The local implications of a macrostrategy on the villagers and the environment

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Article

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The local implications of a macrostrategy on the villagers and the environment

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Abstract

Nature subcontracted mankind for temporary management stipulating a rigor that does not disregard the smallest details because this is where the difference between perfection and riskiness lies, which inevitably leads to disasters. It establishes binding general rules and local imperatives to be fulfilled otherwise it takes back the reins. For this reason, anthropic macrostrategies must frame their priorities and objectives according to a sustainable social-ecosystem. Here, we evaluate the environmental effect of the triggered land use change of the metropolis-portuary-industrial park of Tangier (Strait of Gibraltar) on ecosystem services (i.e. vegetation and water) and anticipate their interactions with indigenous villagers. We established a multifactorial analysis including long-term (1985-2021) land-use dynamic assessment, 16-years pixel-based Mann-Kendall phenological trend, EPM soil erosion modelling and assessment of the total volumes of the detached soil, and an NDVI/NDWI monthly drought monitoring. Later, we compared these outcomes with a social survey with 171 households to analyze their living conditions, and their environmental perception and attitude. We have observed that anthropogenic intervention is the precursor of erosion which
is likely to worsen natural weaknesses, which are already at the origin of a massive potential loss of soil estimated at 1.2 kg/m²/year. We correlated the negative phenological trend with the lane of the roads and infrastructure and we observed that severe drought episodes are long, frequent and at short intra and interannual intervals. We found a statistically significant association between the low level of education and the rural seclusion with the environmental degradation and the unavailability of water which can evoke serious risks. We anticipate the urgent need for an inclusive reform that implements a behavioral culture, encourages education, and creates social facilitation to build an upward spiral that produces better conditions and more opportunities for the rural society. Broadly, Managers should integrate scientific instructions to master the details and continuously improve macrostrategies to achieve integral and lasting success.

**Keywords:** Household’ survey, Environmental assessment, Soil erosion, Phenology trend, Drought monitoring, Land-use.

### 1. Introduction

Economic and social development results in positive changes at various levels, which create wealth and lead to the improvement of well-being. Achieving this much desired goal requires the creation of long-term macro-strategies where influencing factors intersect in a complex and unpredictable way. These unforeseen events, often qualified as "surmountable", can locally trigger unprecedented mutations likely to be accentuated in the presence of structural vulnerabilities and the systematic recurrence of extreme climatic phenomena.

Recently, the World Meteorological Organization asserted that water-related hazards have dominated disasters in the past half-century and claimed that no country is currently immune (WMO, 2021). Climate change increases the severity and frequency of these hazards and worsens the human and economic toll of devastating disasters. For instance, in July 2021, powerful and secure countries of Central Europe and Asia were overwhelmed by the force of nature that exposed their weaknesses.

The complete impacts of large-scale climate change are hardly predictable. However, they are already observed at the local and regional scales to affect political decisions, local development plans, shipping routes, and basic supplies (Mathbout et al., 2021; Vincent, 2020). However, despite the consensus about the existence of overlapping interactions between climate change, macro-strategies, and local influences, multifactorial studies on these
interactions are very few despite being a pivotal framework for understanding, predicting, and neutralizing negative impacts on the environment and population, and building resilience (He and Silliman, 2019; Viccaro et al., 2019).

The contribution of this paper lies in the fact that it tackles a multifactorial analysis to understand the implications of a major North African port-industrial strategic project on the environment and the surrounding rural population. The objective was to evaluate the environmental impact of the triggered land-use change on ecosystem services (i.e. vegetation and water) and anticipate their interactions with indigenous villagers.

The specific objectives of the environmental assessment were (i) to examine the pattern of cover changes based on temporal landuse dynamics based on long-term high-resolution images (1985-2021), (ii) to characterize the key drivers of landuse change with regard to the state and quality of vegetation on the basis of quantitative measures of remotely detected phenological changes between 2001 and 2016 and a statistical evolution of a pixel-based Mann-Kendall trend to evaluate the anthropogenic impact. Then, (iii) on the basis of the Erosion Potential Model (EPM), the soil erosion was mapped and the total annual volumes of the detached soil were estimated. Afterward, (iv) the droughts were monitored on a monthly scale through the combination of the two complementary indices NDVI and NDWI over a period of 30 months. In addition to the environmental assessment, we performed (v) a social survey with 171 households to analyze the living conditions of local villagers, and their perception with regard to vegetation, water, and environment.

We have approached this research to help straighten out the course of this core project, make it inclusive of the Sustainable Development Goals, and help build social resilience.

2. Material and methods

2.1. Study area

The Alian watershed is at the centre of an area of great geostrategic importance and rapid social and economic activity. This coastal watershed borders the southern shore of the Strait of Gibraltar, one of the world's major shipping lanes. Although it is not currently under strong human pressure, it will soon become, as it is a triangular center of gravity consisting of a large port complex (East), a vast metropolis (West), an industrial multinational and the site of a city under construction (South) (Fig. 1). In other words, the study area has been surrounded for twenty years by a huge sectoral development project made up of industrial, commercial and economic zones within
the framework of a national, integrated and multidimensional vision. For instance, Tangier (metropolis) is nestled
between two maritime facades (Mediterranean and Atlantic) and has long played the role of a gateway between
Africa and Europe. This metropolis in full phase of socioeconomic transformation has three very active industrial
areas and two scheduled, and it continues to grow demographically to the point it appears that the current 1.3
million inhabitants will soon increase exponentially. About forty-three kilometers to the east, the Tangier-Med
port has a strategic priority for the economic and social development of Morocco and it is, by capacity, the largest
port in the Mediterranean and Africa with a handling capacity of 9 million containers. This global logistics gateway
is an industrial hub for more than 1.100 companies representing an annual export turnover of more than 5.9 billion
USD in various sectors such as automotive, aeronautics, logistics, textiles and trade.

