vegetation index so that the minimum values represent the limits of the sixteen growing seasons.

All parameters were analysed using boxplot which is a statistical method for graphical distribution of data based on the extremes, first quartile, median and third quartile (McGill et al., 1978). The generated boxplots allow comparisons across the phenological parameters in order to choose the most reliable of them to characterize the variability of phenological metrics.

Later, based on the annual great integral value in each year from 2001 to 2016, it was calculated the spatiotemporal trend of phenological parameters at the pixel level, according to the normalized Mann–Kendall (Kendall, 1975; Mann, 1945) and the Sen's slope tests (Sen, 1968). The linear regression was calculated between the integral values and time (year), save the slope value, and calculate the p-value of the regression for each pixel. It was considered a relationship with $p \leq 0.05$ as a significant trend. The test outputs were classified into positive, negative or non-significant trend.

3.3. Water sampling and analysis

Groundwater is becoming ever more important in areas with water stress, in particular when surface water is chronically unavailable. This problem is observed in a majority of coastal regions with an arid or semi-arid climate such as the Mediterranean basin where the lack of surface water is combined with a high anthropogenic pressure (Erostate et al., 2020; UNEP/MAP, 2012). Increasing human water needs often lead to overexploitation of aquifers and/or degradation of groundwater quality, which present a risk both to the well-being of human activities and to the freshwater needs of coastal marshes (expected to be worsen under the effects of climate change).

The accessibility to safe and reliable source of water is crucial for sustainable development especially in coastal watersheds, where the tourist and socioeconomic acceleration towards the downstream runs counter to the needs of the rural population upstream in terms of the distribution of drinking and agricultural water. Often, the strategic priority benefits large socioeconomic and industrial activities with more infrastructure and supply, while the rural population and low-income activities are the least served.

In addition, the low population density in rural areas makes it technically and economically difficult to connect them to the drinking water supply network, causing their absolute dependence on the available natural water points. These latter, under the influence of socioeconomic activities, are subject to the risk of pollution that could damage agriculture, spread diseases and affect the health and well-being of populations.

With this in mind, we assessed the groundwater quality in the Smir-Negro watershed by means of two sampling campaigns carried out in May and October 2018 to compare the quality parameters under different intrannual pluviometric conditions. Fifty-six groundwater samples were selected from the existing twenty-eight rural drinking water springs (21) and wells (7) (**Fig. 1**). Samples were analysed according to the physical and chemical parameters. The physical parameters such as temperature, electrical conductivity (EC), pH, Redox potential, salinity and dissolved oxygen (DO) were measured in-situ, during sample collection using Hanna Instruments 9828 Multiparameter. This last was calibrated according to manufacturer's recommendations to ensure the accuracy of the reading.

Samples were taken directly from the field in double capped polyethylene bottles and sent to the Laboratory of Geography and Development Group at Abdelmalek Essaadi University where the analysis were performed. Water analysis, including total dissolved solids (TDS), major anions (Cl^-, SO_4^{2-}, PO_4^{3-}, HCO_3^-), major cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) and other minor elements (NH_4, NO_3, NO_2) were conducted in the Laboratory using photometers certified by Hanna Instruments. The collection, storage, transport and analysis of groundwater samples strictly followed standard methods (Quebec Ministry of Sustainable Development, 2012) in perfect accordance with current Moroccan water quality standards (NM-03.7.001, 2006).

Water type classifications were performed by the free software ‘Diagrams’ which projects chemical analysis data on a Piper and Schoeller-Berkaloff diagrams, among others, using major element water chemistry (Simler, 2020). The water types are often used in the classification of water as a diagnostic tool. Thus, Piper diagram emphasises water facies to reflect the morphology of the lands that this water pass through. It is used to assess the overall characteristics of water by projecting the position of the plots to identify different types of groundwater according to their positions. It displays the chemical facies of a set of water samples on two triangles which represent the cationic and anionic facies, and a diamond-shaped field synthesizing the global facies (Ben-aazza et al., 2020). Schoeller-Berkaloff diagram is also interesting to see more clearly the spatial variation of each element. It is a semi-logarithmic diagram that allows to visualize the different water classes based on the logarithmic concentration, unlike the Piper’s diagram that gives the relative percentages of the element concentration (Brahim et al., 2020). It plots the concentration of each chemical element (as points) to illustrate the chemical facies of several water samples, where each sample show as a broken line formed by connecting all the points representing the different chemical elements.

3.4. Integrated water quality index (IWQI) calculation

There is a panoply of water quality indices to evaluate water suitability for potable use. However, every index has strengths and weaknesses (mostly when considering the desirable or permissible limits), which constrains the applicability and ease of use. In contrast, the recently developed Integrated Water Quality Index (IWQI) has the advantage of considering both desirable (DL) and permissible (PL) limits to avoid the confusion around the adoption of standard values (Mukate et al., 2019). Consequently, this index was applied here following a well-determined empirical process.

First, the values of DL and PL (Table 2) were defined on the basis of their threat to health according to the World Health Organization’s guidelines for drinking-water quality and to the Moroccan standards (ABHL, 2015; WHO, 2017). Afterwards, the range between the two limits for each parameter was calculated according to the following equation (Mukate et al., 2019).

$$\mathrm{Range} = \mathrm{Permissible\ limit\ (PL)} - \mathrm{Desirable\ limit\ (DL)} \qquad (2)$$

Subsequently, a sub-index (SI) was calculated for each parameter of the same sample. In fact, the concentration of any parameter below DL and above PL is not suitable for drinking, while the values in between DL and PL are supposed as excellent for drinking. For that reason, the relative relationship between the concentration of a respective parameter (P_c) and both limits is important to consider according to three potential scenarios (Mukate et al., 2019):

- If P_c is above DL but less than PL, then the sub-index (SI) will be zero, which means that the concentration of the respective parameter is ideal.

$$\mathrm{SI} = 0 \qquad (3)$$

- If P_c is less than DL, then SI is calculated according to the following equation:

$$\mathrm{SI} = \frac{DL - P_c}{DL} \qquad (4)$$

- If P_c is greater than PL, then SI is calculated as follows:

$$\mathrm{SI} = \frac{P_c - PL}{PL} \qquad (5)$$

The difference between P_c and DL or PL is divided by the respective DL or PL to normalize the value to identify the concentration evolution of a particular parameter with respect to its DL or PL.

Table 2: Drinking water quality standards and calculated range value (ABHL, 2015; WHO, 2017)

Parameters	DL	PL	Range
pH	6,5	8,5	2
TDS	500	2000	1500
Ca (mg/l)	31	160	129
Mg (mg/l)	0	100	70
Na (mg/l)	0	200	200
K (mg/l)	0	12	12
Cl (mg/l)	9	750	741
SO_4 (mg/l)	1	250	249
NO_3 (mg/l)	0	45	45

Later, the integrated water quality index (IWQI) is calculated by adding all the sub-indices of each sample obtained from the corresponding equation (equations 3 to 5), according to the following equation (Mukate et al., 2019):

$$IWQI_i = \sum_{j=1}^{n} SI_{ij} \tag{6}$$

Where, SI_{ij} is the sub-index of i sample and j water quality parameter.

Finally, water quality is classified into five categories (excellent, good, marginal, poor and unsuitable), which are inversely proportional to the calculated value of the integrated water quality index (Table 3).

Table 3: Classification criterion of the integrated water quality index (IWQI) (Mukate et al., 2019)

IWQI value	Class	Explanation
< 1	Excellent	Excellent for drinking
1 – 2	Good	Good for drinking
2 – 3	Marginal	Acceptable for domestic use
3 – 4	Poor	Not suitable for drinking
> 5	Unsuitable	Unacceptable

3.5. Rural population's perception surveying

There is a big contrast in infrastructure and economic means between the narrow coastal zone and the larger rural upstream. Therefore, studying the perception of the rural population with regard to water and environmental issues is of great interest not only to resolve current development constraints but also to anticipate imbalances that may arise in the future.

