FLOODPLAIN STRUCTURING ACTION MOROCCO PROJECT

Writer:
Guillaume Lacombe

Contributors:
Hajar Choukrani, Ali Hammani, Marcel Kuper & Abdelilah Taky

With the support of
AFD AGENCE FRANÇAISE DE DÉVELOPPEMENT

Ordered by
AFEID

COSTEA ENSEMBLE POUR RELEVER LES DÉFIS DE L'AGRICULTURE IRRIGUÉE

CIRAD
42, rue Scheffer
75116 Paris - France
Tél. : +33 1 53 70 20 00
www.cirad.fr

IAV Hassan II
Institut Agronomique et Vétérinaire Hassan II
Maroc
iav.ac.ma/fr

FLOODPLAIN STRUCTURING ACTION MOROCCO PROJECT

GENERAL INTRODUCTION

The coastal plains concentrate populations attracted by fertile land that is easy to develop and open to trade. However, these environments have risks (flooding and pollution) and they are threatened by a decline in biodiversity and the degradation of natural ecosystems. In this context, the intensification of agriculture, the control of its environmental impacts and the future of the natural ecosystems are becoming major issues.

This final report of the COSTEA2 structuring action on floodplains is made up of three parts. The first presents the issues of the Gharb plain located on the Atlantic coast in north-west Morocco. It highlights the importance of its wetlands (locally known as 'merjas'), and explores the modalities of their development with a view to sustainable, ecological agricultural production that minimises the risks linked to excesses and deficits of the water resources. The second part provides answers to this ambition of development by considering the merjas of the Gharb plain from the perspective of the ecosystem services they offer. Finally, the last part explores the spatio-temporal variability of spectral indices of flooding and vegetation in the Gharb plain using remote sensing in order to highlight two ecosystem services of the merjas: flood control and irrigated farming.

PART I: ISSUES OF THE GHARB PLAIN

1. STUDY ZONE

This section briefly presents the Gharb plain catchment area (the Wadi Sebou catchment area) and then describes the Gharb plain, the subject of our study, in detail.

1.1 The Wadi Sebou catchment area

With a surface area of 40 000 km^2 (Figure 1), this catchment area was populated by 6.2 million inhabitants in 2004, 51% of whom in urban areas. Its economy is essentially agricultural and industrial.

Climate

The Wadi Sebou catchment area has a Mediterranean climate with an oceanic influence (in its western part) and continental influence (in its eastern part). Its average annual rainfall is 640 mm and it is marked by high spatial variability (from 400 mm on the upper Sebou to 1000 mm on the heights of the Rif). 90% of the annual rainfall is concentrated between October and May, which corresponds to the coldest period.

Water resources

The Wadi Sebou catchment area covers less than one tenth of the surface of Morocco but produces one third of its water resources. The Wadi Sebou's source is at an altitude of 2030 m and it is 500 km long. Its average annual water intake is 5.6×109 m^3 (equivalent to 140 mm on the surface of the catchment area, i.e.

Figure 1. Water network of the Wadi Sebou basin (map designed by ABHS, the water basin agency of Sebou)

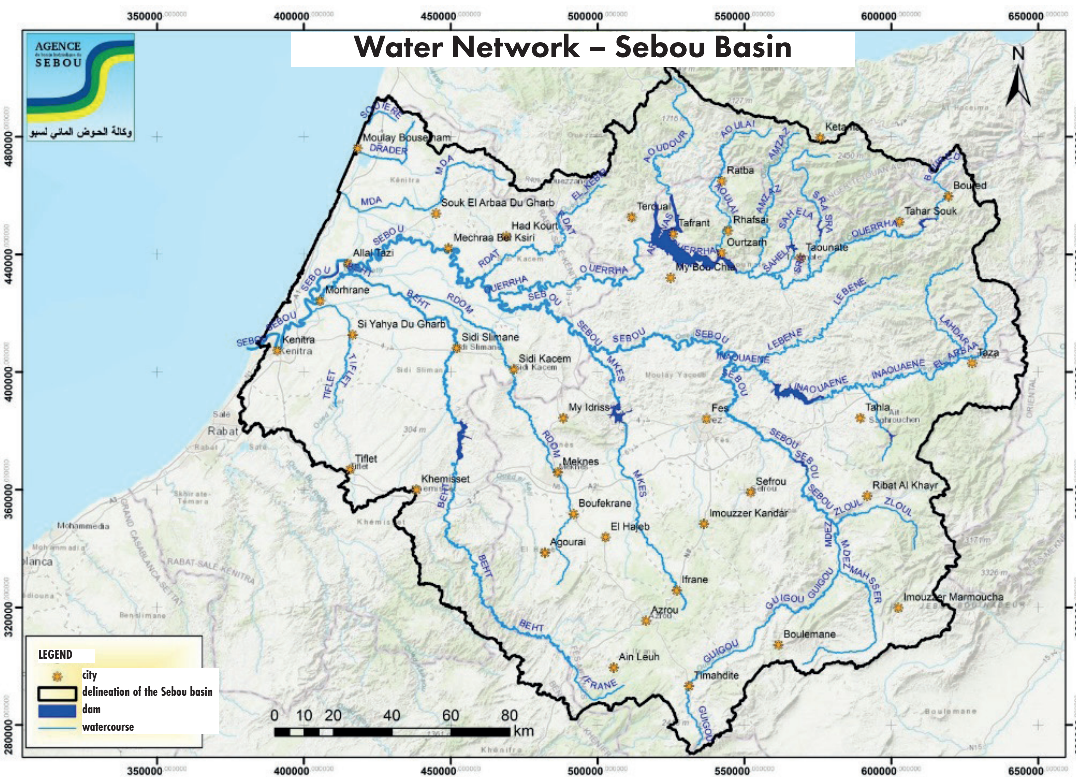
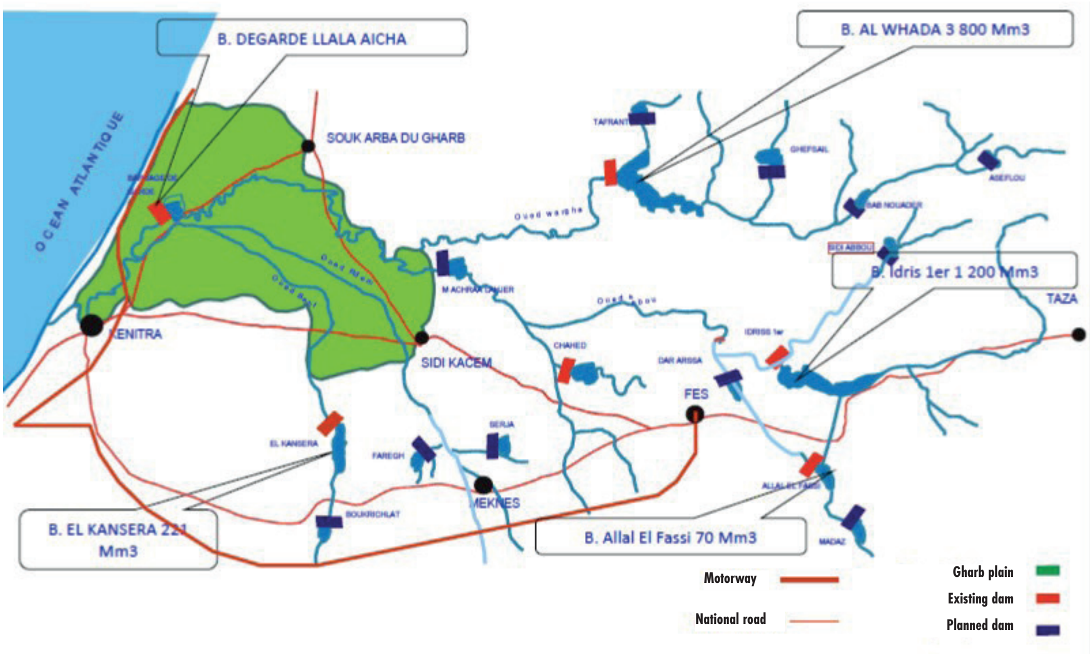


Figure 2. Main dams in the Wadi Sebou catchment area (from a map designed by the ABHS)



a runoff coefficient of 140/640 = 22%) (1939-2002). Part of the runoff is stored in several dams, the largest of which have the following storage capacities: Al Wahda (3.5 × 109 m^3), Idriss I (1.2 × 109 m^3), Alla El Fassi (0.06 × 109 m^3) and El Kansara (0.3 × 109 m^3) (Figure 2).

The Sebou Water Basin Agency (ABHS), established in 1995 under the 10/95 water law, is responsible for water resource management. Its many missions include: i/ the quantitative and qualitative metrological monitoring of water resources, ii/ the preparation and monitoring of the implementation of the integrated water resource development master plan, iii/ the management of shortages in the event of drought, iv/ taking flood prevention and protection action in partnership with public establishments and local authorities, v/ pricing and issuing authorisations for the use of the public water domain, vi/ the upkeep and maintenance of public waterworks, and vii/ contributing to research and the development of techniques for the mobilisation, rational use and protection of water resources in partnership with scientific institutions and laboratories.

Agriculture

The cultivable potential of the Wadi Sebou catchment area is 1 750 000 ha and its irrigable potential is approximately 375 000 ha. The area of irrigated land is 269 600 ha, of which 114 000 ha is in large-scale hydraulic systems and 155 600 ha is in small- and medium-scale hydraulic systems or under private irrigation.

1.2 The Gharb plain

With an area of approximately 6 200 km^2, the Gharb plain is located in the downstream part of the Wadi Sebou catchment area in north-west Morocco, 40 km north of Rabat. It straddles the provinces of Kenitra, Sidi Slimane and Sidi Kacem. The Gharb plain is the country's main agricultural basin thanks to its water resources, fertile soils and proximity to major urban centres. It was home to 1.9 million people in 2014.

Climate

The Gharb plain is exposed to a contrasting temperate climate (hot, dry summers; cold, wet winters). Average annual rainfall (1973-2010) decreases from west (556 mm in Menasra) to east (463 mm in Khenichet) and is concentrated in winter. In Khenichet, the six months from November to April bring 80% of the annual total. The inter-annual and inter-decennial variability of annual accumulations is high, for example: 827 mm in 2009 and 240 mm in 1998 (Khenichet). Strong contrasts can be observed in consecutive years: 298 mm in 2006 and 732 mm in 2008.

Topography

The Gharb plain resembles a basin: dominated to the north and east by the pre-Rif hills then by the Rif and Middle Atlas ranges, and to the south by the Mâamora Glacis and the central plateau. In the west, it is separated from the Atlantic Ocean by a dune belt leaving only two possible outlets to the sea: the Nador canal which flows into the Merja Zegra and the Wadi Sebou whose estuary is located at the level of the city of Kenitra. The beds of Wadi Sebou and Wadi Beht, and their banks, are a few metres higher than the Gharb plain due to the phenomenon of accretion (raised beds). Alluvial deposits are particularly high due to the slowing down of sediment-laden flows from the catchment area when they reach the plain with its lower slopes. This configuration explains its vulnerability to flooding.

Hydrology

Variability of intakes in the plain

The intakes from the different wadis in the plain are highly variable:

- in quality: variable sediment load depending on the land use and the slope of the different sub-basins),
- in quantity: regulation of flows by dams, and variable intakes depending on rainfall and the runoff coefficient, as well as the possible raising of the wadi beds which influences the way in which the intakes flow into the plain.

When crossing the Gharb plain, the flow rate of the Wadi Sebou decreases upstream to downstream, from 2 700 m^3/s at the confluence with the Wadi Ouergha (Mechraa Belksiri) to 800 m^3/s at Briber. This leads to its banks overflowing in high water periods (Figure 3).

Stagnation of intakes in plain

The most severe flooding of the plain is caused by the winter overflows of the wadi at high water. Due to the wadi's elevated position in relation to the plain, its water that has overflowed cannot return directly to the wadi when it recedes. It flows through flood corridors to reach the lowest areas. The stock of water accumulated in the plain is only drained at two outlets of the Wadi Sebou: the natural mouth of the Wadi Beth at Mograne at an altitude of 7 to 8 m, and the junction between the Rofera canal (Beht-Sebou connection canal) and the Wadi Sebou at an altitude of approximately 5 m. The latter is the main drainage outlet for the plain during high floods (Figure 4). These water intakes, which are mainly in winter, can stagnate in the plain until the end of spring in exceptionally wet years.

Due to topographical irregularities, many wetlands (merjas) remain after the floods have been drained by gravity flow. This residual water eventually disappears through infiltration and evaporation. This process is long and can last until summer due to the very limited infiltration of the clay substrate. This slow evacuation helps to reduce the flood peaks that reach the downstream extremity of the Wadi Sebou near Kenitra, thus protecting the city and other infrastructures from its overflows.

Irrigation developments

Agriculture developed in the Gharb plain from 1920 onwards thanks to the draining of its wetlands (merjas), the construction of 13 irrigation dams upstream of the plain, which regulate flooding, and the development of irrigated schemes. The idea conveyed was that the plain was underexploited despite its agricultural potential (Sonnier, 1935).

This hydro-agricultural development was subdivided into irrigation phases (Figure 5 and Figure 11): the Beht irrigation scheme (from 1928), the first irrigation phase (Première Tranche d'Irrigation, PTI, 1972-1979), the second irrigation phase (Seconde Tranche d'Irrigation, STI, 1984-1998), some sections of which were reconverted to localised irrigation between 2013 and 2015, and the third irrigation phase (Troisième Tranche d'Irrigation, TTI, 1998-2005). The TTI includes merjas that have not yet been developed.

The first operation undertaken by the public authorities was to drain merjas at the beginning of the 20th century under the Sejournet Plan. Of the 250 000 ha of land that could be developed under the large-scale hydraulics identified by the Sebou development project (1963-1968) that followed, 114 000 ha are currently irrigated, mainly by gravity flow, with sprinklers and drip irrigation representing less than 20% of the irrigated areas. These developments were designed entirely by the State: land consolidation followed by the establishment of irrigation-, sanitation-, drainage- and easement networks. Under the 'dam policy' of the 1960s, a strategy based on the principle of the entrepreneurial State's presence in all links of the chain, from the

Figure 3. Overflow points of the Wadi Sebou in the Gharb plain (map designed by ORMVAG, the regional office for the agricultural development of the Gharb)

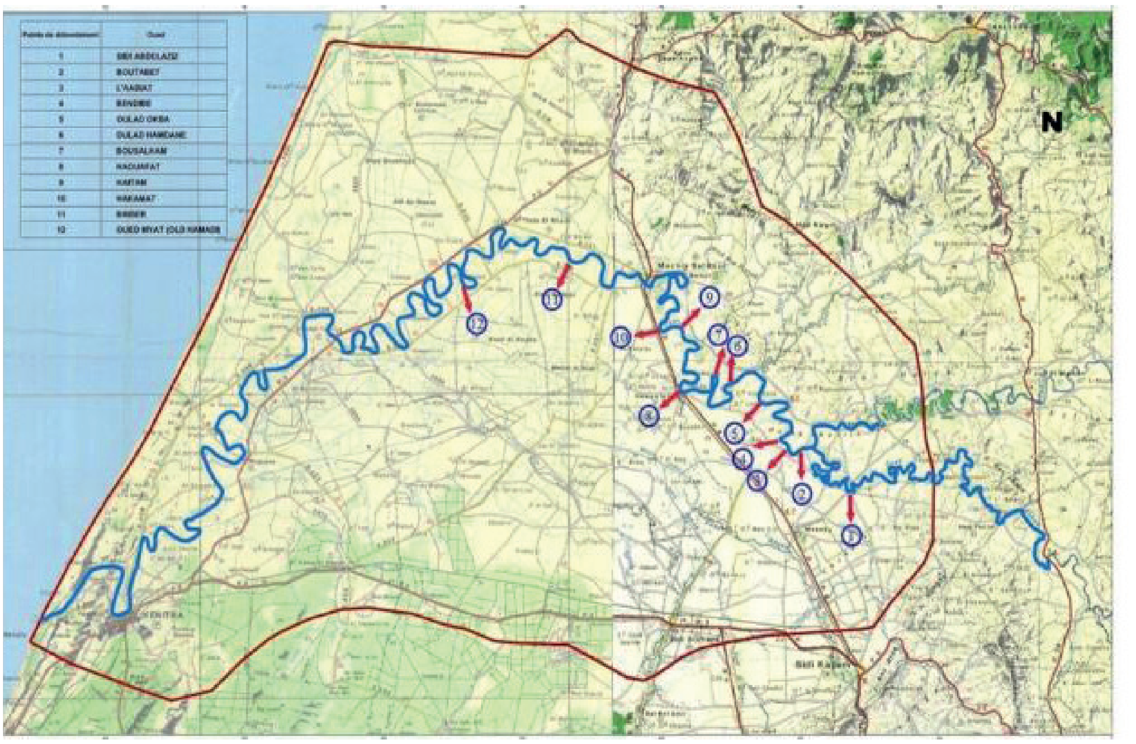
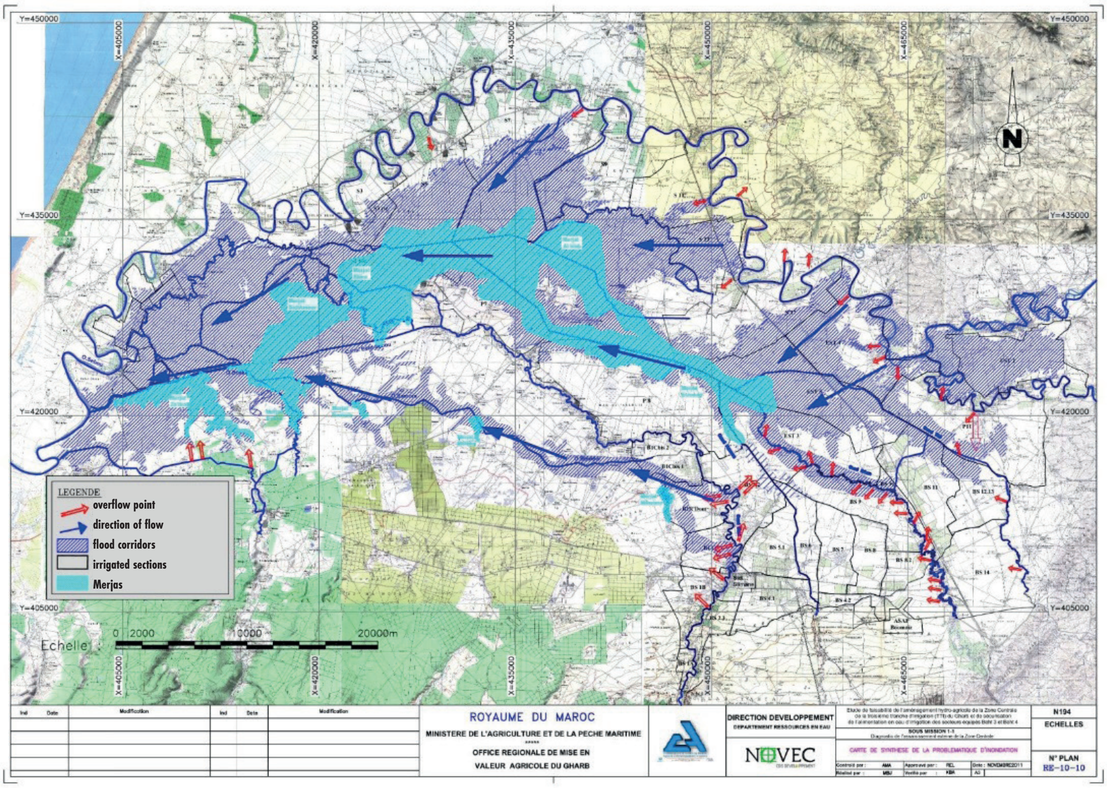


Figure 4. Flow patterns in the central area of the Gharb plain, from the overflows of the Wadi Sebou until their convergence downstream via the sanitation network (map designed by ORMVAG/NOVEC)



setting up of the crops to their processing into finished products, planned the irrigation of one million hectares by the year 2000 with the objective of the country's food self-sufficiency.