The Alian watershed is part of the “Intercontinental Biosphere Reserve of the Mediterranean”, declared in 2006
by the UNESCO after a joint effort between Morocco and Spain to face the impacts of climate change. These
impacts are manifested in increasing levels of severe droughts which alternate with intense and recurrent flooding
resulting together in the intensification of intersectoral competition for water resources, soil erosion, loss of
biodiversity and negative consequences for ecosystem services (Salhi et al., 2020b). In two countries with identical
environmental conditions, although dissimilar cultural and socio-economic backgrounds, and close dependence on
natural resources, the water-related impacts can impact security on both sides, and have significant effects on the
agriculture and economy, thus threatening food and water security, and causing increased migration flows (Abdul
Malak et al., 2017; Salhi et al., 2020c). Moreover, there will be several months of droughts, even in a so considered
“wet year”, that will have deep effects at the social and environmental levels, intensifying land degradation
processes and challenging management scenarios (Benabdelouahab et al., 2020; Salhi et al., 2019).

The watershed originates in the Rif mountains south of the Strait of Gibraltar. It is a coastal, intramountain,
restricted watershed (121 km²), with an intermittent hydrographic network, under the Mediterranean climate, and
luxuriant with intercontinental biodiversity. The precipitation is abundant with an annual average which ranges
around 800 mm but with a significant intra-annual changeability and a strong contrast between rainy and dry
months (Salhi et al., 2019).

From a morphometric point of view, it is an elongated watershed with mild relief and a medium to strong slope
with short and irregular tributaries. The hydrological network is quite dense due to the presence of several ridges
which results in a higher stream frequency. The latter indicates that the watershed is grooved by water erosion
which leads to an increase in the length of the tributaries and therefore a higher drainage intensity. The hydraulic
response is slow, mainly torrential with peaks closely related to precipitation. Drainage density evokes a dominant
permeable geological material and/or dense vegetative cover with moderate relief. The hypsometric integral is a
function of the degree of dissection of the watershed and the relative age of the relief. In our case, it indicates that
the watershed has reached the stage of maturity which means from a geomorphic point of view a great susceptibility
to produce debris flows and that the solid content of the gully is abundant (Table 1). These observations suggest
vulnerability to small-scale geohazards, such as flash floods, debris flows, shallow landslides, and slow extensive
landslides, which can converge into a single large-scale disaster.

Geologically, the watershed includes Flysch structures (Melloussa, Beni Ider, and Tisirene units) formed by more
or less thick sandstone beds interspersed with compact clays (Salhi et al., 2020a). These structures, which favour
erosion and landslides, dominate over 79% of the overall surface against 18% for the Tangier unit (composed of
impermeable clays) and Quaternary deposits downstream and around the main tributaries (3%).

The watershed gives rise to 15 scattered villages, divided between five rural communes (Melloussa, Ksar Seghir,
Bahraouiyin, Anjra, and Jouamaa) which belong to the province of Fahs-Anjra. It includes a weekly rural market
(Melloussa) and is neighboring by several, the most important of which are those of Ksar Seghir and Khemis
Anjra. The population in the basin increased from 10,389 to 13,881 between 1994 and 2014, with an annual
growth rate of 1.38%, while the number of families increased in the same period from 2,035 to 3,117.

2.2. Environmental assessment

2.2.1. Soil erosion modelling

The modelling of soil erosion is evaluated based on the Erosion Potential Model (EPM) which considers four
factors that depend on geology and soils, topography, climate factors (i.e. temperature and rainfall), and landuse
(Gavrilovic, 1988). The coefficient of erosion and sediment yield \( Z \) is assessed according to equation 1:

\[
Z = Y \cdot X_a \cdot (\Psi + J_a^{1/2})
\]

where \( Y \) is the coefficient of the rock and soil resistance to the erosion which vary between 0.25 and 2, \( X_a \) is the
landuse coefficient which vary between 0.05 and 1, \( \Psi \) is the coefficient of the observed erosion process which vary
between 0.1 and 1, and \( J_a \) is the average slope gradient (%) of the watershed calculated directly from the digital
elevation model (Aster GDEM V2 in our case). The assessment of the coefficient of the rock and soil resistance
to erosion used the available data from the Geological Service of Morocco and partial data of the Moroccan Soil Map Database (Fertimap).

The analysis of high-resolution satellite acquisitions (Sentinel 2) in 2019 (10 m) was completed by fieldwork to identify the patterns and consequences of erosion. These consequences are damage caused by major erosion events and sedimentation near tributaries. Land use was divided into five classes (built, barren, rangelands, forests and mixed / irrigated rainfed agriculture) according to a classification system approved beforehand (Farhan and Nawaiseh, 2015).

The assessment of the Normalized Difference Vegetation Index (NDVI) was directly extracted for the entire study area from the EOS Land viewer API according to the following specifications:

- Sensor: Sentinel-2 L2A
- Acquisition data: June, 6th 2019
- Cloud cover: 0%
- Solar elevation: 72%

The pluviometric data was extracted from the spatialization of regional copious (53 stations) long-term (i.e. 30 years) rain gauge measurements together with open time-series (1958–2015) (Salhi et al., 2019). Land Surface temperature was estimated from Landsat 8 data using the NOAA JPSS Enterprise algorithm (Meng et al., 2019).

