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Scientific elements for a Yemeni wetland conservation strategy: overview of the main factors explaining the diversity and characteristics of wetlands

Éléments scientifiques pour une stratégie de conservation des zones humides du Yémen: aperçu des principaux facteurs expliquant la diversité et les caractéristiques des zones humides

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Abstract. Day after day, the wetlands of arid regions reveal new secrets about their importance, in terms of biodiversity as well as functions and services. Yemen, a mountainous country surrounded by seas and a desert, has a flora and fauna heritage shaped by both African, Asian and Palearctic influences, and by a pronounced insularity that has enriched it with endemic forms of world interest. However, this biodiversity has still not received the attention it deserves, in terms of conservation. This lack prompted us to carry out a general diagnosis of the Yemeni wetlands, providing the essential scientific elements allowing to initiate a sustainable use strategy of these ecosystems. This diagnosis focuses first on the main factors that control the functioning of these wetlands, then on the characteristics of these, presented for each type, according to a usual classification scheme. While relating the richness already discovered in the seas and islands, this article provides arguments in favor of the originality of the estuarine and fluvial ecosystems. The creation of a geodatabase, using satellite data (digital elevation model, precipitation, thematic images) has made it possible to illustrate the high density of the river network in Yemen, which is justified by the census of some 450 estuaries, identified along a 2,500 km long coast. This base was enriched by cartographic inventories (in particular those of hydraulic dams and towns and villages), reconstructed from bibliographic and unpublished information, which also gives often non-cartographic information on the distribution of habitat types (especially marine). The striking features of these ecosystems are highlighted through arguments borrowed especially from orography, climate and human pressures. These are very old, but their recent increase is alarming, due to the rapid growth of the population and of its needs in agricultural and urban, even industrial, water and space. Urgent solutions are essential to improve and protect wetlands in Yemen, starting with research likely to lead to a complete classification and inventory of these ecosystems, but also to a better characterization of their originalities and their functioning and of the pressures they undergo.

Key words: wetland, ecology, human pressures, conservation, GIS, Yemen.

Résumé. Jour après jour, les zones humides des régions arides révèlent de nouveaux secrets sur leur importance, tant au niveau de leur biodiversité que de leurs fonctions et services. Le Yémen, pays montagneux encerclé par des mers et un désert, possède un héritage floristique et faunistique façonné par des influences à la fois africaines, asiatiques et paléarctiques, et par une insularité prononcée qui l'a enrichi de formes endémiques d'intérêt mondial. Pourtant, cette biodiversité n'a toujours pas reçu l'attention qu'elle mérite, en termes de conservation. Ce manque nous a incités à réaliser un diagnostic général des zones humides de ce pays, qui fournit les éléments scientifiques essentiels permettant d'initier une stratégie d'utilisation durable de ces écosystèmes. Ce diagnostic porte dans un premier temps sur les principaux facteurs qui contrôlent le fonctionnement de ces zones humides, puis sur les caractéristiques de celles-ci, présentées pour chaque type, selon un schéma de classification usuel. Tout en relatant les richesses déjà découvertes dans les mers et les îles, cet article donne les arguments en faveur de l'originalité des écosystèmes estuariens et fluviaux. La constitution d'une base de données géospatiale, à partir de données satellitaires (modèle numérique de terrain, précipitations, images thématiques) a permis d'illustrer la forte densité du réseau fluvial du Yémen, laquelle est justifiée par le recensement de quelque 450 estuaires, identifiés le long d'une côte longue de 2500 km. Cette base a été enrichie par des inventaires cartographiques (notamment ceux des barrages hydrauliques et des villes et villages), reconstitués à partir de sources bibliographiques et inédites, lesquelles donnent aussi des informations souvent non cartographiques sur la distribution des types d'habitats (surtout marins). Les traits marquants de ces écosystèmes sont mis en exergue via des arguments empruntés surtout à l'orographie, au climat et aux pressions humaines. Celles-ci sont très anciennes, mais leur augmentation récente est alarmante, en raison de la croissance rapide de la population et de ses besoins en eau et en espace agricole et urbain, voire industriel. Des solutions urgentes pour améliorer et protéger les zones humides au Yémen sont indispensables, à commencer par les recherches susceptibles d'aboutir à une classification et un inventaire complets de ces milieux, mais aussi à une meilleure caractérisation de leurs originalités et leur fonctionnement et des pressions qu'elles subissent.

Mots clés: zones humides, écologie, pressions humaines, conservation, SIG, Yémen.