In 2021, the areas developed into irrigated and drained schemes corresponded to the lands closest to the Wadi Sebou (therefore the most easily accessible by the irrigation canals), and the highest (therefore less vulnerable to flooding risks) (1st and 2nd irrigation phases). The land still to be possibly developed corresponds to merjas, some of which are crossed by sanitation canals that link the irrigated schemes to the downstream part of the Wadi Sebou (TTI) (Figure 5).

Faced with the farmers' lack of commitment and their dissatisfaction with the 'turnkey' solutions proposed by the State, and to remedy the inefficiency of the irrigated schemes planned by the State, the latter undertook a structural adjustment policy in the 1980s. This policy encouraged 'public-private partnerships' to finance the continuation of hydro-agricultural developments in the areas most vulnerable to flood risks. Despite several consultations aimed at identifying potential financial backers, these vulnerable areas did not attract investment because the works and maintenance they require is too costly: regular cleaning of existing drainage and sanitation structures, extension of this network and construction of new irrigation channels.

The subsequent liberalisation of crop rotations in response to the State's strategic disengagement resulted in a drastic reduction in the area irrigated from the canals, from 80 to 40% of the equipped area. This reduction reflected the farmers' desire to freely choose their crop rotations, mainly made up of rain-fed annual crops whose cycles coincide with the rainfall which spreads from October to May. In the lowest areas, especially around and in some merjas, these winter crops are enabled by the drainage and sanitation network that shortens the flooding periods by facilitating the gravitational evacuation of the flood water accumulated in the lowest parts of the plain in winter. In summer, some of this land is used for market gardening, irrigated from boreholes or using drainage water from the rice-growing plots in the developed schemes located immediately upstream.
The Gharb plain is currently equipped with an extensive hydro-agricultural infrastructure made up of 54 pumping stations, 3 000 km of irrigation network and 16 500 km of sanitation and drainage network (Figure 6).

Agriculture

The plain covers 616 000 ha: 220 000 ha of rain-fed agriculture, 168 000 ha of irrigated land, 168 200 ha of forests and rangelands, 19 800 ha of uncultivated land and 40 000 ha of infrastructures.

The Gharb plain plays an important role in Morocco's agricultural production: 80% of the national production of rice, artichokes, industrial tomatoes and sunflowers, 70% of national sugar cane production, 40% of the production of avocado and groundnuts, 30% of the production of honey and bananas, 20% of red fruit production, 18% of the production of sugar beet and citrus fruits, 15% of milk production and 5% of cereal production.
The ORMVAG (Office Régional de Mise en Valeur Agricole du Gharb) is the main user of water resources for crop irrigation in the Gharb plain. Established in 1966, its missions are to: i/ apply the national agricultural strategy to the Gharb plain, ii/ study and

Figure 5. Agricultural sections of the Gharb plain. PTI = first irrigation phase. STI = second irrigation phase. TTI = third irrigation phase. Note: The Beht 3 and Beht 4 sections, subjects of the NOVEC study (2011a), are located near the Mograne section (map designed by the ORMVAG)

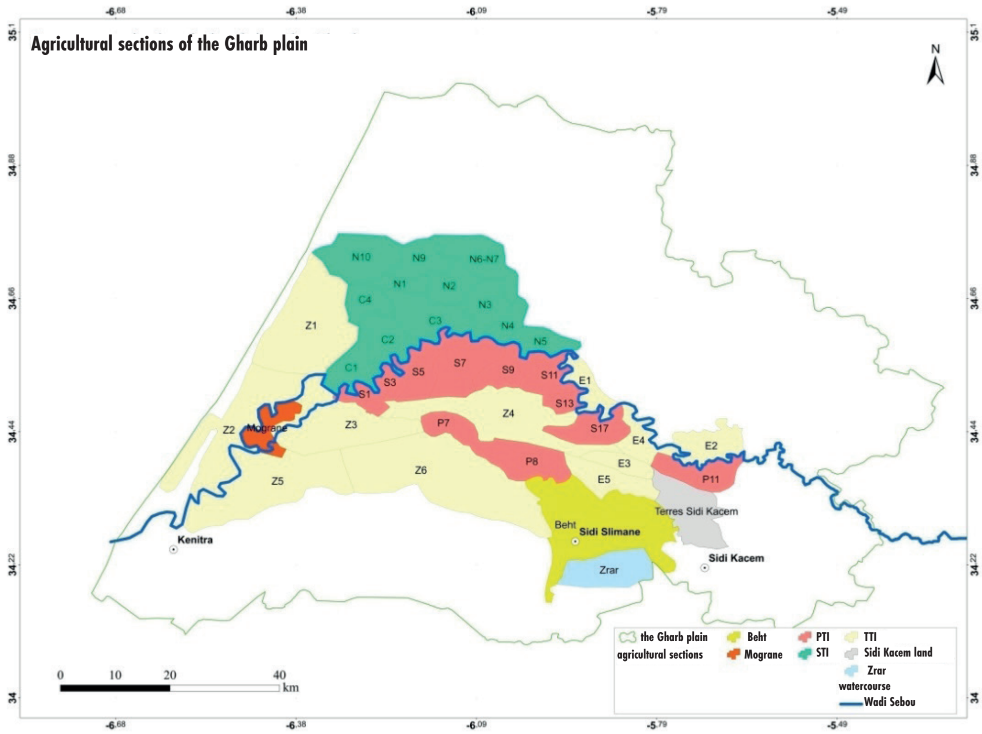
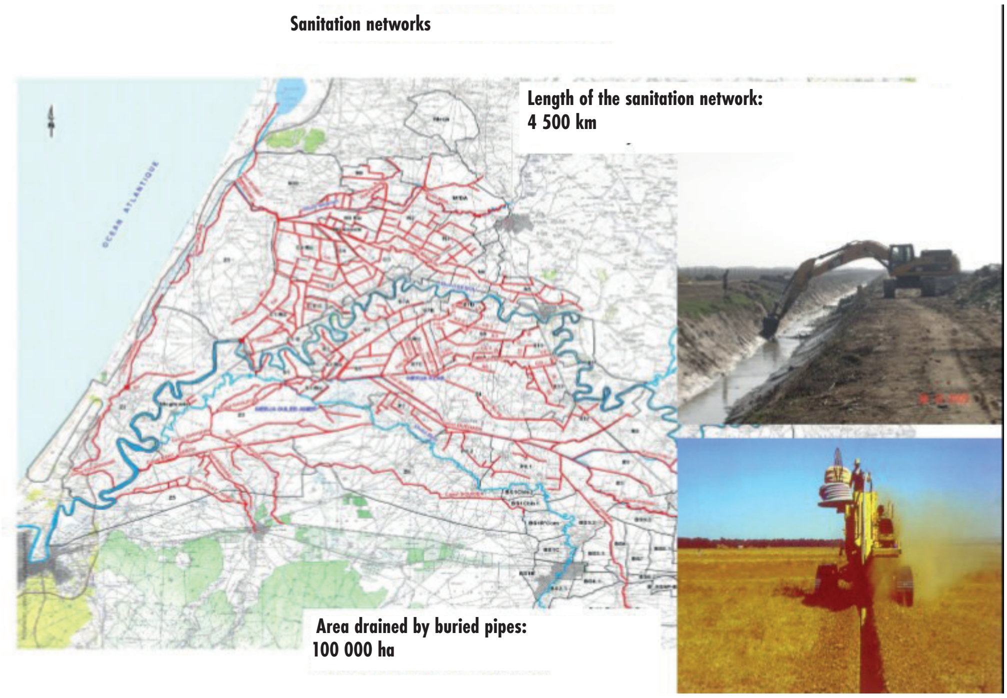


Figure 6. Sanitation network in the Gharb plain (map designed by the ORMVAG)



carry out hydro-agricultural and land development, iii/ manage water resources for agricultural use within its area of action, iv/ maintain and manage hydro-agricultural equipment and water services for farmers, and v/ develop agriculture (promotion and intensification of agricultural value creation, guidance and incentives).

2. ISSUES OF THE GHARB PLAIN

The presentation of the Gharb plain in the previous section shows that it has high productive potential due to its arable, fertile and abundantly watered land. It is one of the regions of the country with the greatest potential for agricultural development, and is becoming a major supply basin for Morocco. Moreover, this plain is located in a densely populated basin corresponding to the region of Casablanca, Rabat, Kenitra and Tangiers, and is therefore directly connected to a significant food demand. However, this situation has risks of pollution (health and environmental problems) and flooding (material damage and yield losses) combined with other problems such as resource governance at national level. In addition, there are interdependencies at the territorial level (regional hydrological impacts of local developments) which are still poorly characterised and controlled, and which constitute additional risk factors that could be accentuated by the dynamics of climate and societal change.

Social and political expectations on environmental issues in Morocco are also evolving. In this context, the intensification of agriculture, the control of its environmental impacts and the future of natural ecosystems are becoming major issues.

2.1 Flooding

Despite the implementation of a sanitation network draining more than 100 000 ha of agricultural land and the construction of 13 flood control dams upstream of the plain, its low slope, clay soils and the low capacity of its natural outlets make the plain particularly vulnerable to winter flooding. These floods have three main types of negative impact:

- By saturating and submerging the lowest cultivated land, they cause agricultural yields to plummet (100 000 ha of crops lost following the exceptional flood of 2010);
- Despite relatively low flow speeds (0.2 to 0.5 m.s-1), the overflows of the Wadi Sebou destroy the irrigation and drainage canals before reaching the merjas;
- The flow rates are highest downstream of the junction between the sanitation canals and the Wadi Sebou; this is close to the city of Kenitra and thus carries a risk of damage to urban infrastructures.

The role of dams

The cumulative storage capacity of the dams in the catchment area (5.8 × 109 m3) provides significant potential to mitigate water peaks and flooding in the Gharb plain. However, while this can be total on the most frequent floods, it is partial on major floods, such as that of 2010 (Figure 7). That year, the intakes largely exceeded the storage capacities: twice that of the Al Wahda dam, 1.5 times that of the Idriss I dam, 3.5 times that of the Kansera dam, and 6.8 times that of the Allal Fassi dam.

As the runoff water in the Sebou catchment area is loaded with sediment, another effect of the dams could be to reduce the sediment load of the discharged or turbined flows reaching the plain. An extreme situation would consist of a transition of the sedimentary dynamics from the elevation of the beds of the Wadi Sebou and Wadi Beth to their incision. This inversion would lead to a progressive reduction of the overflows of these wadis at high water and thus to a reduction of the flood control function of the merjas at the downstream end of the plain. However, this reversal of the sedimentary dynamics in the plain would only last as long as it takes for the reservoirs to silt up. By way of example, the storage capacity of the Rhamsa dam has already been halved.

Figure 7. Flooding of the Gharb plain in 2010 (map designed by the ABHS)

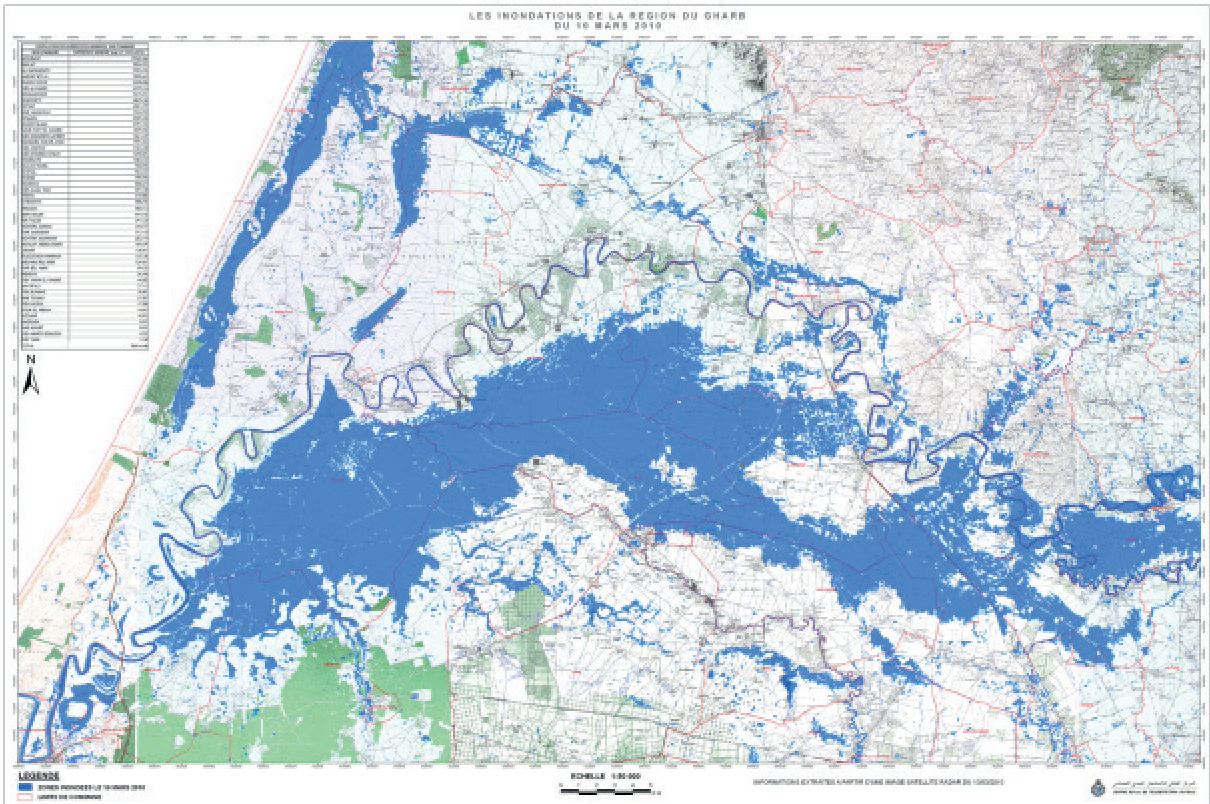


Figure 8. The three variants of the proposal for the development of the Gharb plain according to the study of the master plan to protect the Gharb plain against flooding (map designed within the framework of the NOVEC master plan for land development).

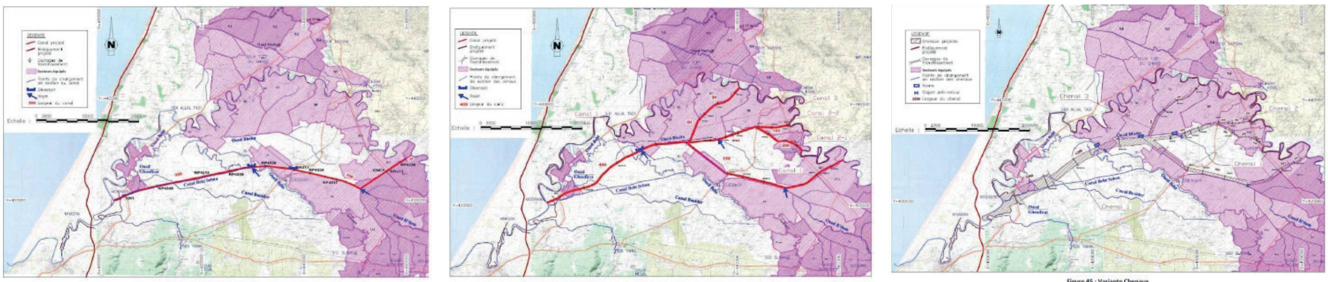


Figure 47 : Variante canal unique — Figure 46 : Variante canaux — Figure 45 : Variante Chenaux

Hydro-agricultural developments in the plain

Impact assessments

Hydro-agricultural developments, which exist in the highest areas of the plain (in and around the merjas) or are planned in the lowest, flood-prone areas, contribute to accelerating drainage speeds via their sanitation network (ditches and drains). Their implementation in the low-lying areas, envisaged in the feasibility studies commissioned by the ORMVAG, would have the consequence of increasing flood peaks in the downstream part of the Gharb plain where the city of Kenitra is particularly vulnerable to flooding. A hydraulic modelling of the plain was carried out by NOVEC (2011a) and confirms this dynamic (see Figure 4).

The ORMVAG entrusted the ADI-NOVEC consortium with the feasibility study for the 'hydro-agricultural development of the central zone of the third irrigation phase (TTI) of the Gharb and securing the irrigation water supply of the Beht 3 and Beht 4 equipped sections'. This study was part of the Green Morocco Plan. If an additional 100 000 ha of the central zone is developed for irrigation, this will have several consequences:

- The drainage capacity of the newly developed area will be increased through the extension of the existing drainage network. This should result in a doubling of the current capacity of 400 m^3/s. This could result in a higher drainage flow rate of the merjas into the Wadi Sebou with an increased risk of flooding at Kenitra.
- On the other hand, an acceleration of this drainage could make it possible to cultivate the land (in the newly developed part) earlier at the end of the winter period.
- During irrigation periods, the newly developed area would result in an increase in the irrigation flow rate and therefore a decrease in the downstream flow rate of the Wadi Sebou, even if part of this drained water would return to the Wadi Sebou via the Roféra canal.

Proposed developments

The study for the protection of the plain against flooding carried out by NEDECO between 1972 and 1978, proposed a development scheme including the construction of the M'jarâa dam ($2.7 \times 109\ m^3$) with a section reserved for floodwater storage and the raising of the capacity of the lower Sebou from 1600 to 2200 m^3/s through embankment over 280 km (1 m on the right bank and 1.5 m on the left bank). This development, which was oversized in relation to the flow rate of the wadi, is no longer relevant.

The study of the master plan for the protection of the plain against flooding (ABHS, 2010) proposes three development variants which consist of channelling all or part of the overflows of the Wadi Sebou via one or more channels or canals to the point of discharge into the Sebou downstream of Moghrane, and of embanking certain sections of the Wadi Sebou between the confluence of the Wadi Sebou and the Wadi Ouargha and the outlet of the Wadi Sebou (Figure 8). This development poses several constraints: expropriation, modification of infrastructure (roads, irrigation canals), increased risk of flooding in the event of a breach in the embankments.

2.2 Pollution

Characterised by a high population density, intensive agriculture in the Gharb plain, a very high number of industrial units and significant socio-economic growth, the Sebou is one of the most polluted basins in the country. More than 80% of the 100 million m^3 of urban wastewater produced annually in the basin is discharged into the rivers. These discharges represent a quarter of the national total and 40% are emitted by the city of Fez (polymetallic pollution, Hayzoun, 2014). Industrial pollution generates nearly 20 million population equivalents of organic pollution. Located in the large urban centres (Fez, Meknes and Kenitra), it comes from agri-food industries (oil factories, sugar mills, dairies, canneries, wine production, etc.), paper mills, tanneries and the production of ethyl alcohol. The discharges are mainly concentrated in the winter months, which is the olive harvest period for the oil factories, January to June for cane sugar, and May to July for sugar beet harvesting.