The severity of erosion is classified according to \( Z \) (computed in a raster environment under ArcGIS desktop software) where values greater than 1.0 indicate severe erosion while values lesser than 0.19 show very slight erosion (Tangestani, 2006). Later, the total annual volume of detached soil \( W_a \) in \( \text{m}^3/\text{year} \) was estimated according to equation 2 (Gavrilovic, 1988):

\[
W_a = T \cdot P_a \cdot \pi \cdot Z^{1/3}
\]  

(2)

Where \( P_a \) is the average annual precipitation (mm), and \( T \) is a temperature coefficient calculated based on the average annual temperature \( T_0 \) in °C according to equation 3:

\[
T = \sqrt{\frac{T_0}{10}} + 0.1
\]  

(3)
2.2.2. Mann-Kendall phenological trend

Spatiotemporal phenological dynamics were assessed based on MODIS products downloaded from the USGS reverb tool (NASA LP DAAC). 16-day MOD13Q1 composites product were used from January 2001 to December 2016 (23 acquisitions per year) at 250 m resolution covering the entire watershed (i.e. a set of 368 images).

Subsequently, Timesat software was used to analyze the NDVI signal and extract the phenological metrics by smoothing the NDVI time series data produced for each season from the NDVI layers (equation 4) of the MODIS (Jönsson and Eklundh, 2004; Lebrini et al., 2019). From representative areas of interest, the phenological profiles were extracted and the phenological metrics were calculated by the Gaussian asymmetric function for the sixteen growing seasons, which made it possible to discriminate the different phenological areas (Bachoo and Archibald, 2007; Chen et al., 2006). All the metrics were analyzed using boxplots to compare them and choose the consistent among them to describe their variability (Lebrini et al., 2021).

\[
\text{NDVI} = \frac{\text{NIR} - R}{\text{NIR} + R}
\]  

(4)

Afterwards, the annual great integral value of each of the 16 years was evaluated at the pixel level to calculate the spatiotemporal trends of the phenological metrics based on the standardized Mann-Kendall (Kendall, 1975; Mann, 1945) and the Sen’s slope tests (Sen, 1968) with a p-value considered significant at a confidence level of 0.05. The test outputs were classified as negative trend, positive or non-significant (Salhi et al., 2020b).

2.2.3. Landuse dynamics

The landuse temporal analysis uses the “Landviewer” cloud service which provides access to satellite data and rapid analyzes. This ‘Earth Observing System (EOS) Data Analytics’ service allows ready to use historical Sentinel and Landsat scenes (among others) to monitor the spatiotemporal dynamics for large periods (between 1985 and 2021 in our case) (Table 2). The choice of scenes was influenced by cloud cover and scene quality (for instance, since June 2003, Landsat 7 ETM + has delivered images with linear gaps caused by the Scan Line Corrector failure).

An NDVI composite was used to assess the evolution of green vegetation and its spatial change. It is a good indicator which uses Red (R) and Near infrared (NIR) according to equation 4 and where the corresponding bands differ, obviously, according to the sensor (NIR/R are B8/B4, B5/B4, and B4/B3 for Sentinel 2, Landsat 8 and


Landsat 5 and 7, respectively). The focus on the general evolutionary trend of plants and infrastructures patterns, and the use of local documents and territorial reports make it possible to overcome this constraint so as not to affect the effectiveness of the evaluation.

NDVI was assessed at the pixel level during the growing season (May-June) each year, except when data are unavailable. To avoid confusion, a special focus was given to three land cover types: dense and moderate vegetation, sparse vegetation, and open ground or no vegetation. NDVI values vary from -1 to 1 with extreme negative values (close to -1) attributed to water and values close to zero (-0.1 to 0.1) generally attributed to barren rock, sand or snow. Positive low values are assigned to shrubs and grasslands (0.2 to 0.5), and high values (0.6 to 0.9) are assigned to dense vegetation at their peak growth stage.

### 2.2.4. Monthly NDVI/NDWI drought monitoring

Most climate change projections predict an increase in the global average temperature with more frequent, severe and prolonged heat waves and droughts that can exacerbate water scarcity and forest decline (Hadria et al., 2019; Stevens - Rumann et al., 2018). Consequently, the most adequate predictor of the risk of this decline is the evaluation of the water status of the calibrated plant against the critical thresholds related to hydraulic failure (Marusig et al., 2020).

NDVI is widely used to monitor drought despite an apparent time lag reported between a deficit of precipitation and the response of NDVI (Gu et al., 2007). Additionally, the Normalized Water Difference Index (NDWI) uses green and near infrared bands to assess variations in water bodies and monitor drought, since it is dependent on both desiccation and wilting in the vegetation cover (McFeeters, 1996). The strong relationship between these two satellite indices (Gu et al., 2008) explains their combination to effectively monitor vegetation drought for 30 months between 2015 and 2018, on the basis of sentinel acquisitions according to equations 4 and 5. NDWI values greater than 0.5 are assigned to water bodies. Vegetation is generally assigned to smaller values while built-up corresponds to values between zero and 0.2.

\[
\text{NDWI} = \frac{B3 - B8}{B3 + B8} \tag{5}
\]
2.3. **Countryside households’ survey**

We developed this research in a watershed that reflects the general rural conditions in Northern Morocco, known for its natural and cultural richness and diversity but which constitutes a focal point of rural abandonment and international migratory flows. The coastal aspect and the situation halfway between attractive towns and a large strategic port strongly influence the living conditions and the perception of the villagers of a rapidly changing territory.