For this reason, a survey was conducted at each of the most representative 7 villages, selected all over the study area on December 2017. A team of PhD researchers were guided through the villages by the key informants. Based on the Cochran's corrected formula (equation 5), 401 of households were selected using stratified random sampling proportional to size (Cochran, 1977).

$$n = \frac{n_0}{1 + n_0/Population} \tag{7}$$

Where n_0 is the sample size at a selected alpha level of 1.96 and a confidence level of 95%.

Households were interviewed using semi-structured questionnaires. The questions were derived from the finding of the expertise owned from previous studies on rural context in northern Morocco (Salhi et al., 2020; Salhi and Chikhi, 2018). Prior to conducting the interviews, the researchers were trained by a senior expert on how to conduct the survey and how to interpret and translate the questions. Their competence was previously pretested on these issues before testing the questionnaires on a sample of households. All respondents were previously informed about the purpose of the survey and assured that it was voluntary and completely anonymous.

The survey contained three sections (Table 4): (i) basic information about household, (ii) perceptions of water quality and environmental issues and (iii) attitudes towards water protection. The statistical methods adopted to interpret the data included the Pearson correlation coefficient and descriptive statistics analysed based on the 'Xlstat' add-in for Microsoft Excel software which allows developing complex statistical and engineering analyses.

4. Results and discussion

4.1. Landuse change and phenological dynamics

Analysing spatiotemporal characteristics of landuse change is essential for understanding and assessing ecological consequence of urbanization. Like in most Mediterranean coasts, the Smir-Negro watershed has witnessed rapid urbanization which has brought on fundamental landuse change during the last 35 years (**Fig. 2**). According to EVI monitoring, the area that underwent change is extended linearly all along the coast between Mdiq and Fnideq cities across dozens of tourist complexes. Farther from the coast, the change is limited to a slight expansion of villages in the west and the emergence of a significant population conglomerate in the North. The total area of the building increased 12 times approximately from 1.5 km² in 1985 to more than 16.2 km² in 2019. The monitoring of satellite imagery series shows that the pace of construction has accelerated since 1997. However, the proliferation of buildings was slowed to the south by the Smir dam reservoir (1991) and then by the special state attention downstream of this dam where the Smir lagoon is located, identified as a site of biological and ecological interest (1996) and classified as green space by the Urban Planning and Development Scheme of the tourist coast of Tetouan (1996). This attention culminated with the declaration in 2019 of the lagoon, the dam lake and the stretch of river that connects them as a Ramsar site.

The expansion of the building was accompanied by a significant increase in the population which evolved slowly from 1960 (14.5 Thousand inhabitants) to 1980 (33) and even until 1990 (57.8). Since then, the population has grown faster, reaching 91.3 in 2000 and 189.7 Thousand inhabitants in 2020 (**Fig. 2**) (HCP, 2004; HCP, 2014b). Besides, the exceptional international attractiveness of this coastal area (considered the preferred summer tourist destination in Morocco) leads to an excessive increase in the number of arrivals during the main months of the summer season (i.e. July and August), which can at least triple the number of ordinary residents (Aderghal, 2016; Flayou et al., 2017; HCP, 2008; Tekken and Kropp, 2015).

Table 4: Descriptive statistics of the physicochemical analysis of the 56 groundwater samples carried out at the end of the wet period (May 2018) and at the end of the dry period (October 2018) in the study area

Campaign	*Water point*	*Name*	*Point*	*X*	*Y*	*DO (mg/l)*	*TDS (mg/l)*	*pH*	*Elect. Conductivity (µs/cm)*	*T (°C)*	Cl^-	Na^+	HCO^-_3	NH_4	Mg^{2+}	K^+	PO^{3-}_4	SO^{2-}_4	Ca^{2+}	NO_3	NO_2
May 2018	**Springs**	Hattach	1	500728.96	572679.02	1.91	92	5	105	17.45	5.3	23	301	3.1	3.83	4.6	16.9	63	26	15	0.1
		Tacha S1	2	501942.92	573289.76	1.57	109	5.5	217	17.49	2.8	22	410	2.8	3.25	3	32	10.9	67	30	0.7
		Tacha S2	3	501942.92	573265.09	0.2	97	5.3	194	16.94	7.2	19	402	6.8	6.36	6.6	63.1	67.5	32	79	1
		Jbel Zemzem	4	501940.2	571359.2	0.17	107	7.2	205	15.21	1.5	22	287	2.7	1.74	1.7	12.9	105	100	75	0.9
		Fersioua S1	5	499788.84	571991.34	1.15	812	7.2	1624	17.06	10	40	491	4.2	4.84	4.3	29.8	626	12	92	0.5
		Fersioua S2	6	500140.78	571359.2	1.91	368	7	737	18.87	3.6	29	476	2	2.41	3.7	10.8	108	160	84	0.9
		Fersioua S3	7	500163.4	571636.72	1.74	437	6.7	873	17.81	3.9	39	480	4.6	4.4	5.5	24.8	167	53	75	1
		Rais	8	497595.17	575507.05	1.41	173	6.6	345	18.98	11	25	240	9.4	9.36	9.7	29.5	184	121	92	0.9
		Salihine	9	498540.34	561368.78	1.41	173	6.6	345	18.98	14	31	291	6.4	5.55	3.2	20.3	11.8	80	91	1
		Machiref	10	498520.3	561926.87	2.26	171	7.6	343	19.56	2.7	27	388	8.4	2.47	3.2	16.7	23	89	61	0.9
		Onsar	11	496954.63	560672.32	1.55	205	7.8	409	14.91	2.7	27	210	5.6	4.35	2.2	63.1	7.92	93	90	1.1
		Sidi Ali Ben Massoud	12	498188.74	565201.53	1.81	143	8.4	285	20.22	4.1	31	204	2.5	2.17	1.9	14.8	5.4	162	94	0.9
		Broudan	13	497778.77	565519.21	2.41	254	9	508	18.13	4.1	33	310	2.7	2.34	4.5	10.4	146	107	77	0.9
		Ras El Oued	14	497834.04	565180.02	2.55	206	8.6	412	15.57	4.5	33	321	1.7	6.62	3.3	24	4.76	99	59	0.6
		Ouad Onsar	15	496356.63	569827.35	2.18	253	6.9	506	16.2	1.5	27	349	1.1	3.1	2.5	45.3	165	135	87	0.7
		Ouad Zarjoun	16	496253.51	569747.21	2.34	251	7.9	505	15.55	2.5	24	356	1.9	2.19	1.5	69.6	9.5	81	74	0.8
		Maa Ahmar	17	496402.01	570132.6	1.23	195	8.8	365	18.19	2.5	22	317	2	2.25	2.5	61	11.4	98	69	0.8
		Amharech	18	496765.99	568396.42	0.96	257	7.5	501	16.63	2.5	29	298	2	1.98	3.1	70.3	7.9	82	59	0.8
		Sakhra	19	496001.19	567678.25	2.68	344	7.7	664	16.63	1.9	30	301	2	5.29	1	114	25.7	94	99	1.2
		Chakchema	20	495887.75	572837.15	1.12	339	7.4	610	17.94	1.4	32	325	2	5.26	0.5	123	32.8	99	89	1
		Maa Rahba	21	498559.54	573700.51	3.17	199	8	409	15.07	67	26	286	4	51	55	66.3	168	105	104	1
	Wells	Tacha W1	22	501299.49	573147.8	1.61	231	5.6	462	16.75	3	22	290	2.4	2.97	6.1	17.6	130	16	74	0.8
		Tacha W2	23	501274.35	573181.72	2.25	121	5.7	243	16.82	2.2	19	210	3.2	3.44	2.9	19.5	451	83	69	0.7
		Tacha W3	24	500698.73	573499.27	2.75	161	5.3	321	18.17	3.2	20	266	3.2	4.39	3.3	38	10.7	66	71	0.7
		Fersioua W1	25	499806.43	571639.81	3.43	203	7.8	406	17.65	2.1	23	292	2.3	3.41	3.1	38	156	99	86	1
		Fersioua W2	26	499049.82	572463.18	0.69	589	7.2	1177	18.23	2.1	41	482	1.1	2.04	2.1	44.1	269	84	156	1.2
		Elliyine	27	502065.62	575374.36	2.31	416	7.7	834	19.73	6.2	35	399	4.8	5.6	3.9	109	450	98	80	1.1
		Haidra	28	500851.73	577064.07	1.24	590	7.4	1036	19.07	4.4	31	405	6.9	0.13	0.1	47.5	710	156	90	1.1