Agricultural pollution, the increasing use of fertilisers (nitrates, chlorides and potassium sulphate) and phytosanitary products (pesticides: copper or iron sulphates used as fungicides), as well as poultry discharges, contribute to the flow of pollution ending up in the Gharb plain and contaminating the groundwater. Nitrate concentrations frequently exceed the drinking water limits and pose a problem for the irrigation of market gardening crops. Landfills pollute surface water via the leachates produced during rainy periods. Their total BOD5 load is estimated at 29 960 tonnes per year, i.e. 1.5 million population equivalents. While the rate of wastewater connection to treatment plants is increasing, the treatment of diffuse agricultural pollution is less easily controlled. There are also natural pollutants (salts) (Sibari et al. 2020). These residues accumulate in the poorly drained plain, which is subject to strong summer evaporation, with infiltration limited by the impermeable clay layers.

The dilution of pollutant loads in the natural environment is low due to the dry climate. The run-off of some wadis that end up in the plain can be entirely made up of wastewater (Wadi Beht and Wadi Rdom), particularly in summer. The marine environment receives a significant share of the pollutant loads transiting through the coastal plain of Gharb at the outlet of the Sebou basin. The pressures on the marine ecosystem are set to increase due to the rising concentration of people along the coast.

Agricultural uses of this contaminated water resource are high in the Gharb plain, most often without pre-treatment, via the pumping stations in the Wadi Sebou, with risks of contamination through human or animal consumption of irrigated agricultural products. This pollution is a potential source of additional health problems through the consumption of drinking water extracted from the aquifers of the Gharb plain, partially recharged by the waters of the Wadi Sebou.

2.3 Climate change and global change

Morocco is exposed to climate change resulting in the increased irregularity of rainfall events and water intakes with negative repercussions on all natural resources.

Negative trends have been observed in flow rate records over the last decades in northern Morocco (Hrour et al., 2022). Droughts, which have become more frequent since 1980, have led to a general decline in water resource availability and agricultural productivity in Morocco (Verner et al., 2018). Climate projections indicate that these declines will continue throughout the 21st century in the Mediterranean region (Tramblay et al., 2020) and particularly in Morocco (Balhane et al., 2022; El Khalki et al., 2021; El Moçayd et al., 2020), with negative consequences on water resources (Ayt Ougougdal et al., 2020; Lespinas et al., 2014).

The social consequences include the intensification of rural exodus and the resulting pressure on urban development, the disappearance of small farms and increased irrigation costs, and the use of fertilisers and pesticides. While the societal debate on climate change is gaining momentum, awareness of the issue remains insufficient. Only those communities heavily affected by the consequences of climate change are implementing measures to build their own resilience.

These issues will become more acute in the face of global change with increased drought and flood risks, growing pressure from domestic food demand, and increased economic and human vulnerabilities. Other factors contribute to the growing vulnerability of populations to hydrological extremes and polluted flows: the loss of agricultural productivity has led to migration to cities, increasing pressure on social services and urban physical infrastructure. Not only is this urban growth detrimental to agricultural land, it is also uncontrolled and not conducive to sustainable development. Most often exclusively male, this rural exodus can be accompanied by family and cultural trauma.

2.4 The constraints of hydraulic and hydrological modelling

The analysis of these issues in order to identify solutions requires an understanding of the causal links between hydro-agricultural developments and the role of flood control, as well as between the development of merjas and the improvement of their self-purifying role. One way of understanding the complexity of these relationships is to model them. This modelling provides a basis for discussion with the stakeholders involved (institutions such as the ORMVAG and the ABHS and civil society, including farmers) and should also make it possible to simulate scenarios of hydro-agricultural and merja development in order to assess their impact on the risks associated with flooding (essentially economic) and pollution (essentially health and environmental, i.e. reduction of biodiversity and of the associated ecosystem functions). The main difficulty in this approach is related to the intrinsic characteristics of sedimentary plains, which are well illustrated by the Gharb plain.

Topography

To assess the flood control and self-purification functions of the merjas, the hydraulic functioning of the Gharb plain needs to be characterised. This requires a precise knowledge of its topography in order to evaluate the direction of the flows in the plain as well as the water storage capacity of the depressions (merjas) and their filling and emptying dynamics. Given the very small variations in elevation, the uncertainties in altitudes provided by digital field models can be limiting (Mukherjee et al. 2013) and lead to significant errors (Minderhoud et al. 2019; Kulp and Strauss 2019).

There are two alternatives. The first is to use a digital elevation model adjusted for use in coastal areas (Kulp and Strauss 2018). The second is to map the flooded areas using satellite images in order to assess the small topographical variations. LiDAR flights would also be possible, but expensive, given the very large area of the plain. One solution could be to select a single merja and measure the inflow and outflow directly on site using measuring instruments (barometric probe, for example). However, the terrain is so flat that the micro-irregularities make it impossible to measure inflows and outflows accurately. Measurements in a sanitation canal crossing the merja might prove to be the best option.

Hydrology

Important information needed to understand the dynamics of the overflows is missing: What is the flow rate of the spillover as a function of the Wadi Sebou's level at each overflow point? There are also the overflows of the small wadis with intermittent flows coming from the south and flowing directly into the central area: the Wadis Canal Tihli, R'dom, Canal Hamma, Canal Beht, Twirsa, Tiflet and Smento. Some of these wadis have been channelled into the merjas in order to increase their drainage but overflow therein during flood periods.

While most of the floods in the Ghrab plain are caused by the highwaters of the Wadis Ouergha, Sebou and Beht, they are also caused by the main uncontrolled tributaries which should be taken into account. Indeed, the flooding history highlights flooding problems linked to these wadis, which can occur without there being flooding due to the major wadis; this was the case, for example, with the flood of 2003. This double variability therefore has consequences on the distribution of water resources in the plain and complicates the modelling of these inflows to estimate the impact of hydro-agricultural developments on floods.

Hydraulics

An additional factor that complicates the modelling, related to topography, is that the direction of the slope of the drainage channels is necessarily opposite from the natural slope within the merjas since their function is to empty them. A modelling of this system should therefore take this structure into account by basing itself not only on an accurate digital elevation model (for the natural slopes), but also on topographic measurements of the sanitation network, which exist within the ORMVAG.

These topographical, hydrological and hydraulic difficulties have been circumvented by using satellite imagery, as presented in the third part of this report.

2.5 Governance

National scale

The national strategies currently being implemented by different Moroccan ministries have generally been developed independently of one another:

- The National Water Strategy developed by the Directorate General for Water (DGE) and adopted in 2009;
- The National Water Plan, currently being finalised and also under the responsibility of the DGE, which sets out the strategic guidelines on which the Integrated Water Resource Development Master Plans are based;
- The National Shared Sanitation Plan (Plan National d'Assainissement Mutualisé, PNAM) of the Ministry of the Interior.

There is a therefore a risk that a consensus will not be reached in their implementation and on the prioritisation of objectives for environmental preservation. Such a divergence between the different institutional actors would slow down the development of the floodplains.

On the scale of the Gharb plain

At their beginnings, the ABHS and ORMVAG were respectively involved in the management of water supply and demand, essentially focused on its agricultural use, and characterised by convergent interests. The more recent diversification of the water sectors (hydroelectricity, drinking water, industry, agriculture) combined with the more restrictive regulatory framework of law 36-15 on water, have modified this bipartite relationship by introducing a market economy. The ABHS must now arbitrate between the demands of the different sectors and allocate the resources in accordance with socio-economic constraints: profitability and priority to the production of drinking water.
Other regulatory imperatives, such as the polluter pays principle, involve 'aggregator' businesses such as sugar factories that contract with sugar beet and cane farmers. The latter benefit from production equipment, particularly in the merja areas where sugar beet and cane crops are those best adapted to excess water. In return, they undertake to sell their harvest to the sugar company that contracted them. There are also other stakeholder groups such as the agricultural water users' associations, members of the ABHS board that lobby for the ORMVAG. In addition, farmers' associations shape the agricultural landscape through their choice of crops and investments to be made.

The ORMVAG, the ABHS and the above-mentioned ministerial departments are in charge of regional plans which are regional versions of the strategies developed at national level. Although the environment is central to these different strategies, it does not systematically federate them due to the relative independence of the ministerial departments, which design them separately.

Moreover, the floodplains are currently used by the local populations (agriculture, grazing, etc.) and no solution can be envisaged without their involvement and participation. The main challenge is therefore to bring all of these stakeholders together to find compromise solutions. Addressing this issue on the scale of the Gharb plain can be envisaged through a coordination effort to ensure the participation of all of the stakeholders concerned in each project development phase.

3. CONCLUSIONS

As ecological awareness grows, the beneficial roles of merjas are being newly recognised: protection of ecosystems (biodiversity reserve and natural purification of contaminated water), provision of services to farmers in summer (pastoralism, off-season cultivation on wet soil) and in winter (storage of flood water, moderation of floods and protection of irrigated schemes and urban areas). The merjas are multi-use living areas that provide a heritage link. Their multifunctionality varies depending on their hydraulic connections with the wadis, irrigated/drained schemes and underlying aquifers. Often vegetated, they also contribute to providing ecosystem services of flood regulation, purification and biodiversity support. Several factors influence the multifunctionality of the merjas and sanitation networks: i/ the proximity of farms and urban centres, which generate agro-economic opportunities but are also responsible for pollution, ii/ the land tenure status of these merjas regulating their use, iii/ national strategic orientations such as the National Irrigation Water Saving Programme.

Understanding and characterising these interactions and their processes should make it possible to identify the merjas' roles as nature-based solutions and to consider their enhancement through a new ecological engineering with the ambition of identifying low-cost interventions that guarantee the sustainable provision of ecosystem services.

PART II: ECOSYSTEM SERVICES OF THE MERJAS

This part essentially reproduces the work carried out by Hajar Choukrani as part of his doctoral thesis and published (Choukrani et al. 2022). Its objective is to reveal the multiple views on merjas through a reading of the ecosystem services they provide.

1. INTRODUCTION

Through their biodiversity, water resources and natural capacity to store runoff and capture carbon, wetlands provide people with many services. However, these functions have long been overlooked, especially with agricultural development aiming to maximise productivity without a vision that is long term or on a territorial scale. It is thus estimated that on a global scale, 64% of the world's wetlands have disappeared since 1900 (Ramsar, 2015), mainly due to their drying out, resulting in the loss of certain associated functions (MEA, 2005). Nowadays, with the growing ecological awareness in the face of environmental degradation related to global change, the ecosystem services of wetlands are being considered attentively (Were et al., 2019).

'Merjas are low-lying areas that can temporarily or permanently retain runoff, flooding and rainwater over part of their surface' (Le Coz, 1964: 99). Historically, these wetlands, locally known as 'merjas' and often malarial, were perceived by developers as unproductive spaces and unhealthy environments (Sajaloli, 1996). They were nevertheless used by local populations: at the beginning of the 20th century, merjas were considered by the local communities mainly as grazing areas. This was not appreciated by the colonial administration which saw this as a source of land tenure tensions. The literature (e.g. Le Coz, 1964) reveals the conflicting views that existed between the semi-nomad and the coloniser at the time, and which, as we shall see, persist today between the local communities and the State.

The occasional floods have left their mark on the minds of developers, reminding them of the high risk of flooding in the Gharb plain. Some 135 000 ha were flooded in 2010, causing tremendous damage (FAO and MAPM, 2010). This flood revealed the importance of the merjas as buffer zones to preserve developed areas and the city of Kenitra (FAO and MAPM, 2010). It therefore appears that the ecosystem services are not all provided at the same time and that some are occasional.

Although merjas play several roles, until now, the term 'ecosystem services' had never been attributed to them, but the benefits they provide have often been discussed (Le Coz, 1964). Generally speaking, 'ecosystem services are the benefits that people obtain from ecosystems' (MEA, 2005). Conversely, ecosystem disservices are 'the functions, processes and attributes generated by the ecosystem that result in perceived or real negative impacts on human wellbeing' (Shackleton et al., 2016). This study aims to explore which ecosystem services are attributable to the merjas of the Gharb plain, to identify the actors concerned by these services, and to analyse how these services vary over time and space.

Wetlands are generally recognised as providing certain ecosystem services: regulating services (climate, pollution, flood risk), provisioning services (food, fibre, fuel and water), cultural services (education, spiritual values and recreational),

Figure 9. Central merjas of the Gharb plain. Source: Choukrani et al (2022)

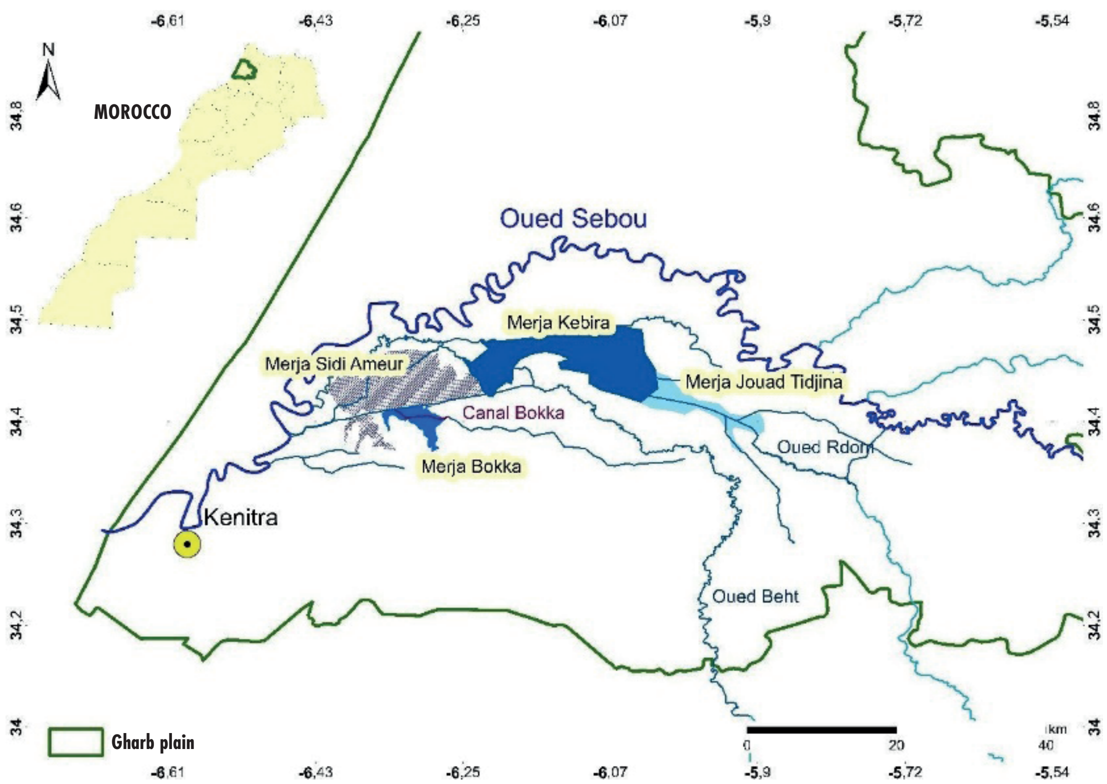
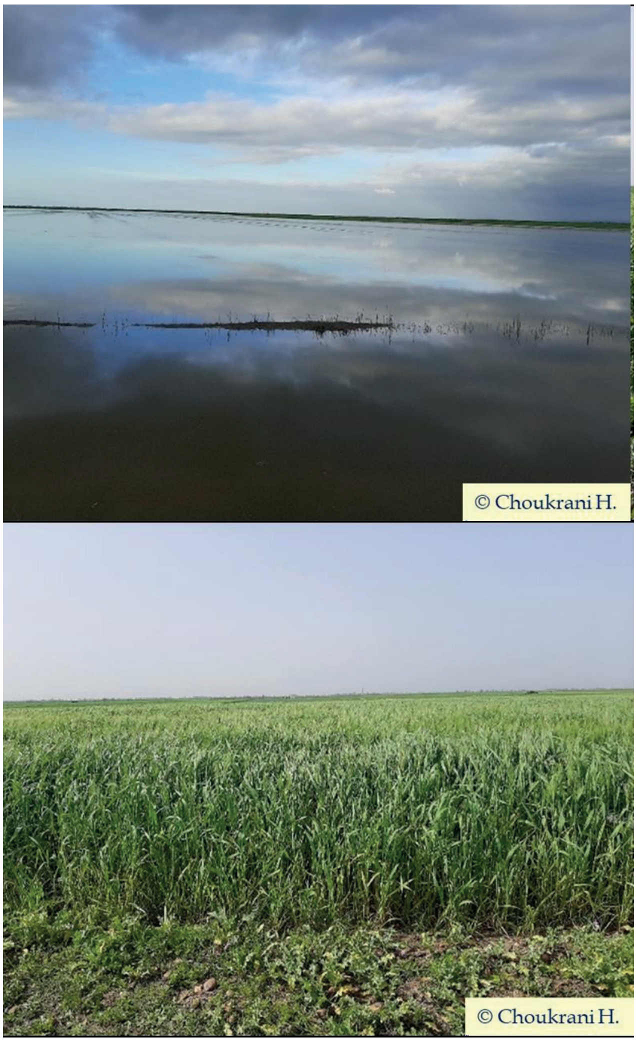


Figure 10. Merja Kebira (a) flooded in winter, (b) cultivated in summer



and supporting services (biodiversity, soil fertility) which are necessary for the production of the previous three categories of service (Kull et al., 2015; Neang and Méral, 2021).

2. SITE OF THE STUDY

The study focuses on the central merjas of the Gharb plain: Sidi Ameur, Kebira, Jouad Tidjina and Bokka (Figure 9). Most of the merjas, apart from the 12 000 ha converted into irrigated rice fields over the whole plain during the first irrigation phase in the 1970s, remain in their natural state because of development difficulties due to the flooding risk and their hydromorphic clay soils. They are nevertheless connected to the sanitation network. The first three merjas are used by the local communities and tenants for farming, but it is considered that they are undeveloped and should be subject to future development by the ORMVAG. Merja Jouad-Tidjina is mainly supplied by the overflows of Wadi Rdom (Figure 9). This merja has an outflow canal which channels the flood waters towards Merja Kebira and Merja Sidi Ameur. The water from each flood generally stays for less than two days, allowing it to be cultivated in winter. The Sidi Ameur and Kebira merjas retain water for long periods. This water comes from the overflows of the Rdom and Beht rivers or from local rainfall. After emptying, these merjas are cultivated in spring and summer (Figure 10). Merja Bokka has a deeper basin than the other merjas and stores more water (Le Coz, 1964).

The expanses of the merjas are difficult to determine and correspond approximately to the area flooded during highwater. Although the actual limits of the merjas vary (Table 1) depending on the extent of the flooding (Célérier, 1922; Le Coz, 1964), the delineation used in this study corresponds to the limits used by the ORMVAG. It combines a hydrological and land approach. After the drainage works (see Part I), the Sidi Ameur, Kebira and Jouad Tidjina merjas were classified as being under to the State's private domain, with in principle one third of the area allocated to riparian communities (collective third) and two thirds placed at the State's disposal for allocation. Merja Bokka has been maintained in the State's public domain.