The study was designed to understand the socio-economic indicators and drivers of transformation perceived by the villagers. We conducted a household survey in 3 villages selected to be representative of the different geographic elements and accessibility to basic infrastructure. A group of PhD investigators was guided by the key informants interviewing households using semi-structured questionnaires. They were previously coached by an expert on the methods of carrying out the survey, communicating the questions and interpreting the answers. Their skills were tested and approved in a preparatory survey.

171 of households were selected according to the Cochran's corrected equation (equation 6), by means of stratified random sampling proportional to size (Cochran, 1977). Certainly, households were updated on the purpose, voluntariness, and anonymity of the survey.

\[ n = \frac{n_0}{1 + \frac{n_0}{\text{Population}}} \]  

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

The questionnaire consisted of three sections: (i) basic household information, (ii) living conditions and (iii) attitudes and opinions towards environmental quality and issues. The statistical interpretation included the descriptive statistics and Chi-squared test (\( \text{Chi}^2 \)) at a significance level alpha of 0.05 based on the Xlstat add-in for Microsoft Excel which allows complex statistical assessments.

3. **Results**

3.1. **Environmental assessment**

Potential soil erosion shows severe erosion (7.5%) concentrated where there is infrastructure, abandoned quarries, roads and railways while moderate erosion (10.9%) is scattered throughout the watershed (Fig. 2). The prevalent
erosion patterns are sheet erosion, elemental and generalized gullying. Excluding roads and infrastructure, the
watershed contains natural spaces with gentle slopes and scattered villages where the lowest rates are observed.
The good news is that most of the watershed is subject to slight erosion (81.6%), hence the value of ending the
problem early.

Evidently, natural factors such as lithological fragility and climatic aggressiveness are active precursors of soil
erosion but anthropic intervention is preponderant in our case and is likely to aggravate the natural weaknesses. In
the Mediterranean, vulnerability to climate and environmental change is reflected, among other things, by an
upward trend in the daily concentration of precipitation, which implies an increase in its aggressiveness and an
acceleration of erosive processes (Benabdelouahab et al., 2020; Monjo and Martin-Vide, 2016). The average soil
loss rate is of 11.6 t/ha/year with a gross amount of 0.2 Mt/year, which equates to a massive potential gross amount
of 1.2 kg/m²/year.

The study of the phenological trend was based on the annual variation at the pixel scale of the large integral which
is proportional to vegetation density and growth. It is below 20,000 under sparse or degraded vegetation, 40,000
in rangelands, 50,000 in rainfed zones up to 120,000 in forests and irrigated perennial crops (Lebrini et al., 2021;
Steinaker et al., 2016).

In our case, the great integrals show a significant spatiotemporal vegetation variability in the study period (Fig. 3).
It is spatio-temporally associated with climatic fluctuations and the evolution of landuse. A repetitive diminution
in vegetation production is detected east of Melloussa village, attesting to the fragility of this area. Since 2006,
there has been a rectilinear decrease oriented SW-NE associated with the establishment of the highway and
railways. Contrariwise, A general increase is detected during the wet years indicating the close dependence of
vegetation growth on the annual variability of precipitation. Unfortunately, the recovery of plant cover in wet years
is partial, probably due to the fragility of topsoils.

The analysis of phenological trends (Fig. 4) shows a dominant positive trend (9.5%) against a negative trend
(1.5%) which traces the construction of infrastructure, roads and railways. On the other hand, the positive trend
follows the ridge line of the watershed away from anthropogenic pressure, then near the river where many crop
fields have settled. These observations demonstrate the great impact of anthropogenic activity on vegetation
density and productivity. The large extension of non-significant trend (89%) is associated with areas where the
large integral values are low or medium. This means very frequent ups and downs of vegetation, which although
have not caused a clear trend so far but could be at risk of deterioration, given the fragility of the topsoils.

Long-term landuse dynamics (Fig. 5) clearly shows the severe drought episodes that affected the study area and
entire western Mediterranean as reported in previous studies (Hadria et al., 2021a; Salhi et al., 2020b). This is the
case of the drought of 2016 where the growth rate in Morocco fell sharply due to the poor agricultural season from
4.5% in 2015 to 1.6% in 2016. In this last year, the Moroccan government carried out an emergency plan of 417
million euros to reduce the impacts, particularly in rural areas, according to three main axes: (i) supplying drinking
water to remote villages, (ii) protecting animal resources and plants, (iii) and support solidarity cultures.

The first observation is that the percentage of vegetation (dense, moderate and sparse) is more or less stable at
95% of the basin surface, except during years of severe drought when the shrinkage can exceed 40%. The second
observation is that the main variations affect dense and moderate vegetation which is much more sensitive to
annual climatic fluctuations. In terms of pluviometric parameters, the one that seems most associated with annual
variations in plant cover is the number of significant wet-days ($\geq 10$ mm) which, logically can contribute to the
improvement of the water reserve and thus to the maintenance of the vegetation.

At a smaller time-scale (months), the changes between NDWI (water content) and NDVI (vegetation) are well
correlated both at the level of the corresponding mean curve as for the ranges (Fig. 6). It is observed that the
maximum NDWI curve barely reaches the threshold of 0.5 (attributable to water masses) for short periods (a few
weeks) and then oscillates below for the rest of the year. The NDVI follows this pattern and its average curve
barely exceeds the 0.6 threshold (dense vegetation) for one or two months and then decreases for the rest of the
year.

Indeed, severe drought events are frequent and at short intervals; this is the case of the droughts of February and
May 2016, the repercussions of which have been shown above. Immediately after reaching the corresponding
NDVI and NDWI thresholds, the rapid falls bear witness to the immediate and prolonged start of the dry season.