Octobre 2018	**Springs**	Hattach	1	500728.96	572679.02	0.04	104	5.2	208	18.92	6.4	15	68.5	4.3	4.16	7.4	14.3	46.8	112	71	1.1
		Tacha S1	2	501942.92	573289.76	0.002	122	5.9	245	17.48	8.1	17	153	4	4.66	4	11.8	68.2	179	95	1.1
		Tacha S2	3	501942.92	573265.09	0.07	124	5.8	248	17.63	6.7	41	88.5	6.3	3.25	3.1	18.1	122	144	53	1.7
		Jbel Zemzem	4	501940.2	571359.2	0	111	7.6	222	14.58	9.8	25	635.5	22	9.07	7.4	25.5	50.6	141	78	1
		Fersioua S1	5	499788.84	571991.34	0	896	7.8	1612	19.36	15	62	37.5	5.9	2.01	2.8	90.9	664	161	110	0.4
		Fersioua S2	6	500140.78	571359.2	0	372	7.8	744	19.5	17	9.2	762.4	13	20.8	12	39.3	168	100	96	1.1
		Fersioua S3	7	500163.4	571636.72	0	710	7.2	1419	17.26	12	33	331.5	8.3	13.9	6.5	49.3	293	76	136	1.7
		Rais	8	497595.17	575507.05	0.2	228	8.4	455	18.89	17	33	240	6.8	6.76	7.2	13.2	219	121	62	0.9
		Salihine	9	498540.34	561368.78	2.6	1300	8.5	221	13.39	8.9	28	117.4	4.7	5.63	3.7	56.8	14.3	197	85	1.6
		Machiref	10	498520.3	561926.87	1.04	126	8	252	15.88	7.2	9.7	280.7	9.6	10.2	8.7	105	31.4	123	210	1.5
		Onsar	11	496954.63	560672.32	1.1	200	7.9	401	15.22	6.3	8.3	66.3	5.6	4.77	7.3	16.4	15.5	295	75	1.1
		Sidi Ali Ben Massoud	12	498188.74	565201.53	2.35	149	8.4	297	14.37	80	0.7	324	93	85.7	8.8	94.7	92	102	118	1.3
		Broudan	13	497778.77	565519.21	0.81	232	8.5	463	17.35	3.9	14	325.2	5.7	2.98	11	33.4	72.4	102	88	1.3
		Ras El Oued	14	497834.04	565180.02	0.77	178	7.7	355	15.53	1.6	45	456.3	2.5	4.52	2.4	14.3	17	69	89	1.5
		Ouad Onsar	15	496356.63	569827.35	2.11	207	7.6	413	16.44	5.1	22	461.9	3.4	3.16	3	26.6	48.2	102	92	1.4
		Ouad Zarjoun	16	496253.51	569747.21	0.02	207	7.5	414	15.55	4.5	12	225	0.7	10.7	3	30.7	12.6	128	86	1.4
		Maa Ahmar	17	496402.01	570132.6	0.46	177	8.7	355	18.2	1.3	18	270.1	1	9.4	3	59.6	11.6	115	71	1.3
		Amharech	18	496765.99	568396.42	0.32	248	7.5	497	16.62	2.3	29	197.1	1.7	5.9	3	63.7	8.9	124	83	1
		Sakhra	19	496001.19	567678.25	0.43	358	7.3	717	16.99	3.3	9.7	180	7.2	1.95	3	53.9	41.1	157	97	1.5
		Chakchema	20	495887.75	572837.15	0.42	236	7.2	558	17.13	2.3	4.7	252.3	4.6	4.23	3.1	104	36.5	127	92	1.4
		Maa Rahba	21	498559.54	573700.51	0.22	242	9.4	485	15.09	35	43	51.6	39	32.9	33	76.9	246	582	106	1.6
	Wells	Tacha W1	22	501299.49	573147.8	0	172	6	356	18.12	2.9	46	40.5	2.6	3.12	2.9	16.5	7.05	116	76	1.1
		Tacha W2	23	501274.35	573181.72	0	221	5.1	421	18.66	2.3	22	136.5	6.5	11.8	2.5	10.2	103	128	79	1.2
		Tacha W3	24	500698.73	573499.27	0	158	5.4	316	19.62	21	3.5	77.7	18	18.1	19	28.4	99.8	225	96	1.1
		Fersioua W1	25	499806.43	571639.81	0	3331	7	6652	18.53	29	9.6	81.5	3.4	3.24	7.3	35.5	744	354	155	1.3
		Fersioua W2	26	499049.82	572463.18	0.21	632	7.7	1263	19.97	5.9	19	315.6	23	10.2	4.5	54.1	262	128	85	1.2
		Elliyine	27	502065.62	575374.36	0.001	355	7.1	709	17.97	17	8.1	239.9	18	19.7	17	47	370	163	86	1.6
		Haidra	28	500851.73	577064.07	0.16	565	7.4	1029	19.71	6	1.4	382.9	7.7	3.1	3.1	18.7	669	165	92	1.2

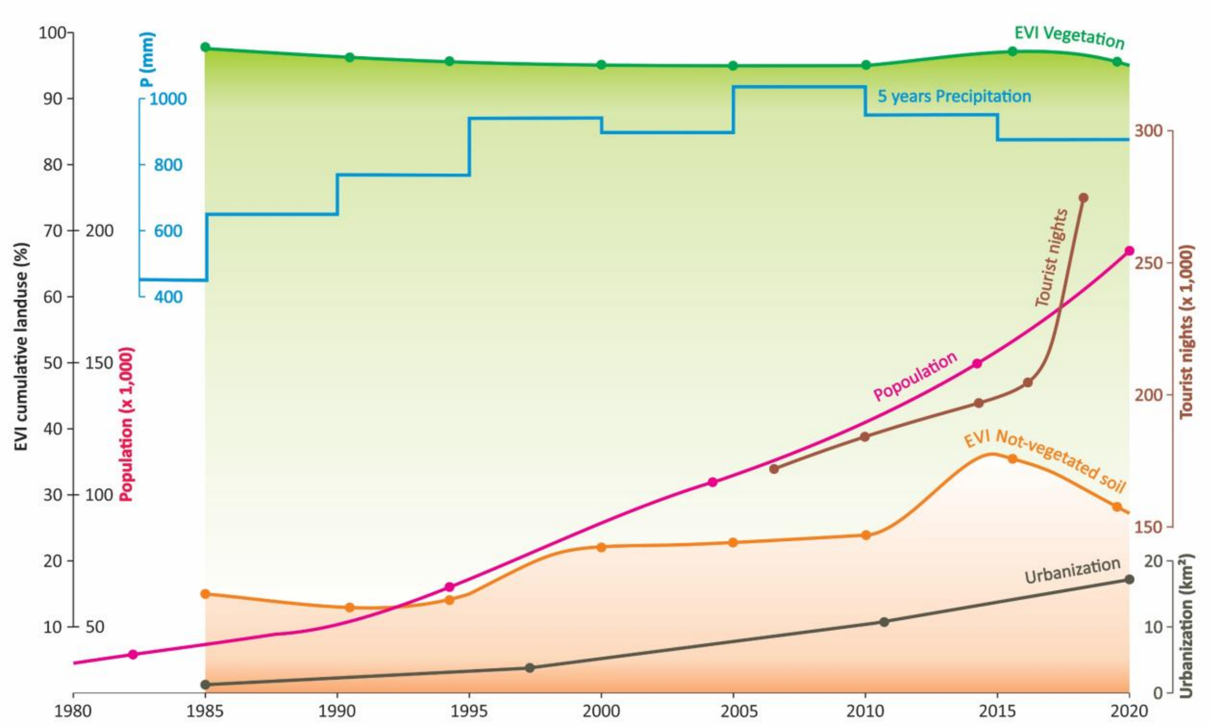

Fig. 2: Landuse change during the period 1985-2019 in the study area according to the Enhanced Vegetation Index (EVI), and evolution of population, urbanization, tourist nights and 5 years annual rainfall.