Table 1. Area of the central merjas of the Gharb plain in hectares

Merjas	(Célérier, 1922)	(Le Coz, 1964)	ORMVAG (no date)
Sidi Ameur	19 000	3 020	6 900
Kebira		12 320	9 581
Bokka		1 600	NA
Jouad Tidjina	NA	4 730	5 300

(NA: not available)

3. METHODOLOGY

Field observations and semi-structured interviews were carried out to identify the actors concerned by the merjas, to clarify what they consider to be the spatial boundaries of the merjas and the regulatory framework that governs them, to understand their perception of the different ecosystem services of the merjas and the uses associated with them, and to analyse their discourses and practices. Several categories of actors were targeted: farmers, institutions responsible for water, agricultural and environmental management, institutions responsible for land tenure management and an NGO involved in environmental protection.

3.1 Surveys of farmers

Interviews were conducted between February and July 2021 with 92 farmers whose land or part of their land is located in the four merjas. A snowball sampling method, which is practiced in qualitative research, was used to progressively build a network of social relationships where the first respondents engaged other respondents in the study. The interviews focused on the role of the merjas in the functioning of the farms, agricultural practices and the characterisation of ecosystem services. Due to the farmers' unfamiliarity with the concept of ecosystem services, these were translated into benefits associated with the different uses of the merjas.

Figure 11. Land use of the central merjas. Source: Choukrani et al (2022)

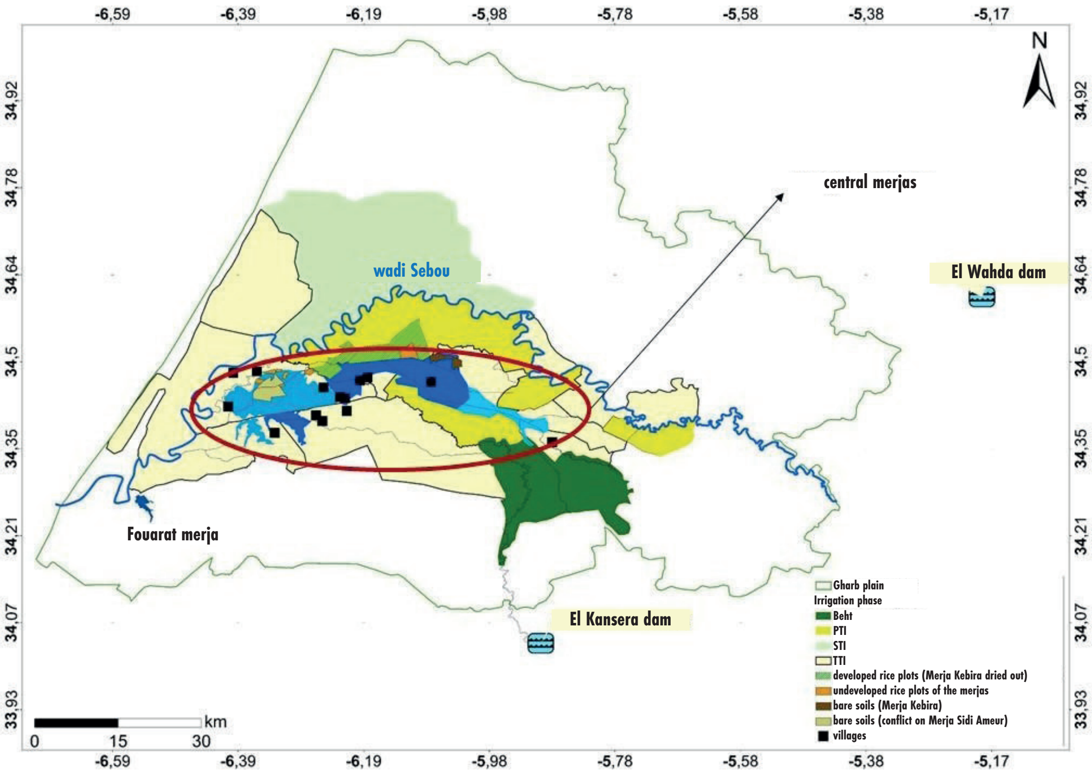
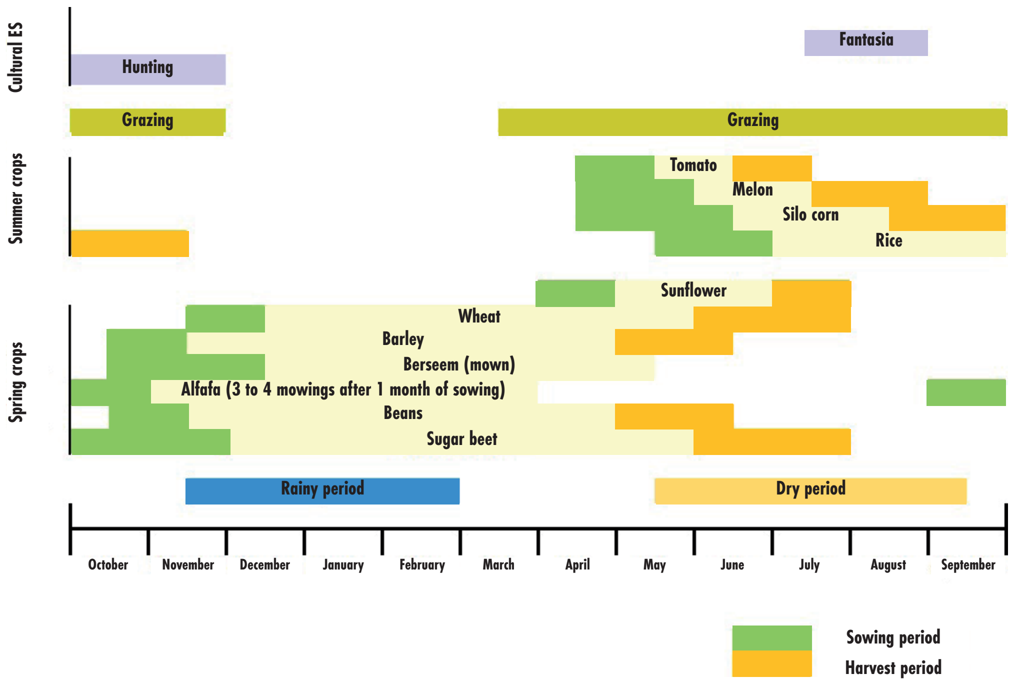


Table 2. The multiple ecosystem services (ES) mentioned by the stakeholders surveyed

Categories of actors	Sub-categories of actors	No. of surveys	Provisioning ES						Supporting ES		Regulating ES	Cultural ES		
			Livestock	Rain-fed crops	Irrigated crops	Bee keeping	Rangeland	Agricultural revenue	Soil fertility	Biodiversity	Flood control	Fantasia	Hunting	Attachement
Farmers	Merja Sidi Ameur	47	0,85	0,57	0,68	0,11	0,62	0,89	0,83	0,13	0,06	0,43	0,28	0,57
	Merja Kebira	20	0,75	0,4	0,9	0,1	0,45	0,75	0,7	0,65	0,10	0,15	0,4	0,65
	Merja Jouad Tidjina	23	0,78	1	0,35	0	0,17	0,87	0,83	0	0	0	0,17	0,26
	Merja Bokka	2	0,5	0	1	0	1	1	0	1	1	0	1	0
Ministry of the Interior (caïdats of the rural local authorities)	Merja Sidi Ameur	4	0,5	0,75	0,75	0	0,75	0,75	0,75	0,25	0,25	0,75	0,25	-
	Merja Kebira	3	0,33	0,67	0,67	0,33	0,33	0,67	0,33	0,33	0,33	0,33	-	-
	Merja Jouad Tidjina	3	0,33	1	0,33	0	0,33	0,33	-	0	0,67	0	0	-
	Merja Bokka	2	0	0	0	0	1	0	-	1	-	0	1	0
	Directorate of Rural Affairs	2	-	-	-	-	-	-	-	-	-	-	-	-
Ministry of Finance	Delegation of Domains of Kenitra	1	-	-	-	-	-	-	-	-	-	-	-	-
Agricultural institutions	ORMVAG (except Merja Bokka)	5	0,4	0,4	0,2	0	0,6	-	0,2	0	0,6	0	0	0
	FNIR	3	0,67	1	0,67	0	0,67	1	0,67	0,33	-	0,33	0,33	0,33
Hydraulic institution	Department of Water	2	-	0,5	0,5	-	0,5	0,5	0	-	0,5	-	-	-
Other institutions	Directorate of Water and Forests of Kenitra	2	0	-	-	-	-	-	-	0,5	-	-	1	-
	Environmental association	1	-	-	-	-	-	-	-	-	-	-	-	-

Figure 12. Crop calendar and other uses of the central merjas of the Gharb plain (cultural ES = cultural ecosystem services). Source: Choukrani et al (2022)



Stakeholder perceptions of each ecosystem service were quantified as follows: the number of times an ecosystem service was mentioned by each type of stakeholder was converted into a ratio (number of mentions divided by the number of respondents in a socio-professional group) (Table 2) and plotted in radar charts to compare stakeholder perceptions of the ecosystem services of the merjas.

3.2 Institutional surveys

Semi-structured interviews were conducted with 28 institutional actors on their perceptions of the ecosystem services of the merjas, the problems associated with their use and their vision of the future of the merjas. The institutions concerned were: the ORMVAG, the National Inter-professional Rice Federation (Fédération Nationale Interprofessionnelle du Riz, FNIR), the Delegation of Domains (Délégation des Domaines) of Kenitra (Ministry of Finance), the Directorate of Rural Affairs of Kenitra and the caïdats of the rural territorial collectivities (Ministry of the Interior), the Kenitra Directorate of Water and Forests, the Department of Water in Rabat, and an environmental association involved in the fight against urban pollution of Merja Fouarat (Figure 11).

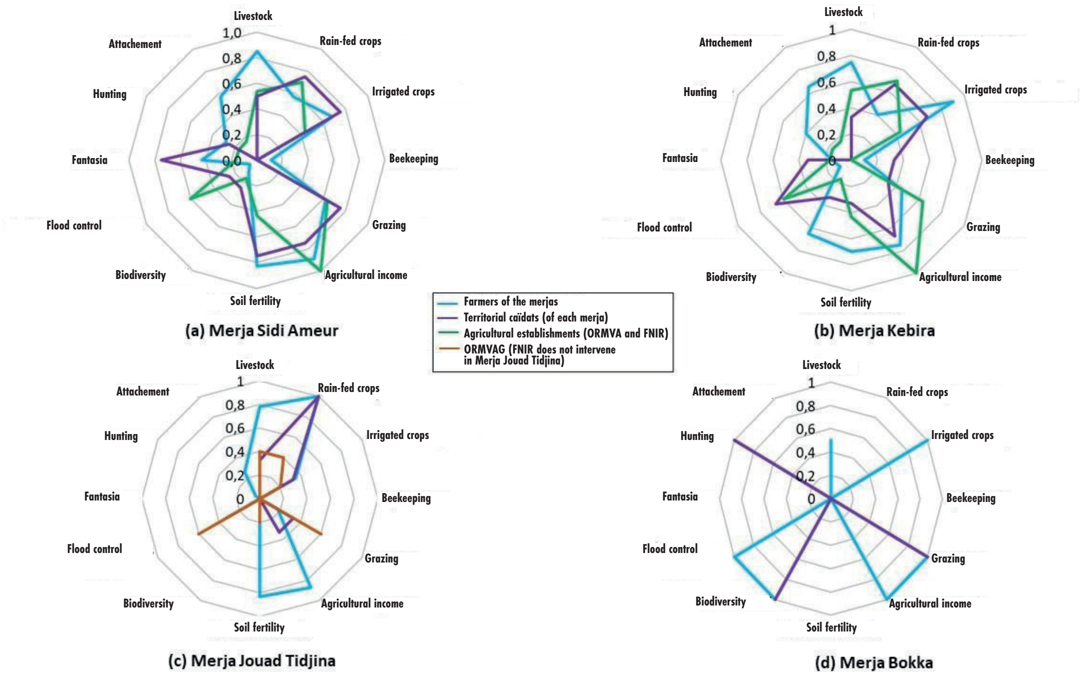
4. RESULTS

4.1 Plant production service

The Sidi Ameur, Kebira and Jouad Tidjina merjas are not formally part of the developed area and are used by the residents of the local communities.

In winter, rain-fed crops (sugar beet, wheat, barley, berseem) benefit from the autumn and spring rains but are exposed to waterlogging during rainy periods on the one hand, and to flooding due to highwater on the other. Sugar beet is cultivated by farmers who have more than 5 ha (6% of the farmers surveyed). Their produce is sold to the Dar El Gueddari sugar factory. The farmers whose land is exposed to excess water would like better protection of their plots against flooding but have developed practices to manage this risk: in the event of waterlogging, wheat is not harvested but mowed and used as fodder for livestock, showing the complementary nature of the crop-livestock association. The use of catch-up crops in spring (sunflower) if winter crops fail is a widespread practice. Some irrigated crops such as alfalfa are also grown in the rainfed system and then replaced by rice or other irrigated crops in summer (Figure 12).
In summer, the water supply to crops (melon, tomato, artichoke, corn, rice) comes exclusively from irrigation. These irrigated crops are above all present in the Sidi Ameur and Kebira merjas where some farmers have access to sanitation canals that convey water from the developed rice fields (Figure 11). Other farmers, often tenants providing the necessary capital, have set up boreholes of up to 120 m in the deep water table as the upper aquifer is salty. More than 2 000 ha of Merja Kebira were developed into rice fields in the 1970s (Figure 11). In addition, 1 000 ha of rice-growing areas not developed by the ORMVAG are managed by the FNIR in part of the Sidi Ameur and Kebira merjas. The drainage water from the developed rice-growing areas, which are supplied by the ORMVAG, provides water to the rice fields in the undeveloped areas (Figure 11). According to a member of the FNIR, the rice theoretically needs to be drained three to four times per cycle (whether in areas developed by the ORMVAG or not), with the volume of water of each drainage being approximately 2 000 m^3/ha. The farmers are responsible for levelling and installing the irrigation network.

Figure 13. Ecosystem services according to the riparian communities and institutional actors, (a) Merja Sidi Ameur, (b) Merja Kebira, (c) Merja Jouad Tidjina, (d) Merja Bokka. Source: Choukrani et al (2022)



Whether they are developed or not, the rice fields create agricultural jobs for more than 6 months/year and industrial jobs with an estimated added value of 200 million dirhams (approximately €18.5 million in Oct. 2022) (Moinina et al., 2018). The rental of rice land to farmers, who may or may not belong to the community (1 000 ha in total for amounts of 2 500 to 3 000 dirhams/ha/year) is an appreciable source of income for the owner-farmers. In addition, women in some douars sell compost from the merjas (crop residues) to farmers growing high value-added crops in the irrigated schemes, thus generating a modest income.

The surveys highlight difficult access to water for farmers of the merjas, particularly due to their lack of development. This is the case of Merja Jouad-Tidjina. Access to water resources in summer is limited because the canals are not supplied by the ORMVAG. Indeed, the observations show a large area of bare soil in summer. A more regular supply by the ORMVAG would improve the agricultural development of the merjas.

4.2 Animal production services (livestock, grazing and beekeeping)

According to the farmers, livestock, which is profitable and less exposed to flood risks, is their main activity in the merjas. For sheep-cattle breeding, berseem (Alexandria clover) is cultivated after rice and used as fodder. The surplus is sold to neighbouring villages. Farmers with large herds move to graze on the uncultivated land of the central merjas (Figure 11), such as the 1 200 ha of Merja Sidi Ameur where the State has prohibited cultivation since 2005 due to unresolved land issues. The local communities want to reserve this land for their own farmers whereas the State wants to rent it to other farmers. Some villagers set up beehives in the isolated areas of the Sidi Ameur and Kebira merjas, taking advantage of the presence of catnip (nepeta cataria) which is an aromatic plant

4.3 Biodiversity and hunting

Biodiversity is linked to the water regime (El Blidi et al., 2006) but is not mentioned by the local communities or institutional actors as an important feature of the merjas (Figure 13). Some members of the local communities mentioned various migratory birds that shelter in the merjas (in winter and spring) and rice fields (in summer). These birds are hunted, which can be presented as a recreational service. Woodcocks, storks and white herons have been observed, especially in the rice fields. Given the temporal nature of the floods, the regression of their hygrophilous vegetation since they were drained, and their integration into the ORMVAG's development project, neither the environmental association surveyed nor the Water and Forestry Department attach importance to the biodiversity of the merjas.

Merja Bokka is a special case due to its floral biodiversity. In 1952, a request to classify this merja as a botanical and zoological reserve was unsuccessful (Sauvage, 1959); instead, the merja is considered a Site of Biological and Ecological Interest (SIBE). However, it scarcely attracts attention from ecologists or environmental institutions. According to the Central Clearing Mechanism on Biodiversity of Morocco (CHM, 2006), Merja Bokka has lost its floristic richness: 'Until recently, this merja was home to an abundant and very rich flora fully representative of the aquatic flora of the Gharb, which has now disappeared due to the systematic draining of the merjas…'. Merja Bokka receives less and less water, giving way to agricultural activities marked by the use of pesticides that threaten the aquatic ecosystem

(Flower, 2001). However, agricultural activities and hunting are prohibited as it belongs to the public domain of the State. It is used as a grazing area and there are some informal agricultural plots.

4.4 Ownership and attachment: cultural service

The sense of belonging and attachment to the merjas of members of the riparian communities is an important cultural service. During the devastating flood of 2009-2010, the inhabitants of the flooded villages were moved to new villages in protected locations. However, some of them decided to move back near to their merja lands, thus affirming their strong connection to them despite the risks incurred during rainy episodes. According to the respondents, the merja lands provide a sense of autonomy and freedom which is not felt by farmers in the public scheme who are accountable to the public authority, often indebted and obliged to take water turns.

The riparian communities also practise Fantasia, an equestrian tradition in Morocco, in the merjas once the water has receded. They train and organise a festival in summer. This is not a cultural service exclusive to wetlands but the communities take advantage of the flat, crop-free spaces in summer.

4.5 Stakeholder perceptions of merja ecosystem services

The farmers expressed an interest in provisioning ecosystem services, particularly agricultural production in the Sidi Ameur, Kebira and Jouad Tidjina merjas (Table 2). For Merja Bokka, the low number of active farmers is explained by the prohibition of growing crops in it.

The specific interest in livestock or agriculture varies across the merjas as shown in Table 2 and Figure 13. In Merja Jouad Tidjina, the farmers are particularly interested in rainfed crops and livestock, while irrigated crops are mentioned much less despite their observed but limited existence. This can be explained by the fragmentation of the land resulting in small plots, which are considered unsuitable for irrigation, and by the difficult access to water. On the contrary, in Merja Kebira, 90% of the farmers irrigate their crops. Within the farmer groups, there is a dichotomy between large-scale farmers who are interested in irrigating crops and small-scale farmers who cannot afford to access irrigation water due to the prohibitive cost of drilling a well or the fees for accessing water from irrigation canals, and who content themselves with rainfed agriculture.

With regard to the institutions, their interest in provisioning ecosystem services differs. While the ORMVAG considers the merjas to have low productivity, the FNIR is very interested in them, particularly for rice cultivation in the Sidi Ameur and Kebira merjas. The other institutions show a lack of knowledge of agricultural production in the merjas, with the exception of the caïdats of the riparian communities which have a vision fairly close to that of the farmers for the Sidi Ameur, Kebira and Jouad Tidjina merjas (Figure 13). The person interviewed at the water department in Rabat considers the merjas as a buffer zone for floods, but as a native of the area, he is also aware of their agricultural use.