3.2. Households’ perception

The survey results include information on households, living conditions and perception of the environment. The
results were described statistically and the association between variables were tested based on Chi$^2$ categorical test
at an alpha of 0.05. Among the 171 heads of households identified in the sample, 24.7% were over 60 years old,
while the majority of them (74.1%) were of middle-aged. Families are often large (more than 6) or made of 3 up to 5 members (47%). The heads of household are often married men who live in the same village of their birth.

Similar to the official data, the majority of respondents (93.1%) were illiterate or barely having primary education (HCP, 2014)). It is also observed that the main activity is agriculture (27.2%) while the inactive are 15% mainly because they have reached retirement age. The majority of respondents own their households, which increasingly acquire the apparent urban character even though it is a rural area. Indeed, the increase in the percentage of apparently urban households in rural areas is increasingly observed in northern Morocco.

Obviously, there is a significant association (p-value = 0.010) between low level of education and types of activity that do not require a specific level of education. Significantly, 54.4% of farmers are illiterate and 45.6% have reached primary school at most. All the women heads of households are unfortunately illiterate.

A significant association (p-value = 0.008) is also observed between confusion regarding the dangers of the forest and low level of education, regardless of profession. The same observation is repeated when comparing the low level of education and the favorable opinion on the use of pesticides (p-value = 0.005) and the use of fertilizers (p-value = 0.011).

Drinking water is mainly supplied by the public network (39%) and then by dug wells or by purchasing cistern water while direct use of springs is very rare. In general, adults are responsible for bringing water to homes that are not connected to the public water supply network. The electricity network covers the entire study area and supplies almost 97% of households.

A strong association (p-value = 0.025) can also be observed between the sector of activity and the most frequent places of mobility: farmers and housewives move more locally.

Shopping is the main driver of villagers’ trips followed by work, and it should be noted that the most common trips are made locally or in the immediate vicinity. The attractiveness of large cities appears (in ascending order) when it comes to pursuing higher education, receiving certain administrative services not available in the immediate vicinity, shopping in large markets or receiving health services.

Difficulties in accessing drinking water are evident among 37% of the villagers who consider it an urgent need. The rest believe that the change in their living conditions depends on the simultaneous improvement of all basic
infrastructures. Significantly, there is a close association between most urgent need and gender (p-value = 0.04) on the one hand and sector of activity on the other; women and farmers express a greater need for drinking water.

When it comes to attitude and opinion towards the environment, all households dump sewage into septic tanks, solid waste uncontrollably outdoor perceive the lack of intervention of municipal services in this regard. The lack of water previously identified is combined with potential pollution problems in relation to direct discharges into nature and the quantitative and qualitative deterioration during prolonged low-water periods. Besides, the use of conventional fertilizers and pesticides is very widespread (93.3% and 66.7% respectively) which creates a risk of pollution of natural waters. However, a small minority of respondents perceived at least once the pollution of drinking water. The prevention of pollution is limited to unsystematic individual attempts by adding chlorine, purification by tablets, or boiling water, while the majority (60.8%) are doing nothing to tackle the problem. The low perception is accentuated when it comes to exposure to diseases linked to water pollution: only 1.1% answer yes and all respondents cannot name a disease, except one of them. For farmers, the harvest is mostly traditional for self-sufficiency. They claim not to be irrigated by wastewater directly, except that the flow of small rivers is supported by polluted discharges especially in periods of low water.

The use of forests for agriculture is widespread (22.3%) without a license. Only 39.7% of the respondents perceive the existence of dangers to forests but are unable to identify dangers other than fire. Later, when some of the possible causes of forest decline were dictated to them, they confusedly identified human interventions and climate change as the main causes, forgetting what they mentioned about fires and not paying attention to the impact of projects and infrastructure.

It should be noted that all respondents had positive reactions to the national strategic projects that are taking place around them. Even if the immigrant rate among immediate relatives is very significative (9.2%), almost all heads of households are very attached to their lands and do not plan to venture into emigration in the foreseeable future.

4. Discussion

Definitely, it is observed that most heads of households find it difficult to identify potential environmental problems in association with their poor educational level. Significantly, 100% of them deposit all liquid and solid waste directly into nature without any intervention by collection services (according to their statements). However, they are not aware of the potential consequences of this waste on the degradation of the quality of water, soil, vegetation and air, and thus of the sustainability and productivity of the environment. This difference in the
assimilation of cause and effect associations is explained by the low level of education and the seclusion of this rural population.

The same can be observed for the uncontrolled use of pesticides and fertilizers and its probable impacts on the degradation of the environment and health: the villagers do not manage to link causes and their effects. Undoubtedly, this constitutes a high risk on the health (by accumulation of pollutants, intoxication, etc.) of the villagers because 90.5% consume their crops locally. However, almost all of them have never observed diseases associated with the use of polluted water (drinkable and irrigation). The reason is obvious, they are unable to identify any waterborne disease due to their low level of education and poor environmental culture.

The use of the forest without a license is quite widespread by the villagers, but they do not think this poses a risk. Strangely, 88.6% of those who said they know the forest is in danger could not name any of them a few minutes later. Besides, the activity of the transient population (tourists in summer) is considered by them as the main reason for forest decline in recent years. On the contrary, only 2.5% of respondents perceive the direct action of national strategic projects (construction of infrastructure) as the main reason for this decline. The environmental assessment shows clearly the opposite.