The result is an extreme shrinking of available space, personal comfort, and excessive momentary pressure on available natural resources. Obviously, the number of tourist nights (**Fig.** 2) follows this trend with great acceleration in recent years (HCP, 2000; HCP, 2011; HCP, 2018), although the majority of tourists choose irregular temporary rent with locals, for which there is no official data.

Annual rainfall calculated from data observed at the Smir dam station (located in the study area) has an irregular pattern that is contrasted from one year to another (Salhi et al., 2019), unlike the EVI evolution which has a gradual and continuous pace (**Fig. 2**). To simplify the analysis, the rainfall time series for the period 1980-2020 was divided into eight sub-periods, each with a fixed 5-year moving window. Consequently, we obtained a curve of the average of the 5 years annual rainfall which shows a more regular pattern (**Fig. 2**). In all cases, the curve of the evolution of the EVI is neither parallel to the 5 years annual rainfall nor to the annual rainfall, which is consistent with the conclusions of previous works which correlate the evolution of vegetation with intense anthropogenic pressure, while dependence on rainfall is observed only in areas where anthropic action is weaker, which is not the case in our study area (Benabdelouahab et al., 2020; Hadria et al., 2019; Salhi et al., 2020; Salhi et al., 2019).

The expansion of the constructions is done at the expense of the plant cover which is gradually declining according to the EVI monitoring (EVI vegetation) (**Fig. 2**). The decline accelerates sharply in 1994 and in 2010 then decelerates from 2015. This retrieval of plant cover since 2015 is associated to three factors: the unavailability of coastal space for more construction, the proliferation of artificial recreational green spaces, and reforestation and fire-fighting efforts upstream of the watershed. In relation to this last factor, official data show a zigzag in numbers of forest fires and in burned area from 2008 (172 Ha burned in 7 fires) to 2016 (213 Ha burned in 5 fires). However, a total decline can be observed in the burnt area from 2017 (only a few hundred square meters) despite the lone fire that took place (Province de Mdiq-Fnideq, 2017).

Similarly, the monitoring of phenological dynamics confirms the above-mentioned observations. It should be noted first that this monitoring used NDVI time series for the period 2001-2016 to calculate for every year a pixel value based on the phenological profile derived from the corresponding 23 acquisitions. Theoretically, the annual pixel value of the great integral ranges approximately between 40,000 in rangelands, 50,000 for rainfed areas up to 120,000 for irrigated perennial crops and forest (Benabdelouahab et al., 2019; Salhi et al., 2020; Steinaker et al., 2016; Wei et al., 2012). It is proportional to the density of vegetation and its growth, so it is less than 20,000 in areas with sparse or deteriorated vegetation. Back to our findings, the spatiotemporal dynamics of the great integral metric during the period 2001-2016 (**Fig. 3**) show an important spatial variability in vegetation density and its temporal trend across the 16-year study period (N.B.: do not confuse the brownish patch south of the study area which corresponds to the lake of the Smir dam). Still, vegetation retreat continues to increase throughout the coastal zone at the expense of the growth of the city of Mdiq (South) and tourist complexes. The complex variability in the centre and in the west is associated to annual rainfall changes and sporadic degradation due to anthropogenic activity or forest fires.

Furthermore, the pixel-based spatiotemporal trend of phenological parameters according to the normalized Mann–Kendall test show a significant decrease in vegetation production along the coastline and western Boujmil village (upstream) where various quarries are installed (**Fig. 4**). In contrast, the significant increase shown in scattered green pixels in the centre and upstream is correlated with public reforestation efforts. It should be noted that the areas with a non-significant trend (blank) on the coast were initially (in 2001) not vegetated (urbanized or subject to high anthropogenic activity), at the study pixel size. Overall, it is clearly observed the intense deterioration of the vegetation at the coastal marshes of Smir (near Kabila Marina) and Negro (Near Tres Piedras beach).

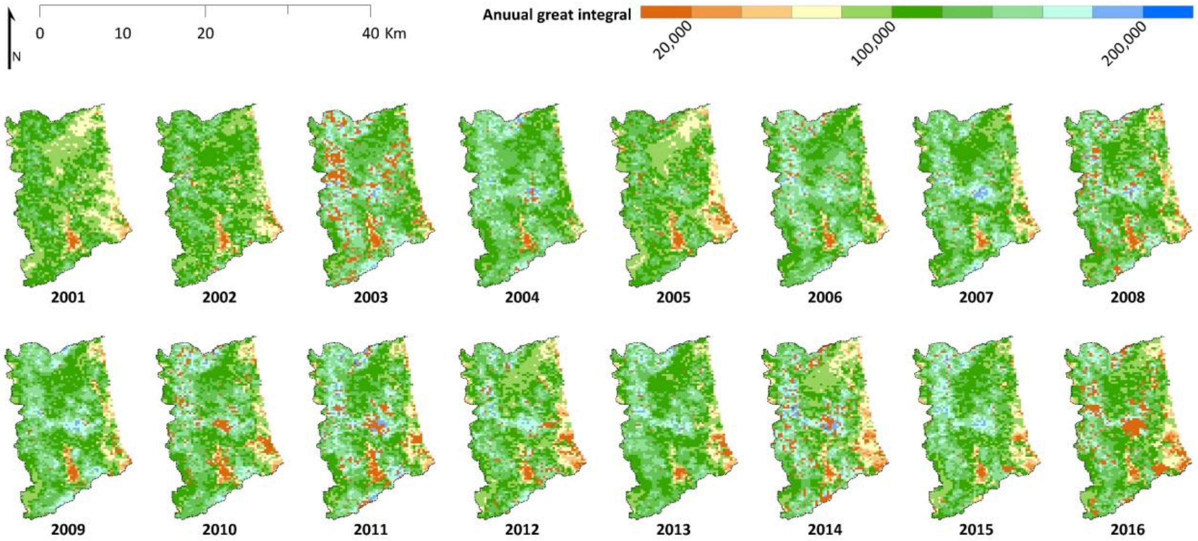

Fig. 3: Spatiotemporal dynamics of the great integral metric in the study area during the period 2001-2016.

To sum up, the phenological assessment shows an overall positive trend (4.8%) slightly higher than the negative (3.7%) (**Fig. 4**). Both trends stand for the close association between the anthropogenic activity and its impact in vegetation density and productivity. Nonetheless, the widespread areas of non-significant trend (91.5%) corresponds to areas already urbanized (i.e. coastal city and tourist complexes) or which have undergone little changes so far. Definitely, a special attention should be paid to these latter areas to restrict environmental deterioration and control the urban invasion. This will certainly generate numerous conflicts of concepts and interests (economic versus social versus ecological) between international, public and local actors, which is an obstacle to the alignment and coordination of actions between them.

For this reason, it is necessary to establish a common ground for the exchange of ideas and communication in order to arrive at feasible, lasting and mutually beneficial solutions. It is, therefore, necessary to evaluate the perception of the local population to study their concern and behaviour regarding the problem of environmental degradation. Currently, the local population lives in scattered rural villages with an absolute dependence on the available groundwater points (with the exception of the city). With this in mind, it was decided to tackle the subject of water quality in these rural villages before addressing the population perception issue; water quality certainly impacts on the socio-economic activities of these population, it can generate risks of pollution, spread of diseases and affect the health, well-being and opinion of the population.