The first support service mentioned is that of fertility, linked to the deposit of sediments during floods. With regard to biodiversity, 23% of the farmers consider it as a cultural ecosystem service as it allows hunting (Table 2). Farmers in Merja Bokka reported the presence of several bird species when it is flooded in winter. For the Sidi Ameur and Kebira merjas, 13% and 65% of farmers respectively mentioned the presence of birds in the rice fields in summer, which is considered a disservice as it harms their production (Table 2). The high percentage in Merja Kebira is explained by the presence of large rice fields.

4.6 Conflicting perceptions of farmers and institutional actors

Flood control

Farmers' perceptions:

Flood control was only mentioned by seven of the 92 farmers surveyed (Table 2), who described the merjas as 'large reservoirs' that hold back the waters of the Wadi Sebou and its main tributaries: the Beht and the Rdom. However, they perceive this regulating function as a disservice that harms agriculture when the soils are waterlogged, and threatens their lives in the event of catastrophic floods such as those of 1973, 1996 and 2010, which are engraved in their memories.

Farmers are aware of the hydrology of the merjas: 'the merja is a reservoir' or 'the rivers disappear into the merjas' are common expressions. But according to them, the merjas are above all fertile land, even if they are marginalised by developers. They believe that the water should be 'gotten rid of' as it causes waterlogging (59 mentions out of 92 farmers), makes their plots inaccessible, hinders their agricultural activity, leads to drops in yield and can threaten their lives. They stated that the so-called 'buffer zone' is a disservice and that external drainage and sanitation solutions should be undertaken to alleviate this problem. In addition, the tracks are in a deplorable state, which often prevents intermediaries from buying directly from the farms.

Agricultural production takes precedence for the local communities. One farmer from Merja Sidi Ameur responded, 'It is no longer a merja, we can cultivate this land', feeling that the term merja had a pejorative connotation of stagnant water. For the riparian communities, the merjas have been made productive thanks to the setting up of dams and the sanitation network, which, in addition to allowing irrigation in the developed areas, helps to reduce the risk of flooding in the lowest undeveloped areas, allowing them to cultivate them and have an agricultural income. However, these merjas remain impracticable if there is a lot of rain: 'It has to rain a little, below normal, to ensure our production', according to a farmer from Merja Kebira.

Institutional perceptions: the merjas are low productivity buffer zones. The water and agricultural management institutions interviewed consider the merjas to be undeveloped land outside the irrigated scheme. After more than a century of development, the institutions believe that their development can cause many problems. According to the interviewees, these agricultural areas have limited productivity and their complex legal status is a source of conflict. For the water department, the merjas mainly serve to retain excess water in winter. They could be considered as buffer zones for flood control. This perception was reinforced by the 2009-2010 floods, when water accumulated in the merjas creating a flood corridor (Figure 7). This view runs counter to the development proposals long promoted by the ORMVAG to improve the drainage of the merjas to facilitate cultivation. Indeed, as shown by NOVEC (2012) based on the hydraulic modelling of the plain, such an intervention would reduce the flood control capacity of the merjas.

Cultural services

Farmers' perceptions: Cultural ecosystem services are mentioned by the farmers and to a lesser extent by the caïdats (Table 2, Figure 13). Fantasia, hunting and a sense of attachment are expressed by farmers from riparian communities. These cultural ecosystem services are overlooked by the institutions.

Institutional perceptions: Brichambaut's work in the 1950s highlighted the presence of plant formations specific to the merjas (ranunculus, reeds, bulrushes, rushes (Le Coz, 1964), used by local people to build habitats or make mats. However, the works to dry out these areas have led to the degradation or even disappearance of this flora (CHM, 2006). The merjas' biodiversity support service is no longer considered as such by the stakeholders, including the environmental association and the Kenitra Water and Forestry Department. These stakeholders give more importance to permanent wetlands such as Merja Fouarat. Even Merja Bokka, although a site of biological and ecological interest, is now considered a dried out merja that has lost its floristic richness.

5. DISCUSSION AND CONCLUSION

This study has shown contrasting views of the benefits provided by merjas. Considered by local residents as agricultural land when drained, they have put in place agricultural practices adapted to a specific edaphic context. They want to be better protected from floods in winter and to benefit from irrigation water in summer. Although the merjas are officially still considered as future areas to be developed by the agricultural and water management institutions, in practice, this ambition is fading. These institutions consider the merjas as potential buffer zones in winter to protect the developed areas and the city of Kenitra from flooding risks. While they believe that their agricultural development can be improved by non-resident tenants in summer, who have greater financial means than the riparian farmers, allowing them to rent larger areas and equip them with boreholes for irrigation (during this period there is no risk of flooding), the riparian farmers are opposed to the arrival of farmers from outside their communities, favouring their own. The local residents are currently claiming greater access to merja land, beyond what the State allocated them in the context of the 'melkisation' of the land. Melkisation, governed by law no. 64.17, is a process that aims to transform the undivided ownership of collective lands located in irrigation schemes into private properties of five hectares (minimum area for farming).

This analysis from an ecosystem services perspective reveals conflicts and contradictions in the planning of merja use and development (Seijger et al., 2016). These differences in appreciation are the result of the history of this environment, which has been marked by conflicts and controversies. In winter and spring, a modus vivendi has been found with a de facto halt to development by the State and cultivation by the local residents, which is only disrupted when there are very large floods. In summer, the absence of an irrigation network complicates the use of the space. The emerging demand is for water supply to allow more intensive use. This new access to the resource could be achieved through new boreholes or the construction of new irrigation canals connected to the existing network.

In her analysis of cultural ecosystem services, Fournier (2020) emphasised that a territory is an extension of the people who live there. While the riparian communities and agricultural and water management institutions focus on their agricultural interests and protection against flooding, the ecological and cultural dimensions still play very little part in the debate on the future of the merjas. They remain invisible to all of the actors. The environmental institutions probably do not take the merjas' biodiversity into account because they are no longer frequently filled with water. The ecosystem services claimed by some stakeholders are generally not shared by the others, and the agricultural institutions underestimate the riparian communities' agricultural use of the merjas. Other ecosystem services appear on the radar chart in an ad hoc manner. For example, water institutions only take account of the merjas when heavy flooding occurs and mention their regulating function. However, this same regulating function is considered a disservice by the riparian communities.

PART III: HYDROLOGY OF THE GHARB PLAIN

1. INTRODUCTION

Part I of this report revealed the contrasting views of farmers and institutional actors on the merjas, which are considered by the former as floodable agricultural land that needs to be drained, and by the latter as buffer zones for the control of floods reaching the outlet of the plain. In this context, the hypothesis formulated is that the merjas, by temporarily storing the overflowing waters of the Wadi Sebou, then restoring them to the wadi downstream, curb the flood peaks and thus protect the city of Kenitra located downstream.

The initial objective of the hydrological analysis, presented in this third part, was to model the hydraulic and hydrological functioning of the Gharb plain in order to simulate the effects of different development scenarios for the merjas with regard to their flood control function. This modelling was envisaged as a support tool for the discussion of different development scenarios with the stakeholders involved (ORMVAG, ABHS, civil society, farmers). However, the modelling exercise proved to be very difficult to implement for several reasons:

- **Topography:** The modelling of the Gharb plain requires precise knowledge of its topography in order to assess the direction of the flows, the storage capacity and the filling and emptying dynamics of the depressions (merjas). The very slight variations in altitude (slopes < 0.1%) combined with the vertical accuracy of digital elevation models (DEMs) exceeding one metre, do not allow for such characterisations (Mukherjee et al. 2013) and can lead to significant errors (Minderhoud et al. 2019; Kulp and Strauss, 2018, 2019).
- **Hydrology:** We were unable to collect data on the flow rate or water height in the Sebou basin, which would have been necessary in particular to anticipate the periods of overflow of the Ouergha, Sebou and Beht wadis in the plain. Recent history shows that flooding can also be caused by the inflows from small wadis coming from the southern slopes that flow directly into the plain, as well as by local rainfall. The multiplicity of these contributions complicates modelling in the absence of data.
- **Hydraulics:** As the direction of the slope of the drainage channels is necessarily opposite from the natural slope within the merjas, since their function is to empty them, a modelling of this system should take this structure into account by not only using an accurate digital elevation model (for the natural slopes), but also topographical measurements of the sanitation network. The NOVEC consultancy firm (2012) undertook a hydraulic modelling of this system under the management of ORMVAG, but it seems that this modelling was not validated by a comparison with said measurements.

Given the difficulty of acquiring the hydrometeorological data necessary for this modelling, we opted for the analysis of satellite images. The choice of remote sensing is justified by the following points:

- The study area is vast;
- It is possible to quantify flooded surfaces and their temporal evolution through the calculation of spectral indices;
- The lack of knowledge on flow rates and volumes stored (due to the difficulty of estimating depths of run-off on satellite images) is not prohibitive insofar as the surface area of the flooded zone of a river or a stagnant water body is linked by an increasing function to its flow rate or volume, respectively. Studying the temporal variability of a flooded surface area therefore makes it possible to appreciate the temporal variability of the corresponding flow rate (watercourse) or volume (water body).

2. METHOD

2.1 Assessment of flooded surfaces

The flooded areas in the Gharb plain are estimated from the sentinel-2 satellite which offers a spatial resolution of 10 meters with a periodicity of approximately 5 days. The spectral MNDWI (modified normalised difference water index) is calculated at each pixel by the formula:

$$MNDWI = \frac{V - IR}{V + IRV}$$

V is the reflectance in the spectral band corresponding to the colour green (Sentinel-2 band 3). IR is the reflectance in the spectral band corresponding to shortwave infrared (Sentinel-2 band 11). The MNDWI is calculated for each satellite pass over the period of image availability (since 28/03/2017), and then the maximum value of the index on each pixel is used to form a composite image. Satellite images with a cloud cover above 30% are not taken into account, as well as pixels with a cloud cover probability exceeding 5%. These thresholds have been determined empirically in order to eliminate non-useable images while keeping a maximum of useful information.

This composite image is used to delineate polygons surrounding areas with MNDWI values above 0.2. This threshold value is considered satisfactory to distinguish flooded areas. These polygons therefore correspond to areas that have been flooded at least once since they have been traced on the composite image of the maximum values. The superimposition of this composite image of the maximum values of the MNDWI on a real colour satellite photo of the studied area makes it possible to identify the nature of these flooded areas (watercourses, merjas, irrigated areas, dam reservoir). To monitor the flow rate of the Wadi Sebou, several distinct polygons are traced on short reaches, integrating the maximum section and preferably where the flooded width varies the most according to the height of the watercourse. Identifying these areas is not simple and can be done by adopting a ‘try-fail-success’ approach. The multiplicity of these polygons on the Wadi Sebou makes it possible to see how hydrological variability evolves from upstream to downstream.

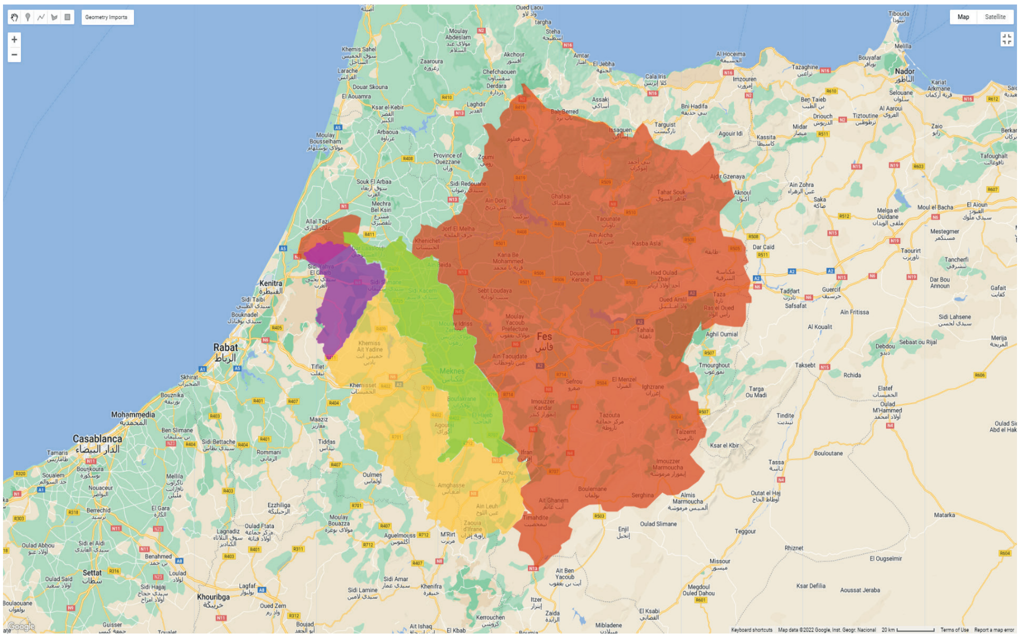


Figure 14. Google Earth Engine delineation of catchment areas. Sebou: red+green+yellow+purple. Rdom: green. Beht: yellow; Tiflet: purple. Central zone: orange

Chronicles of MNDWI values, calculated at each satellite pass and spatially averaged at the level of each polygon, are produced in order to monitor the temporal variability of the flooded surfaces in these areas. The frequency of the Sentinel-2 images for a given polygon (5 days) makes it possible to identify the periods of increase and decrease of the flooded areas, generated by rainfall events of one or two days. The spatial resolution of 10 meters enables work on small polygons whose dimensions correspond to those of the items being monitored. By way of example, the width of the Wadi Sebou is approximately 100 metres and a merja extends over several square kilometres.
The production of spectral index chronicles for different temporarily flooded areas also makes it possible to study the co-variations of these flooded areas using the correlation coefficient, and to deduce possible links of cause and effect (e.g. hydraulic connections between flooded areas) or common causes (e.g. rainy event at the origin of the flooding of two merjas that are not hydraulically connected). The interest of this approach lies in the fact that it does not require an assessment of the exact value of the flooded area of a given polygon at a given time (which is impossible if the spectral index values are not compared with field measurements). Indeed, the value of the correlation coefficient is not sensitive to the values of the correlated variables but only to their relative variations.

Compared to a conventional hydrological analysis based on field measurements (water level, rating curves), this approach has the advantage of not being spatially limited for the monitoring of temporal evolutions in spectral indices. It is thus possible to define as many polygons as there are temporarily flooded areas. Conversely, a hydrological analysis based on field measurements allows the precise measurements necessary for hydrological modelling or water balance calculations, but remains limited to the measurement sites initially chosen for the installation of the measuring devices.

The introduction of a time lag of one or more time steps between the two correlated series makes it possible to identify, through the presence of a maximum in the value of the correlation coefficient, the possible existence of a 'delay' effect in the causal relations identified (for example, a lag of a few days between the MNDWI peaks at the level of two polygons). This lag effect could reflect the time required for flow between two hydraulically connected areas subject to flooding.

The method previously described and applied to the MNDWI is similarly applied to the spectral NDVI (normalised difference vegetation index) allowing the monitoring of the temporal variability of vegetation and its correlation with the MNDWI. The NDVI is calculated as follows:

$$NDVI = \frac{PIR - R}{PIR + R}$$

NIR is the reflectance in the near infrared spectral band (Sentinel-2 band 8). R is the reflectance in the red spectral band (Sentinel-2 band 4).

2.2 Estimation of rainfall variability

Rainfall and its spatio-temporal variability is assessed using the CHIRPS product (Funk et al. 2015) which has been providing pentad (5-day) monitoring since 1981 with a resolution of 5 km. Rainfall is spatially averaged in the catchment areas of the Sebou, Beht, Rdom and Tiflet wadis, and in the central area where the merjas are studied. The resulting rainfall records are compared with those of the MNDWI spectral indices and correlation coefficients are calculated between these two variables. The objective is to verify whether the temporal variations of the flooded area in each merja and each developed area are correlated with local rainfall or that of a catchment area. In the second case, the flooding can be explained by an overflow of the wadi whose flow variations are influenced by the rainfall on its catchment area.

2.3 Processing the satellite images using Google Earth Engine

The algorithms for creating the composite images of the maximum MNDWI values and extracting the time series of spectral indices and rainfall are coded in JAVA on the Google Earth Engine (GEE) platform. The polygons (spectral index calculation areas) and catchment areas (rainfall calculation areas) are manually delineated by visual observation in GEE. Catchment area boundaries are identified using the hydrographic network detailed in the MERIT hydro tool (Yamazaki et al. 2019) and viewable in GEE.

2.4 Processing the spectral index and rainfall chronicles using Excel

The dates of the satellite passes are not always the same for all of the polygons. A complete (date-index) matrix is obtained by selecting all the observed passage dates for all of the polygons and then the gaps are filled by linear interpolations in each chronicle considered independently of the others.

In order to reduce interference related to residual errors on the wavelength values in the satellite products, the chronicles are smoothed out by means of a moving average calculated over three or five time steps.

3. RESULTS

Figure 15 and Figure 16 show the locations of the 48 MNDWI monitoring polygons, defined on the basis of the composite image. They are distributed as follows:

- 2 polygons to monitor the Idriss I and El Wahda dam reservoirs,
- 15 polygons to monitor the merjas,
- 4 polygons to monitor the Wadi Ouargha (upstream of the confluence with the Sebou),
- 1 polygon to monitor the Wadi Beht,
- 13 polygons to monitor the Wadi Sebou (reaches of approximately 2.5 km long),
- 11 polygons to monitor the developed areas,
- 1 polygon to monitor the oxbow of the Wadi Sebou near its guard dam,
- 1 polygon to monitor the tides of the Atlantic Ocean.

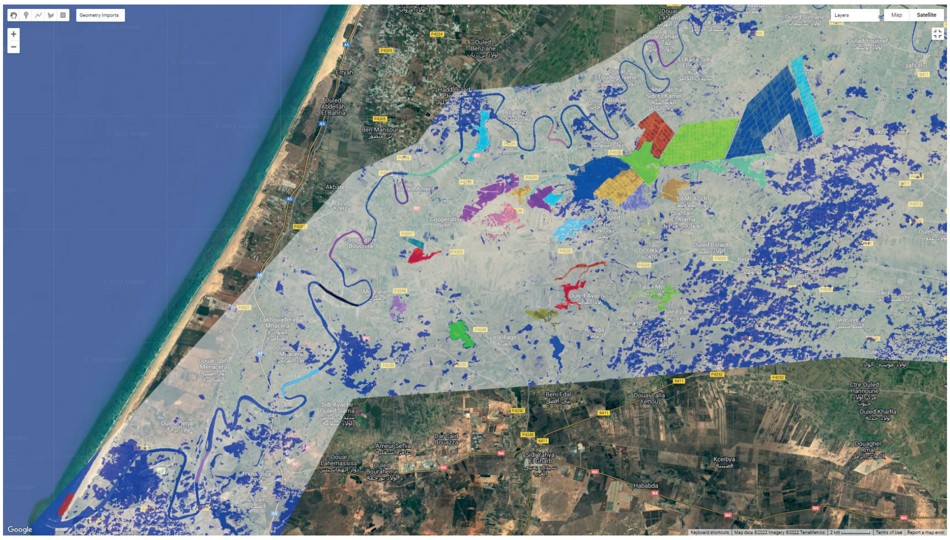


Figure 15. Composite image of the maximum MNDWI value over the period of availability of Sentinel-2 after cloud filtration, and delineation of the study polygons represented by different colours. Note: the cloud filtration is imperfect as shown in the composite image revealing cloudy fields.