INTRODUCTION

Wetlands are well known as rich reservoirs of biodiversity and as sources of socioeconomic services and of knowledge (Stuip *et al.* 2002, MEA 2005, Bruland 2008, Erwin 2008 and McCartney *et al.* 2010). However, these ecosystems are exposed to continuous loss, mainly in arid regions (Sheppard *et al.* 1992, O'Connor & Crowe 2005 and Duffy 2006), due to human expansion, whose needs in terms of land and water are continuously growing. These losses are estimated at 50% since 1900 (Davidson 2014), and have been amplified by climate change and recurrent droughts (Barnard & Thuiller 2008, Elasha 2010 and Crooks *et al.* 2011). Therefore, wetland protection and restoration become highly prior in national policies (Hushulong 2012, Parry *et al*. 2007 and Erwin 2008), more especially in arid countries. These strategies must be based on a solid knowledge of these ecosystems, more especially of their main functional characteristics.

In Yemen, a mountainous country extending on 527,970 km², wetlands are supposed to hold a rich biodiversity due to their high variety and to the original context of their genesis

and evolution (variable orographic and climate situations, long coastline overlapping three different seas, high number of islands, etc.). This richness is well marked by the biogeographic situation of this country at the transition zone between three major domains (Afrotropical, Oriental and Palearctic) and on major routes of waterbird migrations. Besides these aspects, the Yemeni wetlands evolved in an insular context, since they belong to a mountainous area surrounded by seas and desert and to a high number of islands dispersed in a semi-closed sea. This evolution explains the high rate of endemism highlighted in different Yemeni wetlands.

In Yemen, wetlands are endorsing heavy and rapid degradations (EPA 2009, Al-Mahfadi & Dakki 2019), whereas they provide most of the survival resources to the population. In order to design a good conservation strategy for these wetlands, we gather in this article the most significant information necessary to provide a good understanding of the configuration and the sensitivity of these ecosystems.

MATERIAL AND METHODS

This article was essentially based on satellite and published data, supported by our unpublished field knowledge of the Yemeni wetlands and by interviewing research and administrative competencies.

Mapping

Mapping of the natural context concerns essentially orography, hydrography, geology and rainfall, which play a decisive role in wetland configuration. This work was accomplished, using GIS tools (ArcGIS) and Remote Data, mainly the Digital Elevation Model (DEM) of the country, extracted from ASTER GDEMV2 (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and the rainfall satellite data for the period 1981-2014 extracted from CHIRPSV2 (Climate Hazards Group InfraRed Precipitation with Station data). Data were compiled and assembled by watersheds, with the knowledge that wetlands configuration is mainly defined by their watershed characteristics. In addition to natural factors, major human activities (e.g. damming and agriculture) are evocated and discussed, in a way to stand out their historical and actual impacts on wetland characteristics.

Field knowledge and interviews

Although unnoticed in the article, intensive work on wetland identification and location allowed an overview of existing wetland types in the country and an estimate of their representativity. This inventory was mainly focused on coastal and marine wetlands but also on artificial reservoirs, knowing that lacustrine wetlands are quite absent in the country.

Considering our field knowledge and observations, they concern more than fourteen wetlands, which are mostly on the coast, in addition to some mountainous rivers. Moreover, the remote and field data were reinforced through interviews with academicians in the Faculty of Agriculture (Environmental Department) and administrators in different institutions: Directorate of Irrigation and Dams (DID), Environmental Protection Authority (EPA), Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA), Food and Agricultural Organization (FAO), the Ramsar Convention, etc.

RESULTS

Main factors configuring Yemeni wetlands

Using GIS tools and satellite resources, we provide the most useful information for a good understanding of the abundance, the diversity and the classification of the Yemeni wetlands. In addition to some classical results, this analysis highlighted some originalities that should be taken in account in designing an eventual conservation strategy of these ecosystems or in planning researches or inventories or monitoring programs on wetlands.

Oro-hydrographic context: a mountainous country with a dense river network

The simplified oro-hydrographic map of Yemen (Fig. 1), generated from a DEM, shows a mountainous country, with highest altitudes (over 2,000 meters) in its western and South-western sides, including the highest mountain of the Arabian Peninsula (Jabal Al-Nabi Shu'ayb, at 3,666 meters). Further east, the mountains fall away in progressive steps to the North-East (Rub'a Al-Khali) and the East, through a large plateau, where altitudes are around 700-1,000 meters. In the ***Mountain Massif***, slightly parallel to the Red Sea, landscapes are marked by steep slopes and deep valleys, with relatively frequent volcanic craters. This topography plays in favor or a dense riverine network, mainly permanent and semi-temporary, whereas these ecosystems are intermittent or ephemeral in the large ***eastern Plateau*** and ***Desert areas***. Plains are distributed along the western and Southern coasts of the country and along its northern boundary with Oman. They are relatively narrow (less than 30 km wide), slightly sloppy, with highest altitudes around 200 meters. They are also dominated by alluvial landscapes (EPA 2004b) with several large and dry valleys.