The descriptive statistics of the physicochemical analysis of the 56 groundwater samples carried out at the end of the wet period (May 2018) and at the end of the dry period (October 2018) of the same year are summarized in

Table 4. Overall, the analysis of samples collected during the wet period show that the dominant water family is of Calcium-Magnesium Bicarbonate type with the exception of five water points (i.e. 5, 23, 26, 27, and 28), located in the North (between the villages of Fersioua, Haidra, Tacha and Aliyine) which are of Calcium-Magnesium-Sulphate Chloride type, according to the Piper diagram (**Fig. 5, a**).

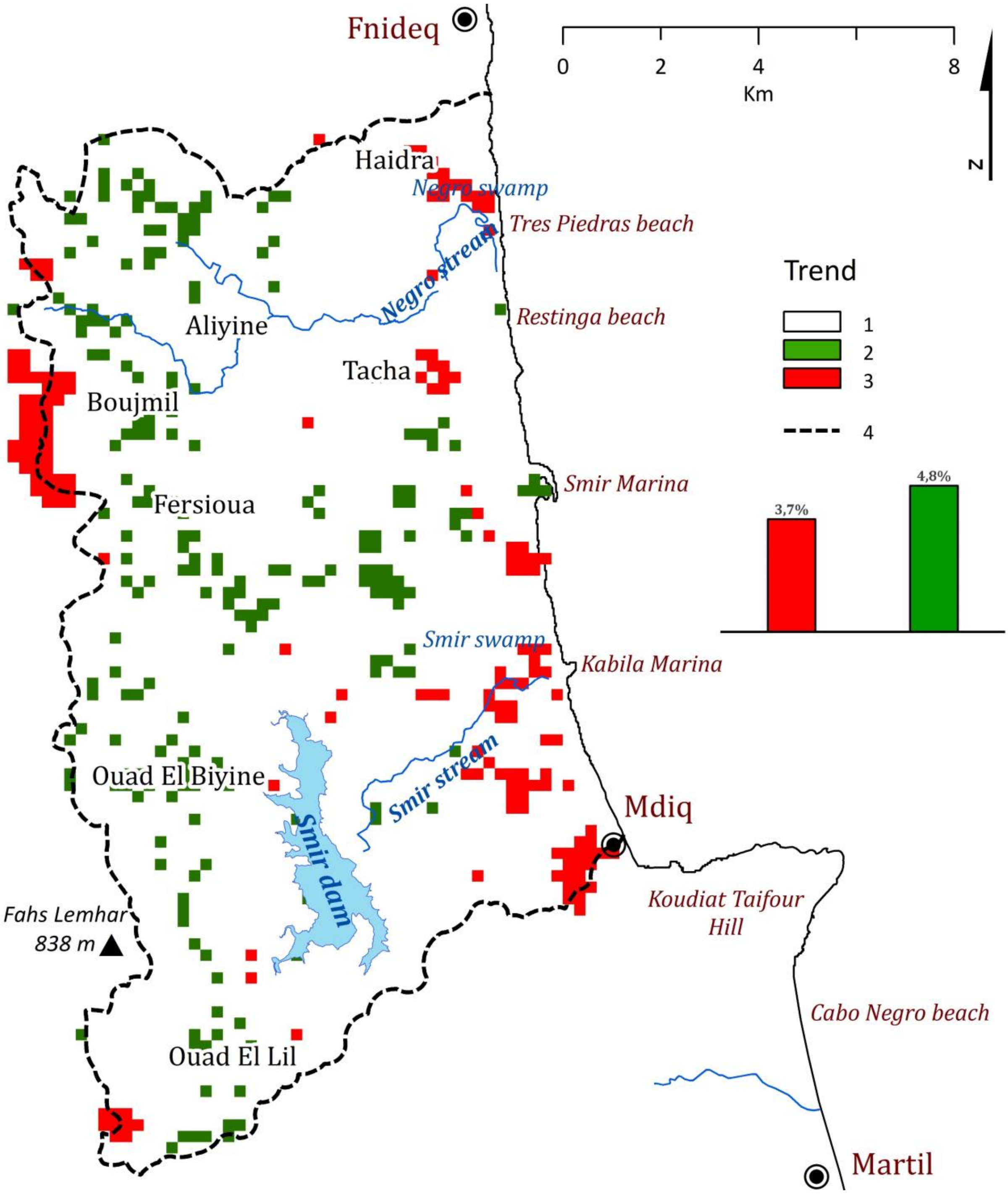

Fig. 4: Spatial distribution of the trend of phenological parameters during the 16 years period 2001-2016. 1: No significative trend, 2: Positive trend, 3: Negative trend.

Similarly, the Schoeller-Berkaloff diagram show that the most abundant ions in these samples are, with the same exceptions, calcium and bicarbonate. Accordingly, it is observed that the water points have a similar hydrogeochemical pattern (**Fig. 5, b**).

4.2. Water quality assessment

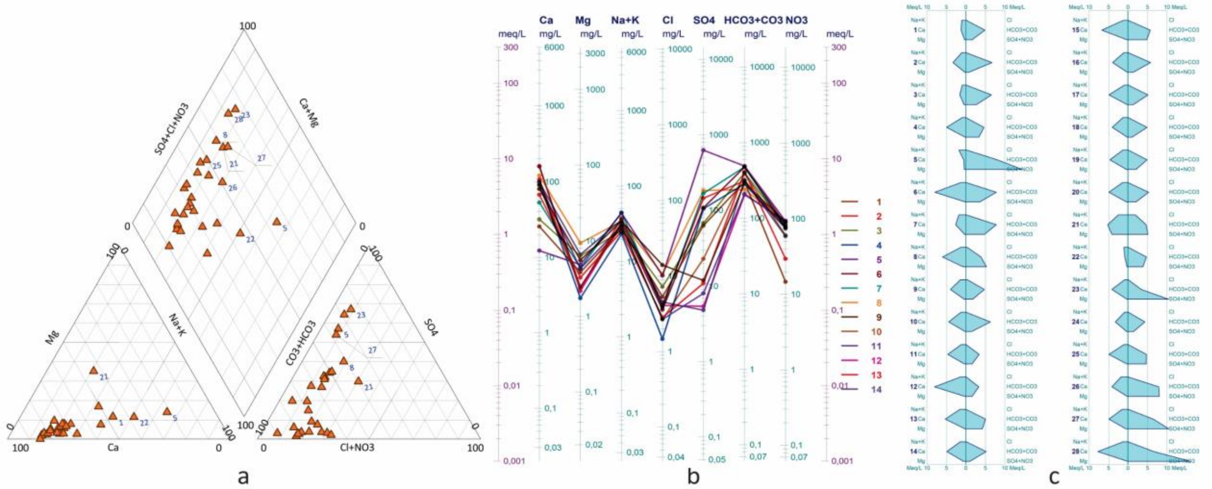

Fig. 5: Hydrogeochemical description of the samples during the campaign of May 2018 according to: a) Piper, b) Schoeller-Berkaloff, and c) Stiff diagrams.

In correlation with the location of the five aforementioned water points, it is concluded that the high concentration of sulphates (**Fig. 5 c**) is of anthropogenic origin because (i) they come from the same karst aquifer with a very short course (residence time), and (ii) they are adjacent to polluting human activities (quarries, chicken farms and rural centres). Undoubtedly, the results of the analysis carried out during the dry period confirms this last hypothesis; the dominant water family remains the same for most samples but the high sulphate contents change, in others, quantitatively and spatially, which can only be explained by the impact of anthropogenic activities. In this case, the high sulphate contents are observed at the water points 5, 7, 21, 25, 26, 27 and 28, which are located in the same villages (Table 4). It should be noted that the water point 23 no longer shows a high sulphate content; this variation is explained by the variability in the duration (temporary or prolonged) of exposure to pollutants.