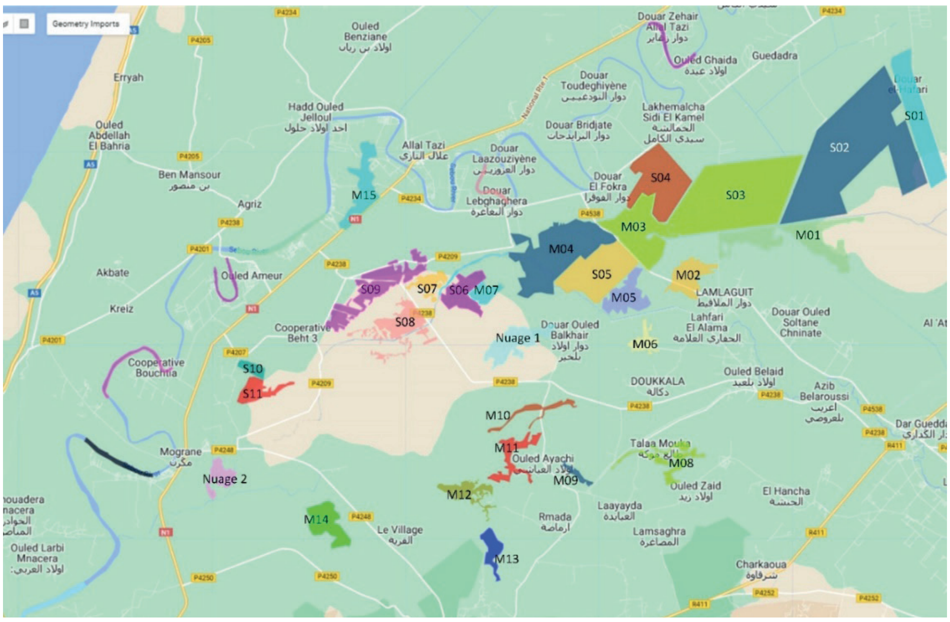
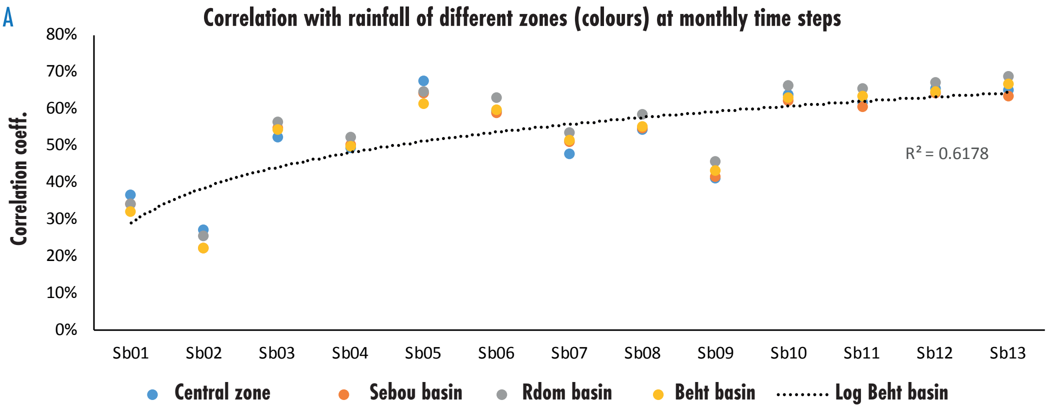


Figure 16. Identification of the merjas, numbered M01 to M15, and of the developed areas, numbered S01 to S11.

A



B

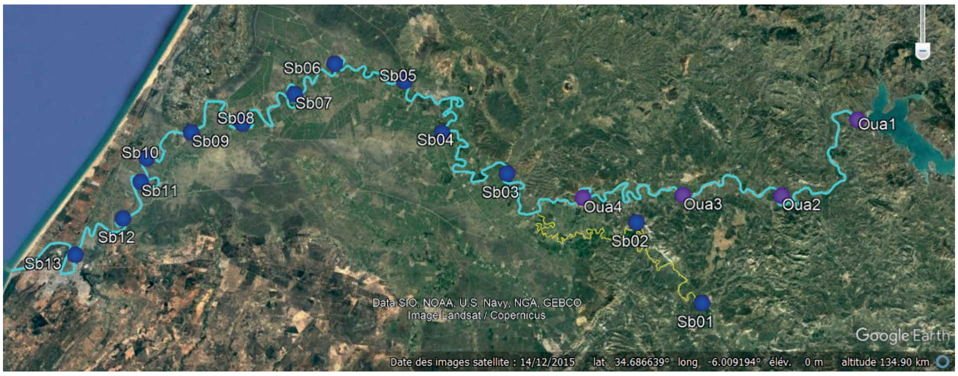


Figure 17. a: Variations of the correlation coefficient between the spectral MNDWI of the Wadi Sebou calculated at different points from upstream to downstream (Sb01 to Sb013) and the spatially averaged rainfall in different zones (4 colours indicated in the legend) spatially delineated on Figure 14).
b: location of the measurement points on the Wadi Sebou.

The NDVI is also calculated in the 15 merja polygons and the 11 polygons of the developed areas.

3.1 Validation of the method

Before analysing the extracted time series, their reliability is checked by comparing them in order to highlight coherences or inconsistencies.

Figure 17 shows the correlation coefficients between the MNDWI time series of the Wadi Sebou (calculated from upstream to downstream at the level of 13 polygons indicated on the map) and rainfall. The regression curve indicates that this correlation increases from upstream to downstream. This can be explained by the fact that the further downstream we go, the more the variability of the Sebou results from the integration of flows over a large area. This result helps to validate the method based on the hypothesis that the variability of the wadi's flow (dependent on that of the rain) is similar to the variability of its spectral index.

Figure 18 represents four hydrological years (from the beginning of August of year n to the end of July of year n+1). The years 2018-2019 and 2021-2022 are similar in terms of MNDWI variability as they have the particularity of decreasing in December and January, while the years 2019-2020 and 2020-2021 do not show a significant decrease in flow between September and April. The rainfall visible in Figure 18 may explain this behaviour (less rain in December-January) during years 1 and 4, but it is not manifest. The study period (August 2018-July 2022), with an average rainfall of 461 mm/year, is drier than the interannual average since 1981 (554 mm/year). The years August 2019-July 2020 and August 2021-July 2022 are among the five driest in the last 40 years.

It is also interesting and reassuring to note that the two highest rainfall events recorded during the study period: 128 mm in five days from 26 to 30 October 2018, then 121 mm in five days from 6 to 10 January 2021, induced the highest MNDWI values. This consistency confirms the reliability of these data (CHIRPS for rainfall and Sentinel-2 for MNDWI as proxi of flow). It is also interesting to note that these two rainfall events are among the four wettest pentads recorded since 1981 in the CHIRPS chronicle for this area. The other two are 148 mm from 21 to 25 January 1996 and 122 mm from 16 to 21 November 2002.

It will therefore be particularly interesting to observe the flooding in the merjas and the developed areas to check whether there were any wadi overflows into the merjas during these two extreme periods (October 2018 and January 2021).

On the other hand, the May-August periods correspond to the lowest flows (low MNDWI value) in 2019, 2020 and 2021. However, it seems that this period was much wetter in 2022. This cannot be explained by rainfall, which, as in previous years, is inexistent between May and August 2022. Did the dams play a role?

Figure 19 shows the evolution of the flooded surface through the variability of its MNDWI for two of the large dams located on the Wadi Sebou and Wadi Ouarda, which merge into the Wadi Sebou crossing the Gharb plain. It is first of all reassuring to note that the two curves follow the same trend, which indicates

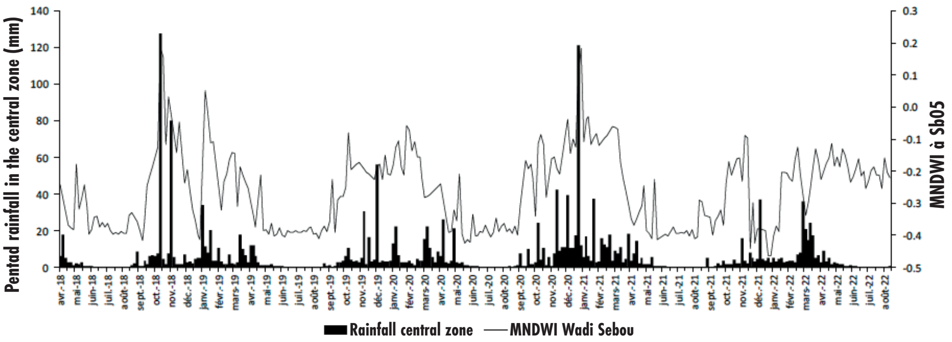


Figure 18. Relationship between the MNDWI of the Wadi Sebou (polygon Sb05, by way of example) and the rainfall of the central zone

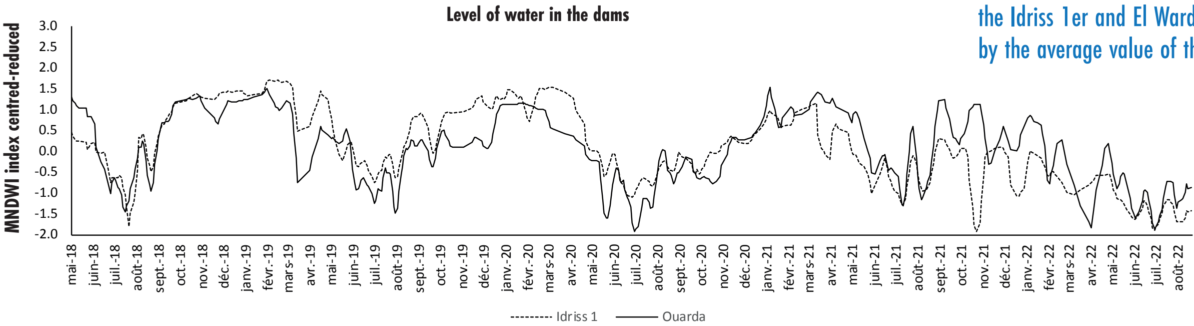


Figure 19. Evolution of the flooded surface of the Idriss 1er and El Warda dams estimated by the average value of their MNDWI index

that the water levels co-evolve coherently in the two dams. Furthermore, the first three hydrological years show similar behaviour. However, the last year (August 2021-July 2022) is different: the variability is higher and the level drops more sharply in March than in previous years. In July 2022, both dams seem to reach their lowest level over the study period, which is consistent with the records communicated by the country's basin agencies (Maroc Hebdo, 2022). The decrease observed between May and August 2022 does not seem to be more marked than in the same months of the previous years and therefore does not seem to explain the sustained flow observed between May and August 2022 (Figure 18), a behaviour that remains unaccounted for.

3.2 Influence of the ocean tide on the flooding of the Wadi Sebou

Figure 20 shows the value of the correlation coefficient between the MNDWI representative of the ocean tide (see red polygon in the intertidal zone near the mouth of the Wadi Sebou on Figure 15) and that of the Wadi Sebou as a function of distance from the mouth. The red dotted line and the red bar mark the location of the guard dam. This dam is intended to limit the rise of saline intrusions to the pumping stations located upstream. The graph shows that the influence of tides on the level of the Wadi Sebou goes beyond the dam upstream. Indeed, the alignment of the dots in Figure 20a is not interrupted at the guard dam. This can be explained by the fact that the flow of the wadi through the dam gates is influenced by its downstream water level. Given that the maximum tidal amplitude exceeds 3 metres at Kenitra (www.tide-forecast.com/), it is predictable that the flood amplitude caused by the highwaters of Wadi Sebou at Kenitra is strongly influenced by the tide. It is probable that this influence exceeds that of the

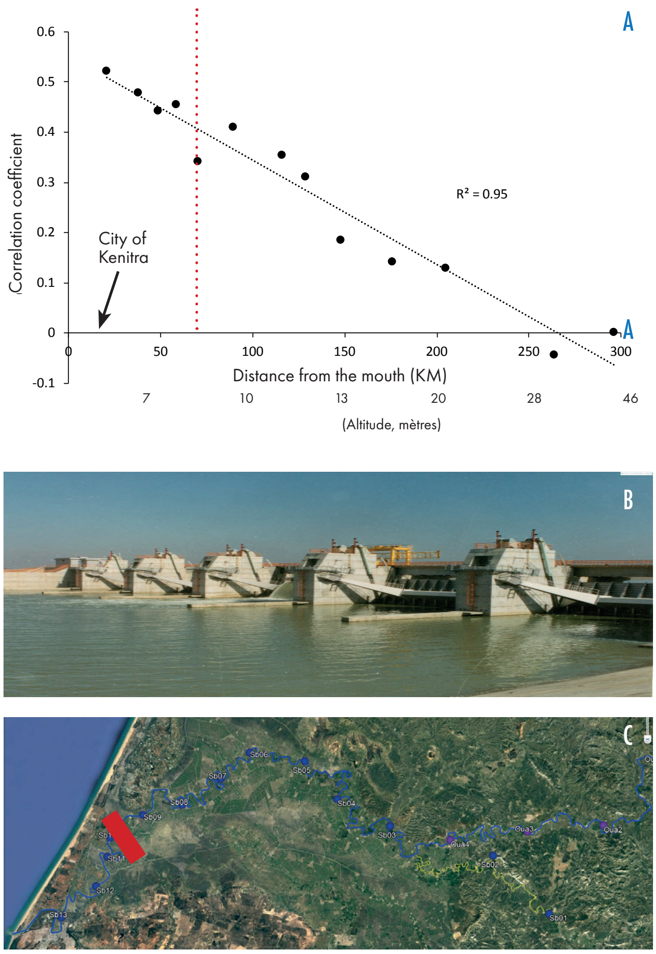


Figure 20. a: Correlation between ocean tide levels and the Wadi Sebou as a function of distance from the mouth where the city of Kenitra is located. Red dotted line: location of the guard dam. b: the guard dam. c: red bar: location of the guard dam on map of the Wadi Sebou

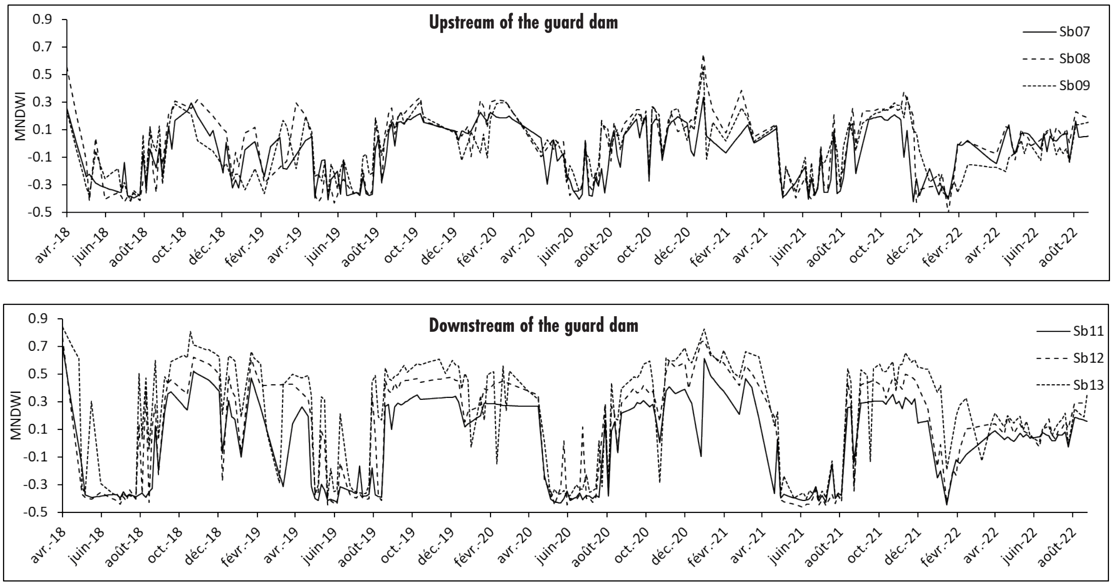


Figure 21. Influence of the guard dam on the seasonality of the Wadi Sebou regime

merjas via their hypothetical function of flood control of the Wadi Sebou, given their low storage capacity resulting from the very low relief of the plain.

Furthermore, it should be noted that the guard dam does not induce a clear break in the gradual decrease in the correlation coefficient in Figure 20. This result raises questions about the guard dam's mode of operation and the nature of the correlation illustrated in Figure 20: does it reflect a direct cause and effect relationship or are the two variables correlated to a third explanatory variable?

From Sb06 to Sb13, the correlation coefficient between two neighbouring stations is greater than 0.8, except between Sb09 and Sb10 because these two polygons are on either side of the guard dam.

Figure 21 shows a strong seasonal contrast of the MNDWI of the Wadi Sebou: low values from May to August corresponding to the low water conditions of the wadi during the dry period; high values from September to April due to the greater water supply from the catchment area. Between May and August, the values are lower downstream because the dam retains the low flows of the wadi upstream for irrigation needs (supply of pumping stations). Between September and April, the values are higher downstream due to the greater width of the minor bed, which is fully occupied by the more abundant flows in this season.

This seasonal contrast is much less marked in 2022, both upstream and downstream of the dam. This attenuation is not yet explained.

3.3 Influence of rain on the filling of the merjas

Figure 22 shows that the flood level of the merjas is generally more correlated with the rainfall of the central zone than the rainfall of the Wadi Sebou catchment area. The merjas with the highest correlation coefficients (M013, M06 and M04) have the following particularities:

M04 is one of the largest merjas located close to the Wadi Sebou and adjoining the developed areas (see location in Figure 16). It corresponds to the downstream part of Merja Kebira. M06 is located slightly south of M04. M13 is Merja Bokka: one of the most distant from the Wadi Sebou and deep (see Figure 16).