Recent studies show that local farmers are confused about the phenomena of land degradation and cannot perceive their own actions (e.g. deforestation, damage to conservation structures and inappropriate agricultural labor) as implicit triggers of soil degradation (Salhi et al., 2021a; Salhi et al., 2020c). Consequently, they carry out little and often inadequate soil conservation measures. When confronted with the results of potential soil erosion and the evolution of plant cover, farmers' confusion can accelerate erosive processes, especially in a context marked by rapidly expanding strategic projects and a high probability of occurrence of extreme climate events (flash floods and severe droughts) (Hadria et al., 2021b; Mathbout et al., 2021).

The urgent need for drinking water already expressed by the villagers is likely to have more serious repercussions, given the recurrence of prolonged severe intra and interannual droughts. These latter will also affect the type and productivity of crops knowing that the products are mainly intended for self-sufficiency (Lionboui et al., 2021). After a severe drought, heavy rains will cause deep erosion of the soil weakened by its lithological texture, climatic conditions and inappropriate human activity (Salhi et al., 2021b). The emergence of a water-vegetation crisis by the conjunction of these factors will constitute an alienating agent for the stability of the population, which will originate a downward socioeconomic spiral.
The phenological assessment shows a dominant but misleading growing trend. In reality, the growth is located far from the areas pressed anthropically and where fields of agriculture have been established. What is worrying is that the negative trend follows perfectly the areas of infrastructure and roads that already divide the watershed. From this perspective, spatial segregation by future roads and infrastructure can reverse the dominant trend and reduce agricultural areas which will consequently affect the living conditions of the villagers.

In theory, the macrostrategy should allow the creation of special privileges in its environment, allowing the local community to create and invest in its talents. Unfortunately, the preparation did not take into account the rural dimension in the hinterland which is languishing under the weight of the lack of education. As a consequence, the prolonged cohabitation with social and material constraints and restrictions made the local villagers receptive to their current situation and not aspiring to improve it neither near them nor to think of immigrating to nearby cities or to the other side of the Mediterranean (unlike villagers in many parts of North Africa). This will not allow them to be easily in tune with the strategic dynamic that surrounds them because they have simply got used to their life and show no desire to change their reality or that of their families.

5. Conclusions

The circumstances surrounding any strategic project are important to its formation and success. Taking care of it is essential for further development, especially as the fine details and disparities grow overtime to make the difference between success and failure.

Of course, macrostrategies are operationalized to serve as a locomotive for national economies and a lever for development, but this must be done with great care on environmental and societal balances, especially in the vicinity of its projects.

The current success of the young Tangier project deserves to be celebrated, but what is also important at this level is to invest in the achievement of a more inclusive development for an integral socio-ecosystem that can reverse the current worrying societal equation, creating an upward spiral that produces better conditions and more opportunities for a rural society that has the capacity to sustain and keep pace with success.

This will only be achieved through a time-consuming process of implanting a behavioral culture, encouraging education, and adapting it to the local and regional context and social facilitation. Of course, mastering details and
continuous improvement are the only ways to achieve complete and lasting success. The goodness of the means is inevitably rewarded by the goodness of the results.

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**Author contributions**

A.S. designed the research and wrote the paper. A.S., T.B. and M.M. carried out the modelling. A.S. and S.B. led the mapping, the analysis, and supervised the survey carried out by Z.B. Guidance on interpreting the results and revising the paper was provided by A.C.P., J.V.S. and M.H.

**Competing Interest**

The authors declare no competing interests.

**Informed consent**

Sentinel 2 and Landsat series datasets are available in [https://eos.com/landviewer](https://eos.com/landviewer), Fertimap dataset is available in [http://www.fertimap.ma/](http://www.fertimap.ma/). Eudasm dataset is available in [https://esdac.jrc.ec.europa.eu/resource-type/national-soil-maps-eudasm](https://esdac.jrc.ec.europa.eu/resource-type/national-soil-maps-eudasm) and Aster GDEM dataset is available in [https://asterweb.jpl.nasa.gov/](https://asterweb.jpl.nasa.gov/).

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Graphical Abstract

**Environmental assessment**

- **EPM Soil erosion modeling**
  - 1.2 kg/m²/year

- **Remotely sensed phenological trend**
  - Negative trend

- **Long-term landuse dynamics**
  - Infrastructure in rapid expansion

- **NDVI/NDWI drought monitoring**
  - Frequent severe drought

**Social assessment**

- **Countryside households' survey**
  - Low education and rural selusion

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Susceptibility to environmental degradation

Water shortage problem

Social vulnerability

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Need for an integral socio-ecosystem to build an upward growth spiral
Tables and captions of figures

Figure 1. Geographic location of the study area. 1: Drainage divide of the Alian watershed; 2: Hydrographic network; 3: Highway; 4: National road; 5: Regional road; 6: Railway; 7: Location of the villages where the surveys have been performed.
Figure 2. Maps of potential soil erosion rates in the study area. A: Map of the coefficient of erosion and sediment yield (Z); B: Map of the total annual volume of detached soil (W_a). 1: Drainage divide of the Alian watershed; 2: Hydrographic network; 3: Highway; 4: National road; 5: Regional road; 6: Railway; 7: Low erosion; 8: Moderate erosion; 9: Severe erosion; 10: Less than 5 t/ha/year; 11: Up to 15 t/ha/year; 12: More than 15 t/ha/year.
Figure 3. Spatiotemporal dynamics of the great integral metric in the Alian watershed for the period 2001–2016.
Figure 4. Spatial distribution of the trend of phenological parameters for the period 2001–2016. 1: Drainage divide of the Alian watershed; 2: Hydrographic network; 3: Highway; 4: National road; 5: Regional road; 6: Railway; 7: No significant trend; 8: Positive trend; 9: Negative trend.
Figure 5: Landuse change during the period 1985–2021 according to NDVI and evolution of the significant wet days in the Tangier station.