Marine context: high representativity of coastal and island ecosystems

The 2,500-km coastline of Yemen belongs to three different seas (Red Sea, Golf of Aden and Arabian Sea) with different hydrological and ecological conditions. The use of satellite images with some existing maps revealed a coastal landscape dominated by long rocky cliffs with variable height, and a minimum of 450 estuaries, which corroborates with the high number of watersheds. The western and south-western margins of the country, overlooked by high mountains, show several large estuaries, most of them being often separated from the sea by natural sediment dams. Between these estuaries exist also many small river mouths, with coastal small watersheds that occasionally flow, whereas these rivers mouths are often separated from the sea with sediment thresholds. These two kinds of estuaries exist also on the Arabian Sea side, but this coast has the particularity to receive the largest estuary in the country, generated by Wadi Hadramawt, which drains the largest watershed of the Arabian Peninsula.

Yemen is also well known for its numerous islands (more than 186), most of which (more than 112 volcanic islands) being in the Red Sea. These reliefs enrich the marine environment in shallow rocky habitats occupied by very rich communities, whereas their terrestrial biodiversity is highly marked by endemism, which has been clearly demonstrated in the biggest islands (Tardelli & Baldini 2000 and RAP 2004), as Socotra (3625 km²) in the Arabian Sea and Kamran (108 km²) in the Red Sea.

Geological context: basic data explaining ecological diversity and endemism

Geology can affect wetland diversity and abundance through different aspects (petrography, permeability, history, etc.), besides its determinism of the orography and the hydrology. A simplified geological map of Yemen (Fig. 2) drawn according to an existing scheme (Van der Gun & Ahmed 1995), shows a relatively high petrographic diversity. The main rocky outcrops date from the Mesozoic and continues