Figure 22. Correlation (with monthly time steps) between the MNDWI of the merjas and rainfall in the central zone (CZ rainfall) or rainfall in the Wadi Sebou catchment area (CA rainfall) or the flow rate of the wadi (via its MNDWI)

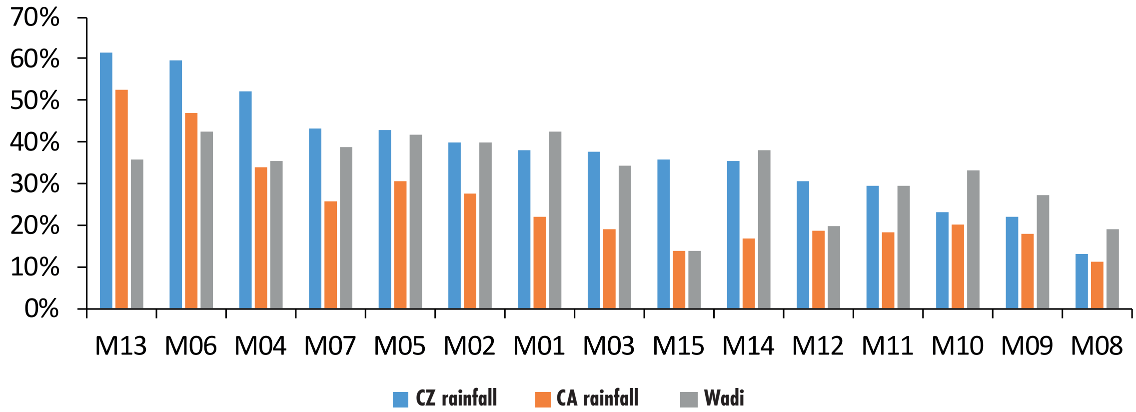


Figure 23. Relationship between the MNDWI of Merja Bokka (M13) and rainfall (CHIRPS) in the central zone

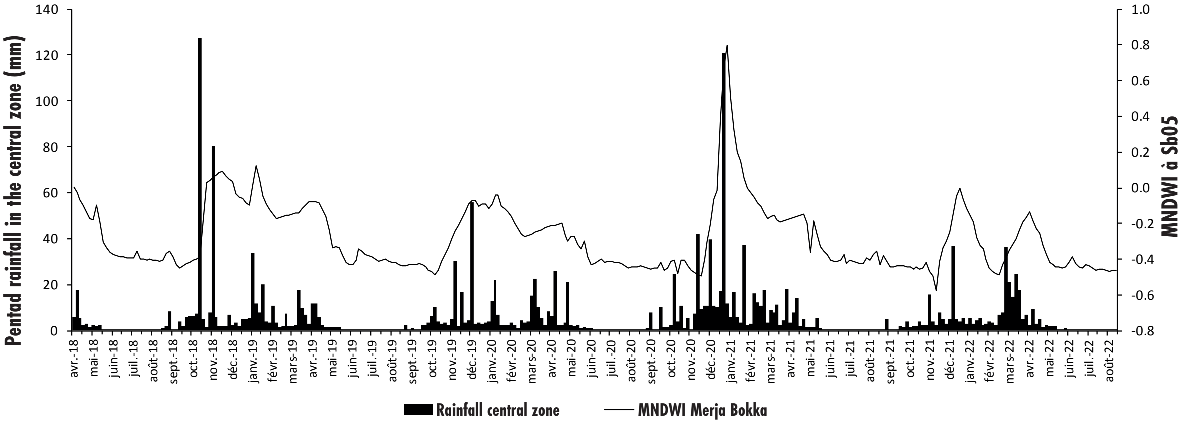
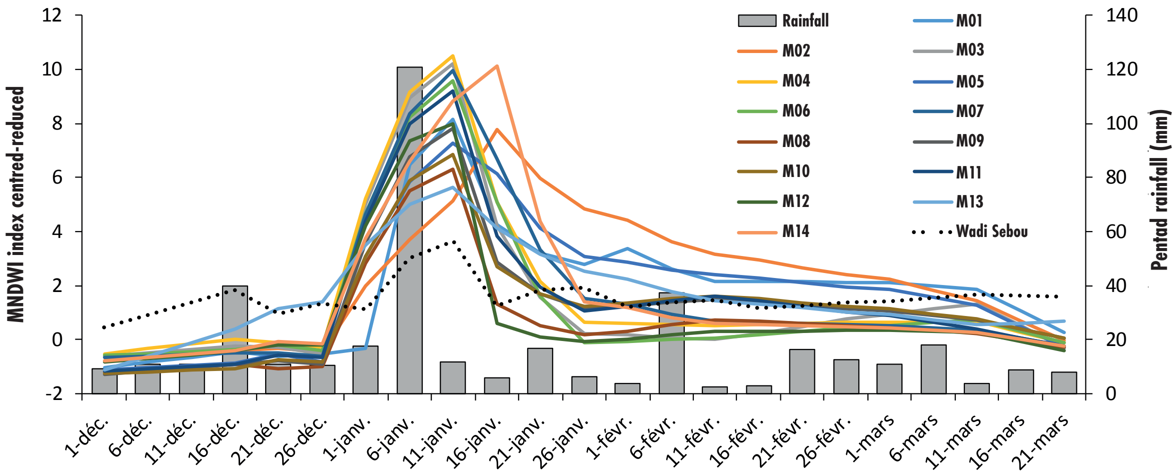


Figure 24. Flooding of the merjas during the event of 6 January 2021: co-variations of the MNDWIs of the merjas



How can we interpret the fact that merjas M13 and M01 to M07 are more correlated with the rainfall of the central zone and catchment area than the others? The reason would seem to be that the others are located downstream of the developed areas and fill up with irrigation water in summer (see Figure 28).

Figure 23 reveals a clear consistency between the flooded area of Merja Bokka and rainfall, confirming the reliability of the method of estimating the variability of a flooded area using the spectral MNDWI. Compared to Figure 18 which illustrates the variability of the flow rate of the Wadi Sebou, Figure 23 shows that the emptying phase of the merja is slower than the decrease of the MNDWI of the Wadi Sebou after a flood, which can be explained by the slower kinetics of the decrease in the water level in the natural reservoir. The consistency between rainfall peaks and water level increases in the merja shows that over the period considered, its filling seems to be mainly influenced by rainfall. The first rain peak (Oct. 2018) led to a lower increase in MNDWI than that of January 2021, probably due to the soils being unsaturated at the beginning of the winter.

Figure 24 aims to compare the variations of the MNDWI indices of the merjas with that of the Wadi Sebou and the rainfall during the extreme rainfall event of 6 January 2021, that of 26 October 2018 having apparently generated much less runoff because it occurred at the beginning of the wet season on drier soils. Considering our study period (beginning of 2018 to summer 2022), it is during this episode that the probability of overflows of the wadis in the plain is the highest. The analysis of the MNDWI co-variations during this episode aims to verify whether they could explain the filling of the merjas.

Figure 24 shows a coherence between the variability of the MNDWIs of the merjas and of the wadi. For most of the merjas, the index peaks five days after the rainfall peak. The existence of a time lag is intuitive (duration of the filling process of the merja after the rain event) but its duration (five days) is not informative because it corresponds to the CHIRPS time step which probably overestimates the response time.

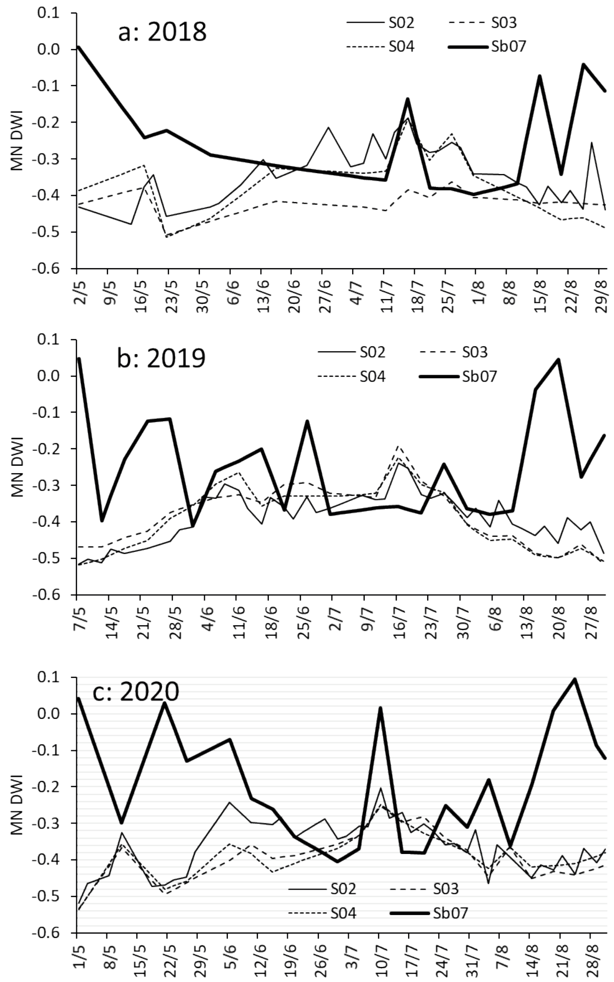
The MNDWI peak of merjas M02 and M14, which occurs 10 days after the rain peak and 5 days after the MNDWI peak of the other merjas, is most interesting. Merja M02 corresponds to the southern part of Merja Kebira. The delay in its filling could possibly be explained by its position at the bottom of a very wide basin with very low slopes. The slowness of its filling could result from the very slow concentration of local runoff. It is therefore not necessarily due to a delay linked to the transfer time of a flow spreading over a long distance and which one might be tempted to attribute to a hypothetical flood control function of the merjas. Merja M14 is comparable to merja M02. It is located in the centre of a very large area (about 15 km by 25 km) in the shape of a basin with very little relief. It is not in the main drainage axis. The time lag in its filling is therefore probably due to the slowness of the flows that concentrate in the centre of this basin, and not to a flood wave spreading from the most upstream part of the central zone located further east, near the overflow areas. If such a flood wave existed, the merjas closer to the wadi would have filled up first.

Another difference that could be used to classify the merjas into groups is the decrease rate of the MNDWI. It can be seen in Figure 24 that after their filling during the January 2021 episode, the MNDWI of some merjas decreases more rapidly than others. These differences may be related to the shape of the merja but also to their drainage network. We do not have sufficiently precise information to distinguish between these two causes, particularly due to the vertical imprecision of the digital elevation models.

Are the filling dynamics of the merjas in the winter season more correlated to rainfall or to the flow of the Wadi Sebou?

The MNDWI of the merjas is more correlated to rainfall than to the MNDWI of the wadi (particularly Sb02 and Sb05). This could be explained by the fact that it is mainly direct or at least very local rainfall that determines the filling level of the merjas, rather than the flow rate of the wadi, which does not seem to have overflowed during the period studied.

3.4 Analysis of summer water flows in developed areas



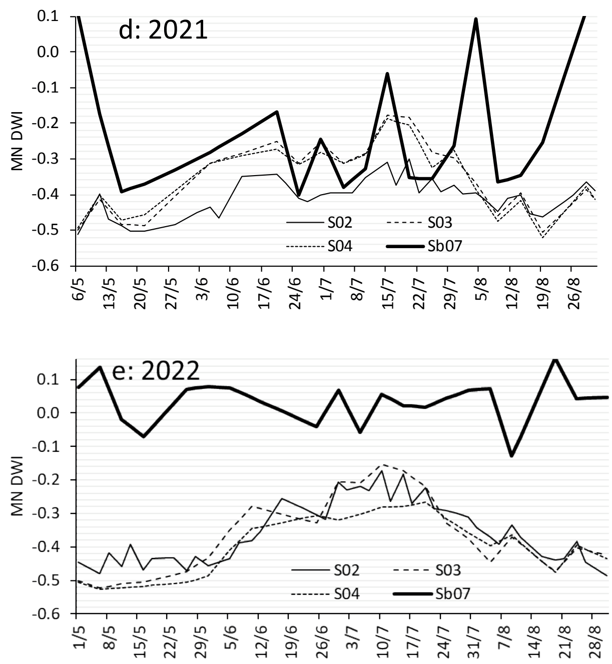


Figure 25. Summer trends of MNDWIs in the developed schemes S02, S03 and S04 and in the Wadi Sebou (Sb07)

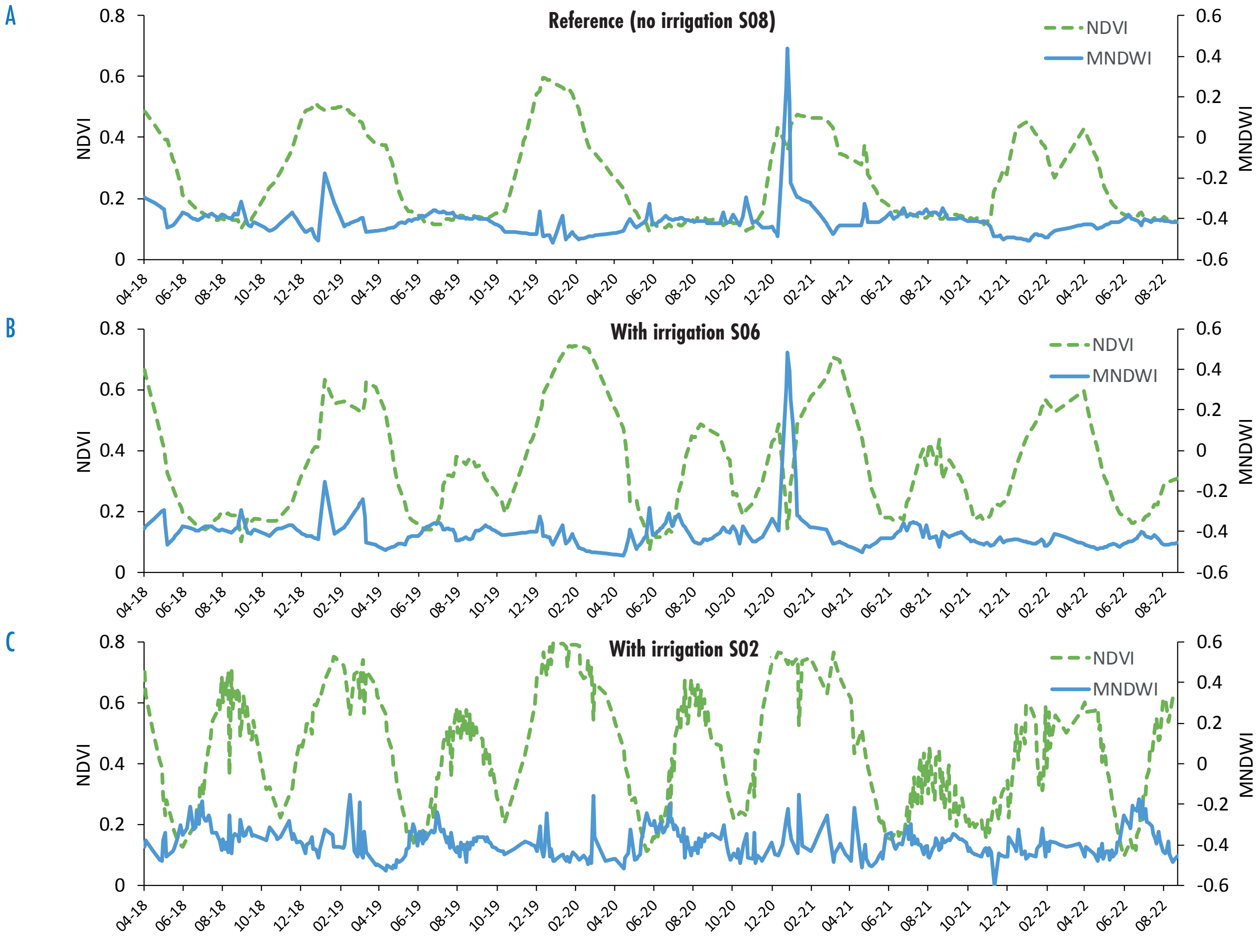
Figure 25 reveals a certain interannual regularity in the summer trends of the MNDWI in the plots irrigated by the Wadi Sebou. Its maximum value is reached in mid-July (16/07/2018, 18/07/2019, 10/07/2020, 17/07/2021, 10/07/2022). In 2018, 2020 and 2021, the Wadi Sebou peaks at the same date, probably reflecting an accumulation of water produced by the closure of a gate of the guard dam. Each year, the watering of the rice plots is relatively well synchronised, with some differences (S03 lower in 2018; S02 lower in 2022), reflecting variable cultivation practices depending on the year. The year 2022 stands out: the MNDWI of the Wadi Sebou remains high throughout the summer, even though it is one of the most severe droughts of the last decade. It is likely that due to the wadi's very low flow, the guard dam maintained a high water level.

There was also an MNDWI peak in the developed schemes in early May (except in 2019). The first watering of the rice fields?

Figure 26 shows the NDVI and MNDWI peaks in three developed areas. These three areas are targeted here because they are each of particular interest as explained hereafter. S08 is located in the heart of Merja Sidi Ameur in a conflict zone where irrigation has been banned (see section 4.2 of Part II). S06 is located in the north-east of Merja Sidi Hameur, in the immediate vicinity of the Wadi Beht. Its MNDWI correlates very highly (74%) with the MNDWI of the Wadi Beht (not shown in this report), probably as a result of hydraulic connections (drainage and/or overflow). S02 is a large rice-growing area north of Merja Kebira.

S08 shows that in the absence of irrigation, the NDVI only peaks during the rainy season. This is rain-fed agriculture and/or natural vegetation. The extreme rainfall event of January 2021 is clearly visible and results in an MNDWI peak and a sharp drop in NDVI induced by water covering the vegetation. S08 is located in a merja that accumulates local runoff when there is heavy rainfall.

Figure 26. Variations of NDVI and MNDWI spectral indices in developed areas. a: reference = no irrigation. b: moderate irrigation. c: higher irrigation



S06 shows lower summer NDVI peaks than the winter peaks, resulting from irrigation that does not occur every years (absent in summer 2018) (Figure 16). In winter, MNDWI peaks induce a decrease in NDVI (submergence or destruction of vegetation by water) (Figure 27).

In S02, the summer increases in MNDWI are more pronounced than in S06, especially in 2022, and the summer peaks in NDVI, which occur just after the MNDWI peaks (irrigation-stimulated vegetation growth), are also more pronounced than in S06

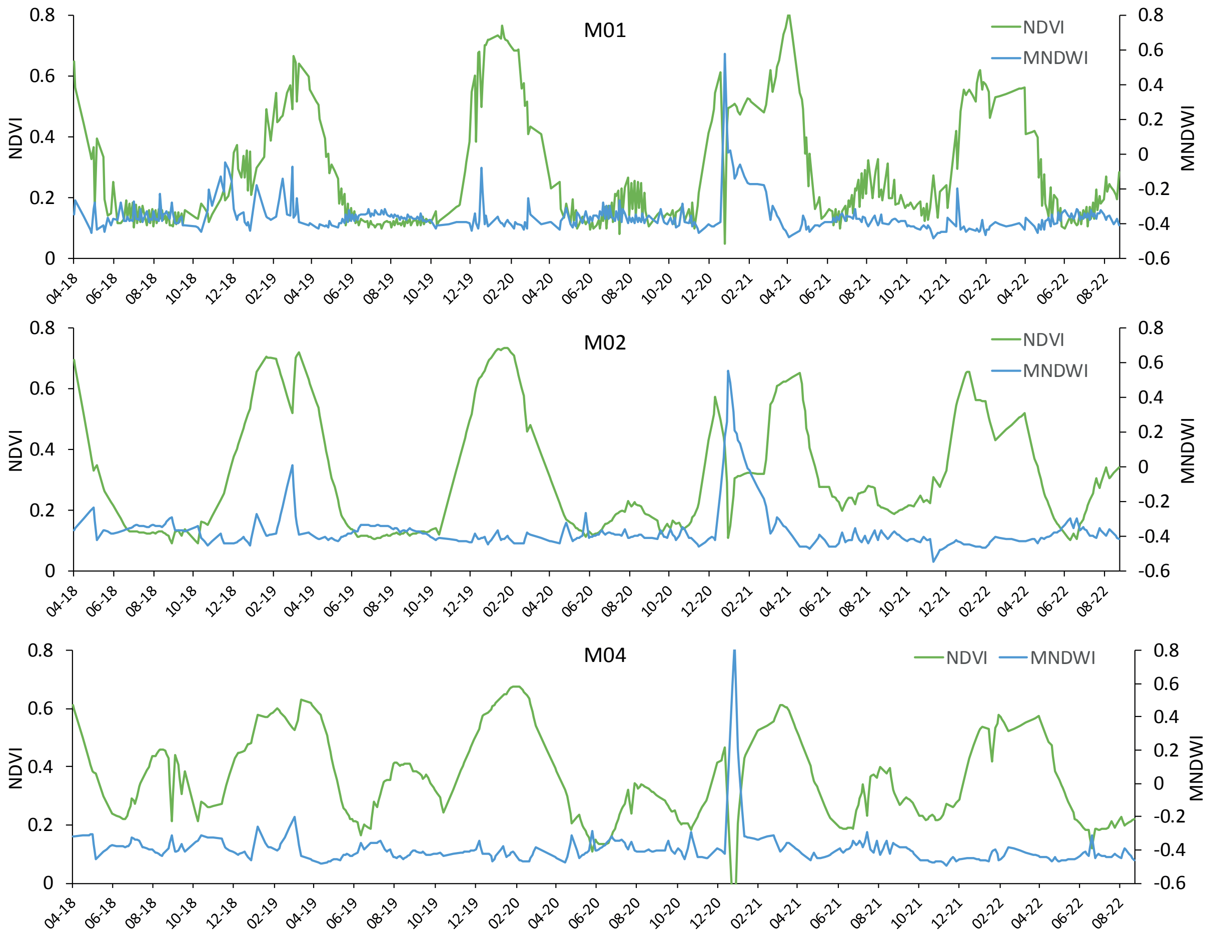
Figure 27. Partially flooded beet field in S06 (January 2021) Hajar Choukrani

and their maximums are close to the winter peaks in amplitude. At the time of the NDVI peak, there is a momentary drop in MNDWI, probably reflecting the rice masking the water in the field. Surprisingly, the extreme rain event of January 2021 did not cause an MNDWI peak in S02, probably due to the efficient drainage of this developed plot, unless the rice masked the rise in water. It is interesting to compare the effects of the January 2021 MNDWI peak on the NDVI of the three developed areas in Figure 26. It can be seen that the engendered drop in NDVI is much greater at the level of S06, reflecting the fact that this plot is less easily drained than S02 due to its topographical situation and its less efficient network.