Figure 6: Comparison of the NDVI/NDWI temporal change during 30 months according to Sentinel-2 data.
| Form characteristics | Reference                              | Watershed |
|----------------------|----------------------------------------|-----------|
| Area (km²)           | (Thomas and Benson, 1970)              | 121.2     |
| Length (km)          |                                        | 18        |
| Width (km)           | (Gregory and Walling, 1973)            | 11        |
| Perimeter (km)       |                                        | 57.4      |
| Elongation ratio     | (Gregory and Walling, 1973)            | 0.61      |
| Circularity ratio    | (Pareta and Pareta, 2012)              | 0.46      |
| Compactness coefficient | (Pareta and Pareta, 2011)        | 1.45      |
| Form factor          | (Zăvoianu, 1985)                       | 0.37      |

| Topological characteristics |           |
|-----------------------------|-----------|
| Max altitude (m)            | 645       |
| Min altitude (m)            | -2        |
| Relief ratio                | (White et al., 1998)                    | 27.5      |
| Relative relief             | (Gregory and Walling, 1973)              | 1.12      |
| Ruggedness number           | (Pareta and Pareta, 2011)                | 0.02      |
| Texture ratio               | (Horton, 1945)                           | 2.76      |
| Hypsometric Integral        | (Strahler, 1957)                         | 0.47      |

| Drainage characteristics    |           |
|-----------------------------|-----------|
| Stream length (km)          | 279.8     |
| Number of streams           | 747       |
| Drainage density            | (Horton, 1945)                             | 0.38      |
| Stream frequency            | (Horton, 1945)                             | 1.02      |
| Constant of channel maintenance | (Schumm, 1956)                       | 2.63      |
| Drainage intensity          | (Pareta and Pareta, 2011)                 | 2.68      |
Table 2: Characteristics of the scenes used to monitor the spatiotemporal landuse change

| Sensor          | Date (dd/mm/yyyy) | Cloudiness (%) | Sun elevation (°) | Spatial resolution (m) |
|-----------------|-------------------|----------------|-------------------|------------------------|
| Landsat 5 (TM) T1 | 04/07/1985        | 0              | 61                | 30                     |
| Landsat 5 (TM) T1 | 05/06/1986        | 2              | 61                | 30                     |
| Landsat 5 (TM) T1 | 07/05/1987        | 2              | 58                | 30                     |
| Landsat 5 (TM) T1 | 23/04/1988        | 0              | 56                | 30                     |
| Landsat 5 (TM) T1 | 15/07/1989        | 6              | 60                | 30                     |
| Landsat 5 (TM) T1 | 02/07/1990        | 34             | 60                | 30                     |
| Landsat 5 (TM) T1 | 02/05/1991        | 0              | 56                | 30                     |
| Landsat 5 (TM) T1 | 05/06/1992        | 1              | 61                | 30                     |
| Landsat 5 (TM) T1 | 24/06/1993        | 1              | 61                | 30                     |
| Landsat 5 (TM) T1 | 10/05/1994        | 15             | 58                | 30                     |
| Landsat 5 (TM) T1 | 29/05/1995        | 12             | 75                | 30                     |
| Landsat 5 (TM) T1 | 31/05/1996        | 9              | 59                | 30                     |
| Landsat 5 (TM) T1 | 03/06/1997        | 0              | 62                | 30                     |
| Landsat 5 (TM) T1 | 24/07/1998        | 19             | 61                | 30                     |
| Landsat 5 (TM) T1 | 24/05/1999        | 0              | 63                | 30                     |
| Landsat 5 (TM) T1 | 11/06/2000        | 0              | 63                | 30                     |
| Landsat 7 ETM+ T1 | 06/06/2001        | 3              | 66                | 30                     |
| Landsat 7 ETM+ T1 | 09/06/2002        | 1              | 66                | 30                     |
| Landsat 7 ETM+ T1 | 27/05/2003        | 1              | 65                | 30                     |
| Landsat 5 (TM) T1 | 22/06/2004        | 30             | 64                | 30                     |
| Landsat 5 (TM) T1 | 25/06/2005        | 5              | 65                | 30                     |
| Landsat 5 (TM) T1 | 14/07/2006        | 27             | 65                | 30                     |
| Landsat 5 (TM) T1 | 30/05/2007        | 3              | 66                | 30                     |
| Landsat 5 (TM) T1 | 03/07/2008        | 0              | 65                | 30                     |
| Sensor          | Date            | Snow Mask | Cloud Mask | Quality |
|-----------------|-----------------|-----------|------------|---------|
| Landsat 5 (TM)  | 06/07/2009      | 0         | 65         | 30      |
| Landsat 5 (TM)  | 23/06/2010      | 5         | 66         | 30      |
| Landsat 5 (TM)  | 09/05/2011      | 3         | 63         | 30      |
| Landsat 8       | 15/06/2013      | 3         | 68         | 10      |
| OLI+TIRS        | 02/06/2014      | 2         | 67         | 10      |
| Landsat 8       | 21/06/2015      | 22        | 68         | 10      |
| OLI+TIRS        | 23/06/2016      | 16        | 68         | 10      |
| Sentinel-2 L2A  | 22/05/2017      | 1         | 70         | 10      |
| Sentinel-2 L2A  | 16/06/2018      | 2         | 72         | 10      |
| Sentinel-2 L2A  | 06/06/2019      | 0         | 72         | 10      |
| Sentinel-2 L2A  | 15/06/2020      | 0         | 72         | 10      |
| Sentinel-2 L2A  | 02/06/2021      | 0         | 70         | 10      |
Table 3: Characteristics of the sampled households, their living conditions, and their attitude towards environmental quality and issues.