In a complementary way, an integrated water quality index (IWQI) has been applied on the physicochemical analysis of groundwater samples to evaluate the drinking suitability. The IWQI value varies from 1.36 to 5.50 in the wet period and from 0.92 to 7.96 in the dry period, with an average of 2.24 and 2.51, respectively. Most samples are of good or marginal quality both during the wet (46% and 39%, respectively) and during the dry period (21% and 57%, respectively), which means that the majority of water points have at least an acceptable quality for domestic use (86% and 82% during the wet and the dry periods, respectively). Sadly, approximately one sixth of the samples are unsuitable for drinking (14% and 18% during the wet and the dry periods, respectively). Obviously, the quality indices worsen relatively during the dry period compared to the wet period except in 3 water points (i.e. 4, 8 and 26). If the worsening is clearly linked to the increase in the ion concentration, the improvement in the indices is related to the temporary increase in chloride at spring 4 and nitrates in the other two water points.

The spatial distribution of the quality indices (**Fig. 6**) shows that, in general, most of the water points in the west upstream have a quality that is at least acceptable for domestic use, either in dry or wet periods. Obviously, exceptions are noted at the points 10 and 26. Furthermore, acceptable quality is observed even at downstream water points wherever it is away from villages and chicken farms.

Unfortunately, the worst water qualities are observed in the centre and north directly downstream of chicken farms and villages (Aliyine, Fersioua and Haidra), which emphasizes the direct negative impact (i.e. pollution) of anthropogenic pressure on the quality of their immediately accessible water points. For this reason, particular and rapid attention must be paid to the above-mentioned villages, given the high risk of damage to public health. Clearly, it is imperative to educate the local population to maintain quality (where it corresponds) and to allocate the appropriate use according to the case of each water point and the position in the watershed.

4.3. Social perception of environmental issues

The results of the survey include information on the level of education, the sector of activity and the land possession (Table 5). Out of the 401 surveys considered in the final sample, 40% of households were illiterate, 52% had a preschool or primary level, while a minority of them had pursuit formal secondary or high education level (7% and 1%, respectively). These results are in line with the officially expressed regional trend, which indicates that an increasing number of rural residents (87.1%) have at most primary educational levels (HCP, 2014a).

Most households had individual (67%) or shared possessions (27%). Moreover, it is observed that agriculture is the sector of activity which occupies the largest number of respondents (28%), and that the majority of them are unemployed or day laborers (25% and 24%, respectively). Implicitly, it is deduced from the survey that half of the respondents often engage in seasonal activities (agriculture and tourism) or non-permanent ones (subsistence contraband).

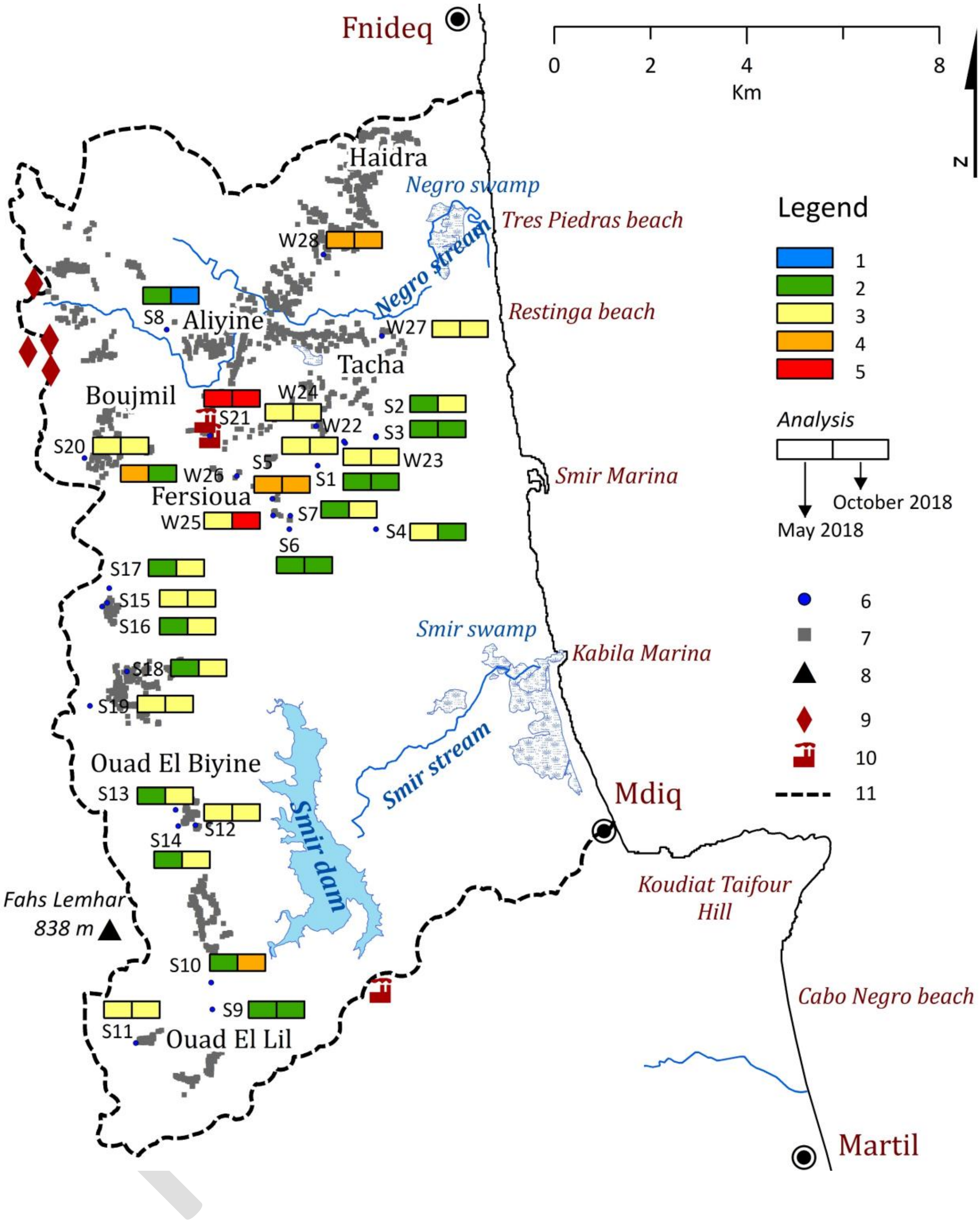

Fig. 6: Spatiotemporal variation of the integrated water quality index in the study area according to the analysis of May 2018 (left rectangle) and October 2018 (right rectangle). 1: Excellent water quality, 2: Good, 3: Marginal, 4: Poor, 5: Unsuitable, 6: Location and codes of the springs and wells, 7: Spatial distribution of habitats, 8: Mountain peak, 9: Quarries, 10: Chicken farm, 11: Drainage divide.

In relation to the perception of environmental issues, it has been deduced from a pre-survey that the main concerns of the population are the quality of water, the goodness of the environment (without distinguishing between its different components) and the impact of flash floods. Consequently, we focused our questionnaire on these elements and on the related factors (use of fertilizers and pesticides in agriculture, and wastewater discharges).

Table 5: Characteristics of the sampled households, their perception of water quality and environmental issues, and their attitude towards their protection (the villages are ordered according to their belonging to the two sub-watersheds).