3.5 Relationships between the merjas and developed zones

Introducing a time lag of one or two time steps between the MNDWI chronicles of the merjas and of the developed areas can, in some cases, increase the value of the correlation coefficient between these series. This is the case for merjas M01, M02 and M05 (Merja Kebira) whose filling is delayed compared to the developed areas S06, S07 and S08, close to Merja Sidi Ameur (Figure 16). The MNDWI chronicles of the merjas (M01, M02 and M05) show the best correlation coefficients with the MNDWI chronicles of the developed sectors (S06, S07 and S08) with a time lag (delay) of 5 or 10 days. This configuration contradicts the theory of a flood wave spreading from east to west (modelled

Figure 28. Variations in the spectral NDVI and MNDWI indexes in merjas M01 (a), M02 (b) and M04 (c)



and simulated for the 2010 flood, see Figure 7). An explanation to be confirmed would be that sectors S06, S07 and S08 fill up faster than merjas M01, M02 and M05 due to the existence of a drainage network accelerating the flows in rainy periods. A particularly flat (but basin-shaped) topography around M01, M02 and M05 could contribute to the delayed filling in this area. The difference with the 2010 event is not contradictory: the latter was dominated by flows essentially controlled by the very abundant overspills of the Wadi Sebou during this extreme event.

Figure 28 shows spectral index trends in three merjas. Their variability is comparable to that of the developed areas illustrated in Figure 16, but the NDVI peaks observed in summer are not due to irrigation water inflows through canals, as these merjas are not developed. Nor is it sprinkler irrigation from wells as these areas have no wells. It must therefore be due to pumping water from the drainage ditches from the irrigation of the developed areas located upstream. It can be noted that in M02, irrigation does not occur systematically every summer. These observations confirm the information collected by surveys among farmers cultivating merjas in summer (see section 4.1, part I).

We also note that in M01 located along the southern bank of the ditch that drains a large rice-growing scheme, the intensity of the summer peak of NDVI increases from year to year. The higher inter-day variability of the M01 indices is due to the fact that the satellite images are more frequent in this zone.

4. DISCUSSION AND CONCLUSION

The remote sensing analysis of the hydrology of the Gharb plain was chosen as an alternative to a more conventional analysis due to the lack of hydrometeorological data available in this area. This choice is all the more relevant as this is a region with very little relief where most digital elevation models do not provide a sufficiently precise description of the topography that determines the direction of flow and the volumes stored in the depressions.

This analysis, conducted on Google Earth Engine using Sentinel-2 and CHIRPS, consisted of comparing the temporal variations of spectral indices (MNDWI and NDVI) in different areas that have been flooded at least once since 2017. This analysis demonstrates that it is possible to better understand the hydrological functioning of a floodplain without using any field measurements. However, there are constraints, such as the impossibility of quantifying flow rates or stored volumes. This analysis has shown that since 2017, the merjas have filled up through the accumulation of rain and local runoff, without any contribution from the wadis. The 'buffer' or 'flood control' function mentioned by some institutional stakeholders during the surveys (see Part 1) therefore seems to come into play only during periods of extreme flooding when a significant part of the flow spills over into the plain and remains there in the merjas before joining the river near Kenitra, as was the case in 2010. This extreme flooding event, mapped in Figure

7, shows that the flooded expanses largely exceeded the merja areas, demonstrating that these merjas do not have the capacity to absorb all flooding events and that they are not the only areas exposed to flood risk in the Gharb plain.

The influence of oceanic tides on the level of the Wadi Sebou at Kenitra, revealed by Sentinel-2, is a result that should be taken into account in any hydraulic modelling aiming to highlight the flood control role of the merjas during an extreme event.

GENERAL CONCLUSION

Parts 2 and 3 of this report reveal the consistencies but also the contradictions between the stakeholder perceptions and the hydrological functioning of the merjas. There are many complementarities between developed and non-developed areas.

- In winter, the storage and/or flood control function of the merjas, often mentioned by the institutional actors and intended to protect the areas most vulnerable to flooding, could not be demonstrated by the hydrological analysis because the Wadi Sebou did not overflow during the period of availability of the Sentinel-2 satellite images, corresponding to a drier period than the interannual average of the last 30 years.
- In summer, the supply of irrigation water from the sanitation ditches fed by the drainage water from the rice-growing schemes illustrates the complementarity between developed areas (irrigated schemes) and undeveloped areas (merjas cultivated in summer). This functionality is revealed both by the surveys (Part II) and the remote sensing (Part III).

The analysis of the ecosystem services provided by the merjas (Part II) revealed a contrast between the vision of the merja's riparian inhabitants, who want to drain them for cultivation, and that of the institutional actors, who consider them as reservoirs for flood protection to spare the areas more vulnerable to excess water. From this stance, the institutional actors would oppose a merja drainage system. This bipolarism should be nuanced, both in terms of optional interventions (drain or do nothing) and in terms of understanding how it works. The conflict between the roles of production and protection does not only depend on the geographical scale considered but also on the temporal scale, as revealed by the remote sensing analysis. Indeed, the protection function, notably through flood control, comes into play only very rarely, when the wadis overflow. However, the frequency of these overflows, with climate change (drying up) and the construction of new dams, is set to decrease. In order to reconcile these two functions, it could therefore be envisaged, at least theoretically, to equip these merjas with drainage systems that would be activated (i.e. open gates) when it is necessary to evacuate water for cultivation, even in winter (cereals), when there is no risk of flooding downstream, or deactivated (i.e. closed gates), when the risk of flooding is significant, even if this closure prevents the cultivation of the flooded land. It should be noted that cereal cultivation, which is currently essentially rain-fed in the Gharb plain and therefore takes place in the winter period (see Figure 12), could be shifted to spring if irrigation was provided in the newly developed areas, thus reducing the risk of yield losses in these low-lying areas with a dual purpose (agricultural production or water storage). However, there is still a risk that the irrigation infrastructure in these areas (canals) would be damaged by excessive flood levels.

The further development of merjas for irrigated agricultural production should be seen as a means to improve national cereal production. The financial investments, often considered too high to be implemented (irrigation and drainage infrastructures particularly costly in the lowest areas), should be assessed and possibly justified considering the relatively high potential benefits (theoretically up to 80 qtls/ha). It would also be advisable to ensure the relevance of the irrigation methods promoted and to avoid the subsidy of drip irrigation by the State in the least favourable areas of the merjas, which are subject to high salt concentrations.

The best choices for the development and management of these merjas need not only negotiations, which can be facilitated by engineering participation, but also a better understanding of the hydrological dynamics that ultimately require the implementation and maintenance of a measurement network.

Given the difficulty of creating the ideal conditions for debating these options, due in particular to the lack of reliable information on the hydrological processes, the design of role-plays, inspired by those implemented in Cambodia and Ecuador in the framework of this structuring action, is an interesting option.

To be more effective, these developments of the plain should be accompanied by measures on the scale of the Wadi Sebou catchment area, aimed at reducing flood risks. This would involve:

- better management of the existing dams:
  - providing a storage volume intended to contain flood waters,
  - better management of releases to limit the silting up of the dams. This can also apply to the Wadi Sebou guard dam.
- building new flood control dams on the wadis from the southern slopes of the plain (Rdom, Rdat, Mda, Tifelt, Smento).
- intervening on the slopes to reduce erosion that could silt up the dams and thus reduce their effectiveness:
  - encouraging conservative cultivation practices: semi-direct, agroforestry, agroecology,
  - implementing developments for water and soil conservation.
- assigning a role of reducing the risks of the Wadi Sebou overflowing to the new Sebou-Bouregreg water transfer project. This project plans to transfer up to 15 m^3/s of water from the guard dam to the Sidi Mohammed Ben Abdellah dam on the Wadi Bouregreg, to supply the cities of Rabat and Casablanca with drinking water. This should also be accompanied by the reinforcement of sections of wadi banks in the plain (recalibration).

REFERENCES

ABHS, 2010. Etude de schéma directeur de protection de la plaine du Gharb contre les inondations. Agence de Bassin Hydraulique du Sebou (ABHS)

Ayt Ougougdal, H., Yacoubi Khebiza, M., Messouli, M., Lachir, A., 2020. Assessment of Future Water Demand and Supply under IPCC Climate Change and Socio-Economic Scenarios, Using a Combination of Models in Ourika Watershed, High Atlas, Morocco. Water 12, 1751. https://doi.org/10.3390/w12061751

Balhane, S., Driouech, F., Chafki, O., Manzanas, R., Chehbouni, A., Moufouma-Okia, W., 2022. Changes in mean and extreme temperature and precipitation events from different weighted multi-model ensembles over the northern half of Morocco. Clim Dyn 58, 389–404. https://doi.org/10.1007/s00382-021-05910-w

Célérier J. 1922. Les merjas de la plaine du Sebou. Hesperis 2: 109–138.

CHM (Centre d'Echange d'Information sur la Biodiversité de la Région Rabat-Salé-Kénitra). [2006/11/19]. https://ma.chm-cbd.net/

Choukrani H, Kuper M, Hammani A, Lacombe G, Taky A. 2022. Visions contrastées des services écosystémiques des zones humides saisonnières du Gharb, Maroc. Cahiers Agriculture. Vol, 220037

El Blidi S, Fekhaoui M, Serghini A, Abdellah &, Abidi EL. 2006. Rizières de la plaine du Gharb (Maroc): qualité des eaux superficielles et profondes. Bulletin de l'Institut Scientifique, section Sciences de la Vie (28): 55–60

El Khalki, E.M., Tramblay, Y., Hanich, L., Marchane, A., Boudhar, A., Hakkani, B., 2021. Climate change impacts on surface water resources in the Oued El Abid basin, Morocco. Hydrological Sciences Journal 66, 2132–2145. https://doi.org/10.1080/02626667.2021.1982137

El Moçayd, N., Kang, S., Eltahir, E.A.B., 2020. Climate change impacts on the Water Highway project in Morocco. Hydrology and Earth System Sciences 24, 1467–1483. https://doi.org/10.5194/hess-24-1467-2020

FAO, MAPM. 2010. Plan d'action d'urgence pour le drainage et l'assainissement de la plaine du Gharb.

Flower RJ. 2001. Change, Stress, Sustainability and Aquatic Ecosystem Resilience in North African wetland lakes during the 20th century-an introduction to integrated biodiversity studies within the CASSARINA Project. Aquatic Ecology 35: 261–280. https://doi.org/10.1023/A:1011978420737.

Fournier A. 2020. The agrosystem and the bush spirits among the Sèmè of Burkina Faso. Some thoughts about the notion of cultural ecosystem services. Cahiers Agricultures 29: 25. https://doi.org/10.1051/cagri/2020024

Funk C, Peterson P, Landsfeld M, Pedreros D, Verdin J, Shukla S, Husak G, Rowland J, Harrison L, Hoell A, Michaelsen J. 2015. The climate hazards infrared precipitation with stations - a new environmental record for monitoring extremes. Scientific Data 2, 150066

Hayzoun H. 2014. Caractérisation et quantification de la charge polluante anthropique et industrielle dans le bassin du Sebou. Doctoral thesis. University of Toulon. 176 pages

Hrour, Y., Thomas, Z., Fovet, O., Sebari, K., Rousseau-Gueutin, P., 2022. Changes in precipitation and discharge in a Mediterranean catchment as a response to climate change and human activities. Journal of Water and Climate Change 13, 3253–3273. https://doi.org/10.2166/wcc.2022.074

Inventaire du degré de pollution des ressources en eau dans le bassin du Sebou. 2015. Agence du Bassin Hydraulique du Sebou. Kingdom of Morocco. 16 pages

Kull CA, Arnauld de Sartre X, Castro-Larrañaga M. 2015. The political ecology of ecosystem services. Geoforum 61: 122–134. https://doi.org/10.1016/j.geoforum.2015.03.004.

Kulp SA, Strauss BH. 2018. CoastalDEM: A global coastal digital elevation model improved from SRTM using a neural network. Remote Sensing of Environment 206: 231–239

Kulp SA, Strauss BH. 2019. New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. Nature communications 10:4844

Le Coz J. 1964. Le Rharb Fellahs et Colons.

Lespinas, F., Ludwig, W., Heussner, S., 2014. Hydrological and climatic uncertainties associated with modeling the impact of climate change on water resources of small Mediterranean coastal rivers. Journal of Hydrology 511, 403–422. https://doi.org/10.1016/j.jhydrol.2014.01.033

Maroc Hebdo. 2022. Le taux de remplissage des barrages atteint 29,2%, le niveau le plus bas de l'histoire du pays. Edition du 19 juillet 2022. https://www.maroc-hebdo.press.ma/taux-remplissage-barrages-29-niveau-plus-bas

Minderhoud PSJ, Coumou L, Erkens G, Middelkoop H, Stouthamer E. 2019. Mekong delta much lower than previously assumed in sea-level rise impact assessments. Nature communications 10:3847

Moinina A, Boulif M, Lahlali R. 2018. La culture de riz (Oryza sativa) et ses principaux problèmes phytosanitaires: une mise au point sur la région de Gharb. Revue Marocaine des Sciences Agronomiques et Vétérinaires 6 (4): 544-557.

Mukherjee S, Joshi PK, Mukherjee S, Ghosh A, Garg RD, Mukhopadhyay A. Evaluation of vertical accuracy of open source Digital Elevation Model (DEM). International Journal of Applied Earth Observation and Geoinformation 21: 205–217

Nassali H, Ben Bouih H, Srhiri A, Dhahbi M. 2005. Influence des rejets des eaux usées sur la composition des eaux de surface et des sédiments superficiels du lac Merja Fouarate au Maroc. 2005. Afrique SCIENCE 01(1) : 145-165

Neang M, Méral P. 2021. Ecosystem services and rice cropping system around tonle sap lake, cambodia. Cahiers Agricultures 30: 44. https://doi.org/10.1051/cagri/2021030.

NOVEC. 2011a. Etude de faisabilité de l'aménagement hydro-agricole de la Zone Centrale de la troisième tranche d'irrigation du Gharb et de sécurisation de l'alimentation en eau d'irrigation des secteurs équipés Beht 3 et Beht 4. Mission 1 : Diagnostic de la situation actuelle (DSA) Sous mission 1.1 : Diagnostic de l'assainissement externe. Rapport

NOVEC. 2011b. Etude de faisabilité de l'aménagement hydro-agricole de la Zone Centrale de la troisième tranche d'irrigation du Gharb et de sécurisation de l'alimentation en eau d'irrigation des secteurs équipés Beht 3 et Beht 4. Mission II : Projet de Mise en Valeur Agricole. Rapport principal. 95 pages

NOVEC. 2012. Etude de faisabilité de l'aménagement de la zone centrale de la TTI du Gharb et sécurisation de l'alimentation en eau d'irrigation des secteurs Beht 3 et Beht 4. Mission 3 : Avant-Projet Sommaire. Mission 3-1 : Assainissement externe de la rive gauche de l'oued Sebou. ORMVAG (Office Régional de Mise en Valeur Agricole du Gharb). 145 pages

Ramsar. 2015. État des zones humides du monde et des services qu'elles fournissent à l'humanité: compilation d'analyses récentes. www.ramsar.org

Sajaloli B. 1996. Les zones humides : une nouvelle vitrine pour l'environnement (Wetlands : a new showcase for environment). Bulletin de l'Association de géographes français 73(2): 132–144. https://doi.org/10.3406/bagf.1996.1894.

Sauvage Ch. 1959. Au sujet de quelques plantes rares et menacées de la flore du Maroc.

Seijger C, Douven W, van Halsema G, Hermans L, Evers J, Phi HL, et al. 2016. An analytical framework for strategic delta planning: negotiating consent for long-term sustainable delta development. Journal of Environmental Planning and Management 60(8): 1485–1509. https://doi.org/10.1080/09640568.2016.1231667.

Shackleton CM, Ruwanza S, Sinasson Sanni GK, Bennett S, de Lacy P, Modipa R, et al. 2016. Unpacking Pandora's Box: Understanding and Categorising Ecosystem Disservices for Environmental Management and Human Wellbeing. Ecosystems 19 (4): 587–600. https://doi.org/10.1007/s10021-015-9952-z.

Sibari M, Hamdaoui F, Lakhlifi M, Elatmani A, Achhar A, EL Kharrim K, Belghyti D. 2020. Modeling physical and chemical pollution of Sebou river waters Kenitra, Morocco. International Journal of Environmental Science

Sonnier A. 1935. Les merjas de la plaine du Rharb. Bulletin économique et social du Maroc 8.

Taky A. 2020. Témoignage - Assainissement et drainage sur la plaine du Gharb au Maroc. Revue Science Eaux & Territoires, Drainage agricole : enjeux, connaissances, perspectives (32): 19–19. https://doi.org/10.14758/SET-REVUE.2020.2.04.

Tramblay, Y., Somot, S., 2018. Future evolution of extreme precipitation in the Mediterranean. Climatic Change 151, 289–302. https://doi.org/10.1007/s10584-018-2300-5

Verner, D., Treguer, D., Redwood, J., Christensen, J., McDonnell, R., Elbert, C., Konishi, Y., Belghazi, S., 2018. Climate Variability, Drought, and Drought Management in Morocco's Agricultural Sector (Working Paper). World Bank, Washington, DC. https://doi.org/10.1596/30603

Were D, Kansiime F, Fetahi T, Cooper A, Jjuuko C. 2019. Carbon Sequestration by Wetlands: A Critical Review of Enhancement Measures for Climate Change Mitigation. Earth Systems and Environment 3 (2): 327–340. https://doi.org/10.1007/s41748-019-00094-0.

Yamazaki D, Ikeshima D, Sosa J, Bates PD, Allen GH, Pavelsky TM. 2019 MERIT Hydro: A high-resolution global hydrography map based on latest topography datasets. Water Resources Research. 55:5053-5073