| Variable                        | Elements          | Percentage (%) |
|---------------------------------|-------------------|----------------|
| **Basic information about households** |                   |                |
| Gender                          | Female            | 10.6           |
|                                  | Male              | 89.4           |
| Family status                    | Married           | 84.7           |
|                                  | Single            | 5.3            |
|                                  | Divorced          | 1.8            |
|                                  | Widower           | 8.2            |
| Number of family members         | ≤2                | 18.7           |
|                                  | [3; 5]            | 43.5           |
|                                  | ≥6                | 37.6           |
| Place of birth                   | Same village      | 62.4           |
|                                  | Another place at the same province | 24.1 |
|                                  | Another province  | 13.5           |
| Age                             | Young (<25)       | 1.2            |
|                                  | Middle-aged (25-59) | 74.1         |
|                                  | Elderly (>60)     | 24.7           |
| Level of education               | Illiterate        | 49.0           |
|                                  | Primary           | 44.1           |
|                                  | Secondary         | 4.1            |
|                                  | High education    | 1.8            |
| Sector of activity               | Farming           | 27.2           |
|                                  | Day labouring     | 26.0           |
|                                  | Retirement        | 11.2           |
|                                  | Construction      | 5.9            |
|                                  | Commerce          | 5.9            |
|                                  | House work        | 5.9            |
|                                  | Unemployment      | 4.1            |
|                                  | Security          | 4.1            |
|                                  | Driving           | 3.6            |
|                                  | Public function   | 3.0            |
|                                  | Self-contracting  | 1.8            |
|                                  | Fishing           | 1.2            |
| **Living conditions**           | Village of residence |           |
|                                  | Alian             | 40.0           |
|                                  | Dar El Foual      | 31.8           |
|                                  | Talaa Lakraa      | 28.2           |
| Housing possession               | Ownership         | 93.5           |
|                                  | Free lodging      | 6.5            |
| Housing type       | Villager | 44.4 |
|-------------------|----------|------|
|                   | Urban    | 55.6 |
| Drinking water supply | Public network | 38.8 |
|                   | Water well | 30.6 |
|                   | Spring   | 5.3  |
|                   | Cistern  | 25.3 |
| Person in charge of fetching water | Adults | 89.8 |
|                   | Children | 1.1  |
|                   | Both     | 4.5  |
|                   | Plastic hoses | 4.5 |
| Light source      | Public network | 97.0 |
|                   | Gas      | 1.2  |
|                   | Solar energy | 1.8  |
| Most frequented mobility | Local | 96.2 |
|                   | to Tangier | 1.3 |
|                   | to Tetouan | 2.5 |
| Mobility motive   | Shopping | 64.1 |
|                   | Work     | 9.9  |
|                   | Family visit | 4.2 |
|                   | Health treatment | 0.7 |
|                   | Various  | 21.1 |
| Where does your family receive administrative services? | Local | 37.7 |
|                   | Nearby rural centers | 49.4 |
|                   | Cities   | 12.3 |
|                   | Changeable | 0.6 |
| Where does your family receive health services? | Local | 19.5 |
|                   | Nearby rural centers | 23.9 |
|                   | Cities   | 50.3 |
|                   | Changeable | 6.3 |
| Where does your family study? | Local | 45.7 |
|                   | Nearby rural centers | 41.4 |
|                   | Cities   | 12.9 |
| Where does your family go shopping? | Local | 1.9 |
|                   | Nearby rural centers | 55.3 |
|                   | Cities   | 35.2 |
|                   | Changeable | 7.5 |
| What are the urgent needs of the population? | Drinking water | 37.1 |
|                   | Education and health | 1.9 |
|                   | Employment | 1.0 |
|                   | Various  | 60.0 |
| **Attitudes and opinions towards environmental quality and issues** | Waste water disposal | Septic tank | 100.0 |
|---|---|---|---|
| **Solid waste disposal** | Uncontrolled outdoor | 100.0 |
| **Does the community intervene to solve the liquid waste problem?** | No | 100.0 |
| **Have you ever detected pollution in your drinking water?** | No | 92.1 |
| | Yes | 7.9 |
| **How do you tackle water pollution problems?** | Nothing | 60.8 |
| | Add chlorine or purification tablets | 35.3 |
| | Boil water | 3.9 |
| **Have you ever been exposed to diseases associated with water pollution?** | No | 98.9 |
| | Yes | 1.1 |
| **What type of disease was it?** | Kidney stone | Only 1 respondent |
| **Do you use sewage water to irrigate crops?** | No | 100.0 |
| **Harvest methods** | Traditional | 88.3 |
| | Modern | 8.3 |
| | Both | 3.3 |
| **Type of fertilizers in use** | Organic | 6.7 |
| | Conventional | 30.0 |
| | Both | 63.3 |
| **Use of pesticides** | No | 33.3 |
| | Yes | 66.7 |
| **Agricultural production target** | Self-sufficiency | 90.5 |
| | Marketing | 9.5 |
| **Do you use the forest?** | No | 77.7 |
| | Yes | 22.3 |
| **You have a license to use the forest?** | No | 100.0 |
| **Do you know the dangers to the forest?** | No | 39.7 |
| | Yes | 60.3 |
| **Can you name some of them?** | Fire | 56.7 |
| | Don't know | 43.3 |
| What is the main reason for the observed forest decline? | Population activities | 35.0 |
|---------------------------------------------------------|-----------------------|------|
| in relation with the projects of development            | 2.5                   |
| Multiple reasons                                        | 62.5                  |