			Villages							Average
			Haidra	Aliyine	Boujmil	Fersioua	Tacha	Ouad El Biyine	Ouad El Lil	
Basic information about household	Level of education	Illiterate	35	38	37	42	31	48	46	40
		Preschool	30	27	35	25	32	25	6	26
		Primary	24	25	24	27	22	25	38	26
		Secondary	11	8	3	5	13	2	9	7
		High education	2	2	1	1	2	0	1	1
	Sector of activity	Farming	37	22	14	21	13	41	49	28
		Day labouring	22	23	42	26	28	12	20	25
		Unemployment	21	22	12	30	36	26	18	24
		All other activities	20	33	32	23	23	21	13	24
	Land possession	Individual ownership	71	71	20	71	83	74	78	67
		Shared ownership	24	21	76	17	17	22	12	27
		Rented	5	7	4	9	0	4	8	5
		Land grabbing	0	0	0	3	0	0	2	1
Perceptions of water quality and environmental issues	Perception of overall water quality	Good	74	89	4	91	100	97	91	78
		Marginal	14	11	0	5	0	3	9	6
		Poor	13	0	96	4	0	0	0	16
	Perception of seasonal change in water quality	Overall	25	25	25	25	0	0	25	18
		Improvement in winter	18	100	89	80	0	0	83	53
		Degradation in summer	82	0	4	20	0	0	17	18
	Perception of other environmental constraints	Flash floods	72	70	41	38	44	55	45	52
		Soil erosion	21	12	47	30	22	38	25	28
		Forest degradation	7	1	8	29	19	6	21	13
		Other	0	17	4	3	15	1	9	7
	Flash floods return period	Every 1 - 2 years	94	90	50	53	52	76	58	68
		3 - 5 years	5	8	20	10	29	14	17	15
		6 - 10 years	0	1	2	2	2	3	3	2
		Not sure	1	1	28	35	17	7	22	16
	Perception of floods damage intensity	High	35	26	14	10	11	9	15	17
		Moderate	57	40	20	26	24	35	30	33
		Low	8	10	13	15	21	19	22	15
		Variable	0	24	53	49	44	37	33	34
Attitudes towards water and environmental protection	Use or in favour of uncontrolled use of fertilizers	Agree	81	40	61	77	82	73	76	70
		Disagree	13	8	13	0	0	8	12	8
		Undecided	6	52	26	23	18	19	12	22
	Type of fertilizers in use	Organic	43	40	70	27	73	50	52	51
		Conventional	0	8	0	10	0	15	9	6
		Both	57	52	30	63	27	35	39	43
		Agree	25	36	35	60	27	38	22	35

Use or in favour of uncontrolled use of pesticides	Disagree	44	60	48	27	36	46	48	44
	Undecided	31	4	17	13	36	15	30	21
Waste water disposal	Public network	3	0	0	0	0	0	0	0
	Septic tank	88	96	96	95	94	97	88	93
	Uncontrolled outdoor discharge	10	4	4	5	6	3	11	6
	Without answer	0	0	0	0	0	0	2	0

First, it is observed that more than three-quarters of households consider the quality of the groundwater they consume directly from water points to be good (**Fig. 7**). It is surprising that households in villages where pollution of water points are identified (Aliyine, Fersioua and Haidra) are among the most satisfied with the quality of water! Still, more than half perceive that the water quality improves during the wet period and the fifth believes that it deteriorates during the dry period. This indicates that the population is carefully monitoring the issue of the quality of their water points. It is concluded that the confusion in the perception of water quality is due to the fact that households value it visually, organoleptically and sentimentally (cultural attachment to their goods and origins). The absence of empirical analyses and the gradual accustoming to the change of water properties are at the origin of this confusion of perception.

Second, 93% of households are aware of the existence of environmental constraints in their local surroundings; the main concerns are, in descending order, flash floods, soil erosion and forest degradation (**Fig. 7**). The impact of flash floods is very significant since only 16% of respondents were unable to estimate the frequency of their occurrence. Most of them believe that the frequency of occurrence varies from less than two years (68%) to less than 5 years (15%). The significance of the problem is also observed in the responses in relation to the intensity of damage from flash floods; two thirds were able to determine exactly the intensity of the damage caused while the third considers that this damage varies according to the flood. Obviously, the intensity of the damage varies according to the position of the property in relation to the hydrographic network, but the strong perception of this factor is closely linked to the recurrence of the phenomenon because of the multiplication of provoking factors (narrow morphology of the watershed, complex density of the hydrographic network, recurrence of rainstorms and expansion of villages at the expense of natural spaces).

Third and in relation to agricultural production, there is a divergence of opinions for the use of fertilizers and pesticides. Proof of this, twice (70%) of households are in favour of the use of fertilizers than for pesticides, while 44% of them are against the use of pesticides compared to only 8% against fertilizers (**Fig. 7**). It is believed that the broad agreement in the use of fertilizers is linked to the fact that most farmers use organic fertilizers exclusively (51%) or alternate them with conventional fertilizers (43%).

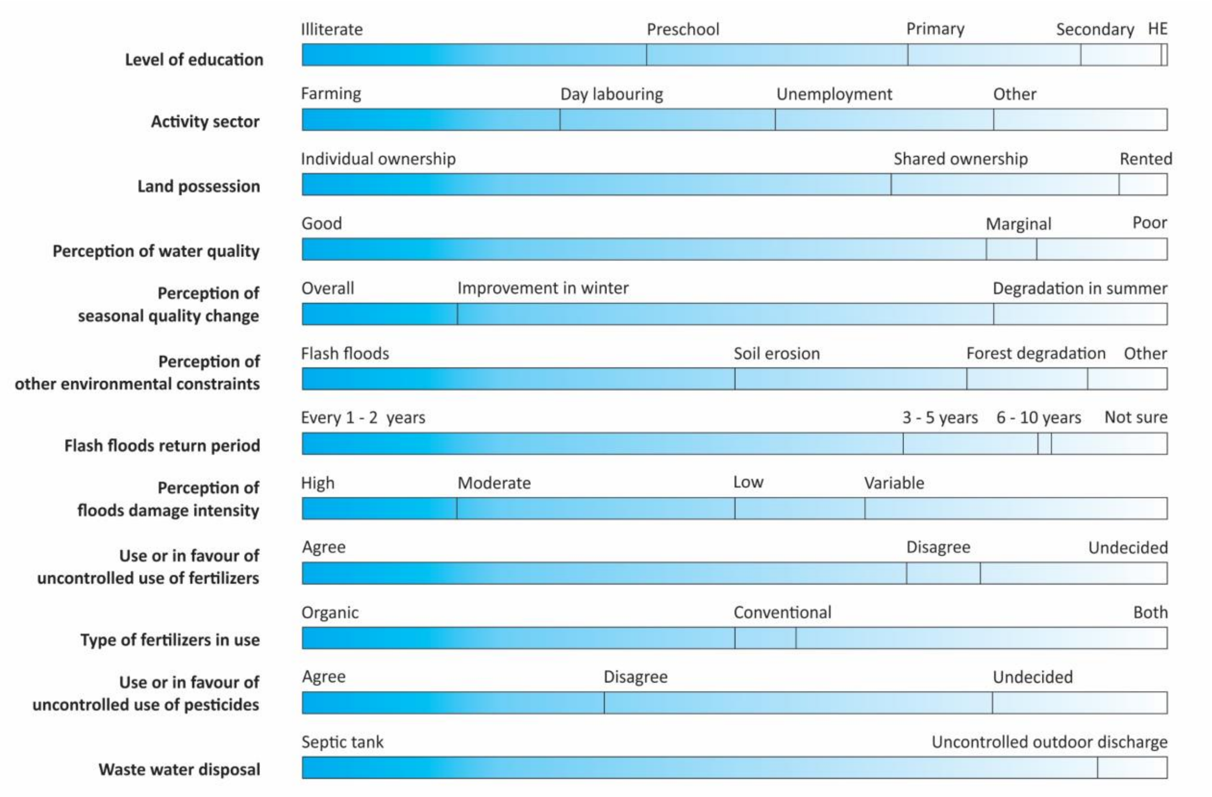

Fig. 7: Descriptive analysis of social perception regarding environmental issues and conservation behaviour.

Finally, wastewater is discharged directly into nature without any pretreatment or sanitation channels, either by a septic tank (93%) or by an uncontrolled outdoor discharge (7%). The environmental concern of households observed in other issues (notably the quality of groundwater) is not reflected in the discharge of wastewater for two reasons: the unavailability of proper sanitation and, unfortunately, the widespread belief that groundwater is by definition safe.

Altogether, despite its low level of education, the local population is aware (to different degrees) of the existence of various environmental constraints and even of the seriousness of these. However, their confusion lies in their weak ability to understand cause-and-effect relationships: for instance, expectations regarding the discharge of wastewater or the use of fertilizers and pesticides to pollute downstream water points have not been recorded. Likewise, there is no correlation of households between the expansion of villages and agricultural land in favour of natural areas (forests) and the recurrence and intensity of damage caused by flash floods. This inconsistency in the understanding of the cause-and-effect relationships is quite normal due to poor qualification (level of education) and improper education (no consideration of regional particularities nor the permeability of concepts to stratified skills). With this in mind, it is observed a strong positive correlation between the very poor qualification (illiterate households and those with preschool or primary levels) and the perception of water quality (r = +0.93, p-value = 0.048) for example. Without a doubt, the relative lack of interest in the upstream (characterized by a living production) was the snowball that stresses progressively the relationship between local society, its needs in landuse and its environment.

5. Conclusions

Our study sought to understand the impacts and social implications of landuse and environmental conflicts at the household level by studying a region particularly vulnerable to environmental change: a Mediterranean typical watershed from northern Morocco. We have approached the study by a synthesis of a comprehensive data collected during in-depth field research by questionnaire to assess the perception of households, a combination of remote sensing and statistical trend tests for the analysis of long-term spatial dynamics of phenological and landuse changes, and empirical analysis and classification of the quality of water consumed by these households according to a complex causal pattern inherent counter pressures between socioeconomic needs and the environment.

Definitely, landuse decisions induce environmental-landuse conflicts in ecologically vulnerable areas with direct social and economic implications (Kim and Arnhold, 2018). For that reason, to produce effective management, indirect drivers such as demographic, economic, and social factors merit additional attention. Therefore, several studies report territorial change and various social and ecological implications that are increasingly accelerated in Mediterranean watersheds (Boix-Fayos et al., 2020; Falcucci et al., 2007; Jodar-Abellan et al., 2019; Lizaga et al., 2019; Quintas-Soriano et al., 2016; Salhi et al., 2020). In our case, it is observed a rapid urbanization which has resulted in a 12-fold increase in the total area of built-up in the past 35 years, at the expense of natural spaces. This change in landuse is mostly linear throughout the dozens of coastal tourist complexes located between the cities of Mdiq and Fnideq (which have experienced a sharp increase in population). Given the exceptional international attractiveness of this favourite summer tourist destination in Morocco, the number of tourist nights will only increase, in particular due to the expansion of reception infrastructures (hotels and rent with locals) and climatic trends of extension of the number of Mediterranean summer days (Altın and Barak, 2017; Tovar-Sánchez et al., 2019).

Consequently, long-term remote sensing monitoring shows a gradual decline of vegetation with abrupt retreats during the periods of acceleration of the built-up (i.e. 1994 and 2010), as well as an intense deterioration of the vegetation in the coastal marshes of Smir and Negro. Certainly, the expansion in construction and tourism has been accompanied by a wide range of necessary infrastructure oriented towards the promotion of a seasonal coastal product, unlike the clear delay observed upstream of the watershed. There, where the population lives in scattered villages with very limited means of subsistence, based mainly on seasonal (e.g. agriculture) or non-permanent (contraband) activities.

Long term unbalanced attention has created an evident territorial contrast, in a few kilometres, with the deprivation of the rural inhabitants upstream suffering the lack of equipment and means coupled with their low educational level (**Fig. 8**). Even if, the local population is aware (to different degrees) of the existence and seriousness of many environmental issues (i.e. water quality, flash floods and forest degradation), while they show confusion that we attribute to their weak ability to understand cause-and-effect relationships. For instance, households in villages where pollution of water points is identified are among the most satisfied with the quality of water, knowing that pollution is associated to domestic wastewater (in septic tanks), use of fertilizers and pesticides, and industrial discharges (mainly chicken farms). Similarly, they do not associate the expansion of villages and agricultural land at the expense of natural areas (forests) and the repetitiveness and severity of flash flood damage. The confusion problem is associated to the poor ability of villagers to understand cause-and-effect relationships, which is linked to the lack of understanding fundamental hydrological concepts (e.g. watershed, hydrological and hydrogeological flows, percolation time, vulnerabilities and risks, water quality parameters, soil purification capacities, etc.) and to the lack of access to information in addition to the incorrect but widespread ideas among them: "the clear groundwater is always drinkable”.

These findings imply social changes affecting the lifestyles and well-being of individuals and groups, creating a socio-economic and territorial disharmony between the coast and the mountains. Definitely, managers are called upon to restore the lost harmony by paying particular attention to natural spaces in order to limit the deterioration of the environment and to control the urban invasion. Imperatively, immediate priority should be given to the health and well-being of upstream villagers and then to their education to maintain the quality of the environment and allocate the appropriate use according to the case of each natural resource and its position in the watershed.

Certainly, this will generate many disputes about concepts and interests (economic, social and ecological) knowing the multitude of actors that intervene in the area (international, public and local), but these disputes will be milder than the landuse-environment conflicts that agitate the current situation. For this reason, it is necessary to establish a common ground for the exchange of ideas and communication in order to reach viable, lasting, and mutually beneficial solutions.

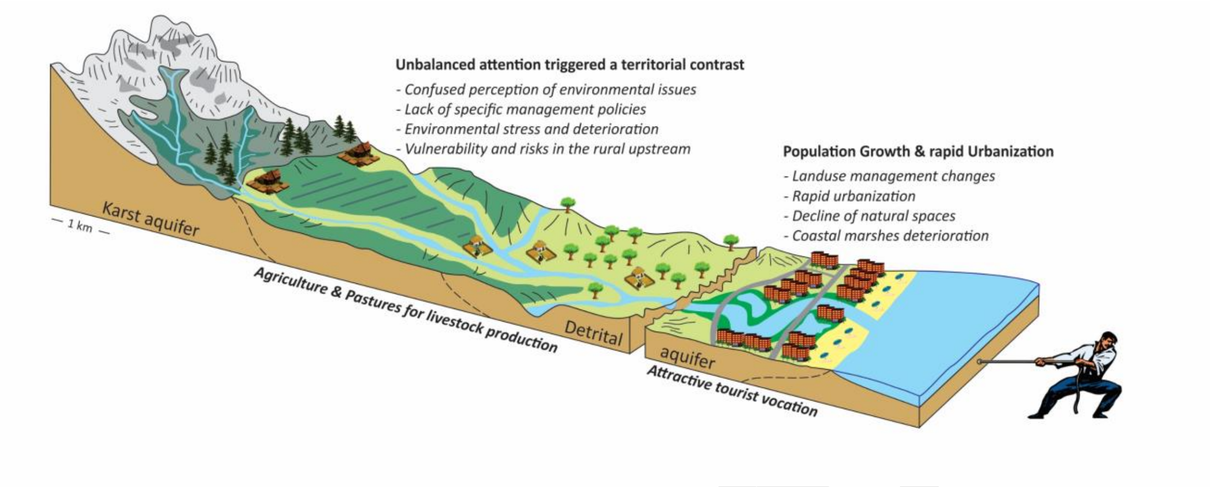

Fig. 8: Services and landuse in coastal watersheds favour coastal tourism and urbanization, depriving rural upstream of infrastructure and attention. This unbalanced management leads to an intensification of socioeconomic changes that generate a structural heterogeneity of the landscape and a reduction in the livelihoods of the rural population

Everyone must understand that watersheds are made to function as a consolidated system; no matter what interest we attribute to it (economic, tourist, social, etc.) or how we divide it, we cannot change its functioning nor can we neutralize its reciprocity. Therefore, the sustainability of interests goes exclusively through the sharing of responsibilities and benefits. We must understand that the beginning of landuse-environment conflicts is not the time to turn away or reproach, it is rather the moment of course correction and partnership.

Acknowledgment

This research was funded by the National Centre for Scientific and Technical Research (CNRST, Morocco) [contracts number PPR/11/2015 and IK/2018/48].

Author contributions

A.S., S.B., T.B. and E.O.B. conceived and designed the research. A.S. supervised the field work carried out by E.O.B. with assistance from I.L., M.EM. and N.A. The modelling, analysis and mapping was carried out by A.S., E.O.B., S.B., and T.B. Support and guidance on mapping and interpreting the results were provided by M.H. and A.C.P. Finally, A.S. led the writing of the paper with contributions from all the authors.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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