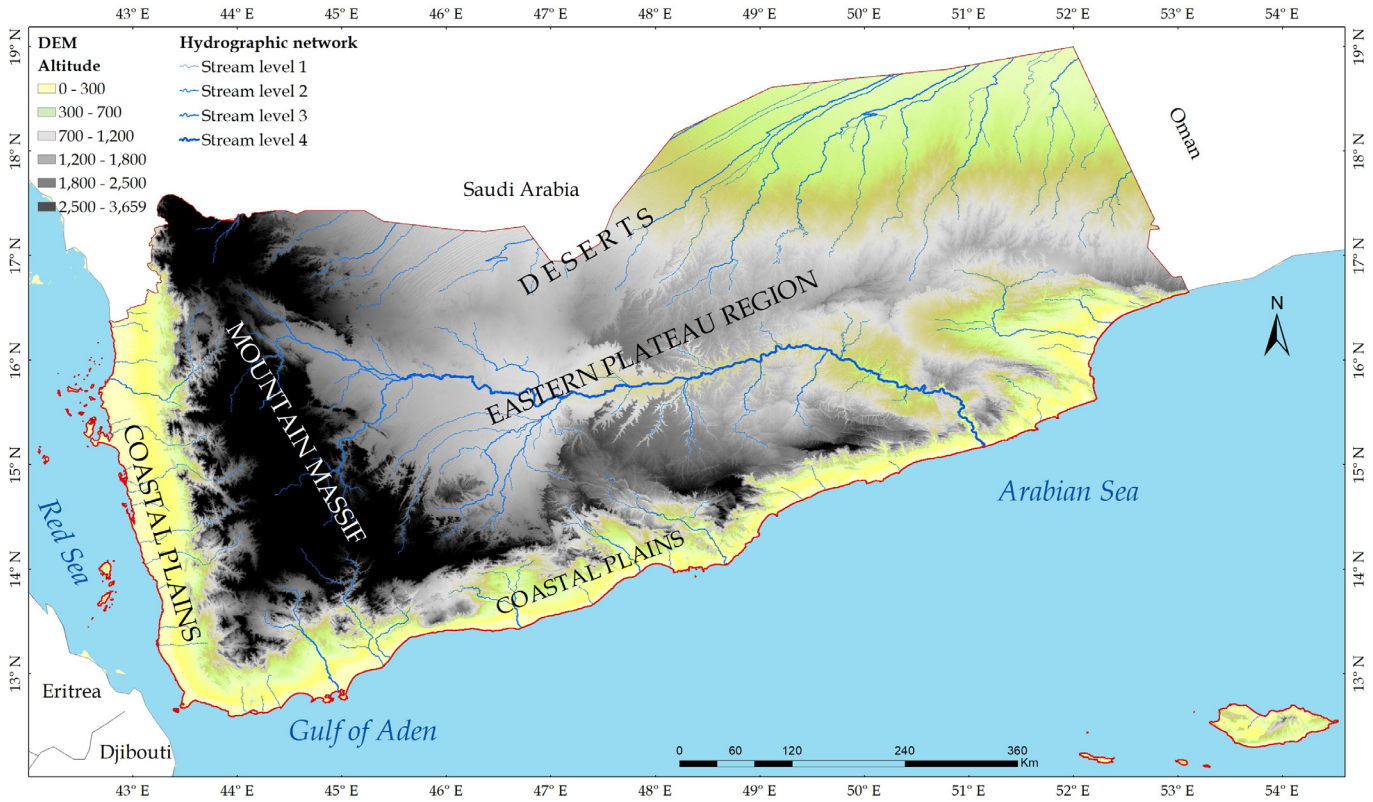

Figure 1. Oro-hydrography and main geographical regions of Yemen.

until now (Geukens 1966); the basement of this cover, which flushes in limited mountainous areas, consists of Precambrian impermeable crystalline rocks (amphibolite's, migmatites, gneiss and granite), Cambrian sandstones and Permian shale. Until the middle of the Mesozoic, Yemen remained attached to the African continent, before being immersed from Jurassic to Cretaceous, when great limestone series were generated, constituting a large part of the high mountainous outcrops.

In the middle of the Tertiary, tectonic movements led to the opening of the Red Sea and the Gulf of Aden and to the overelevation of the Yemeni mountains, simultaneously to an intense volcanic activity (basaltic deposits), that marked a large part of the western mountain relief. The existing limestone series were surmounted by Tertiary widespread river deposits (sandstone) and by Paleocene deposits (thick layer of limestone) that form the Jawl plateau in the eastern half of the country.

During the Quaternary, the volcanic activity resumed locally in the western half of the country. During the wet quaternary periods (e.g. last glaciation), an intensive erosion happened in mountains, creating remarkable deep valleys and abundant alluvial sediments that constructed the main coastal plains and the platforms of Rub-Al-Khali and Hadramawt valley (Mohammed *et al.* 2018).

From this history, it could be concluded that both mountainous and coastal wetlands existed in Yemen since the Tertiary and their actual biodiversity survived under the Quaternary climate oscillations. The impermeable crystalline substratum is generally favorable to groundwater storing, mainly during the Quaternary wet periods, and to springs and rivers abundance. During the Cenozoic, the inland wetlands have evolved in insular environment (country between seas and desert), which generates numerous endemic forms among aquatic biodiversity, as well as in islands.

Climate: a determinant factor of the hydrology stress in wetlands

Yemen lies within the sub-tropical climatic and the northern stretches of the tropical zone (Elasha 2010). It is submitted to the monsoon regime, with two rainfall seasons (March-May and July-September), separated by a dry season (October to February), with some irregular precipitations in the western mountains (Fig. 3).

Annual rainfall, calculated using satellite data for the period 1981-2014, varies from West to East between 1500 mm/year, mainly recorded in the high mountainous district of Ibb, and less than 100 mm/year in the eastern and northern deserts (Fig. 4). Most of the country, including medium altitude slopes, is under more or less dry climate (Van der Gun & Ahmed 1995). The rainfall trend, as illustrated by four watershed examples chosen in different regions (Fig. 5), is slightly negative, characterized by high interannual fluctuations and frequent droughts.

In concordance with the sunshine duration (6-9 hours/day), the evapotranspiration rate is regularly high, with large spatial variation (NBSAPY 2005): 1500-2500 mm/year in the western mountains and 1800-2700 mm/year in the coastal zones and foothills, whereas higher values (2000-3500 mm/year) are recorded in inland arid areas.

Given this climate, inland wetlands should be frequently submitted to hydrologic stress during a large part of the year (EPA 2004b). Therefore, intermittent wadis and ponds are predominant and very few and small lakes are known in the volcanic crater of Bir Ali in Balhaf area of the Arabian Sea as well as on Al Zubair Group in the Red Sea. Due to the recent droughts and the high number of artificial dams, the river waters generally do not reach the sea, in the sense that their low courses are flooded only after violent rain showers. Therefore, most of the estuarine ecosystems are intermittently open/closed (*sensu* Whitfield 1992), due to sediment barriers

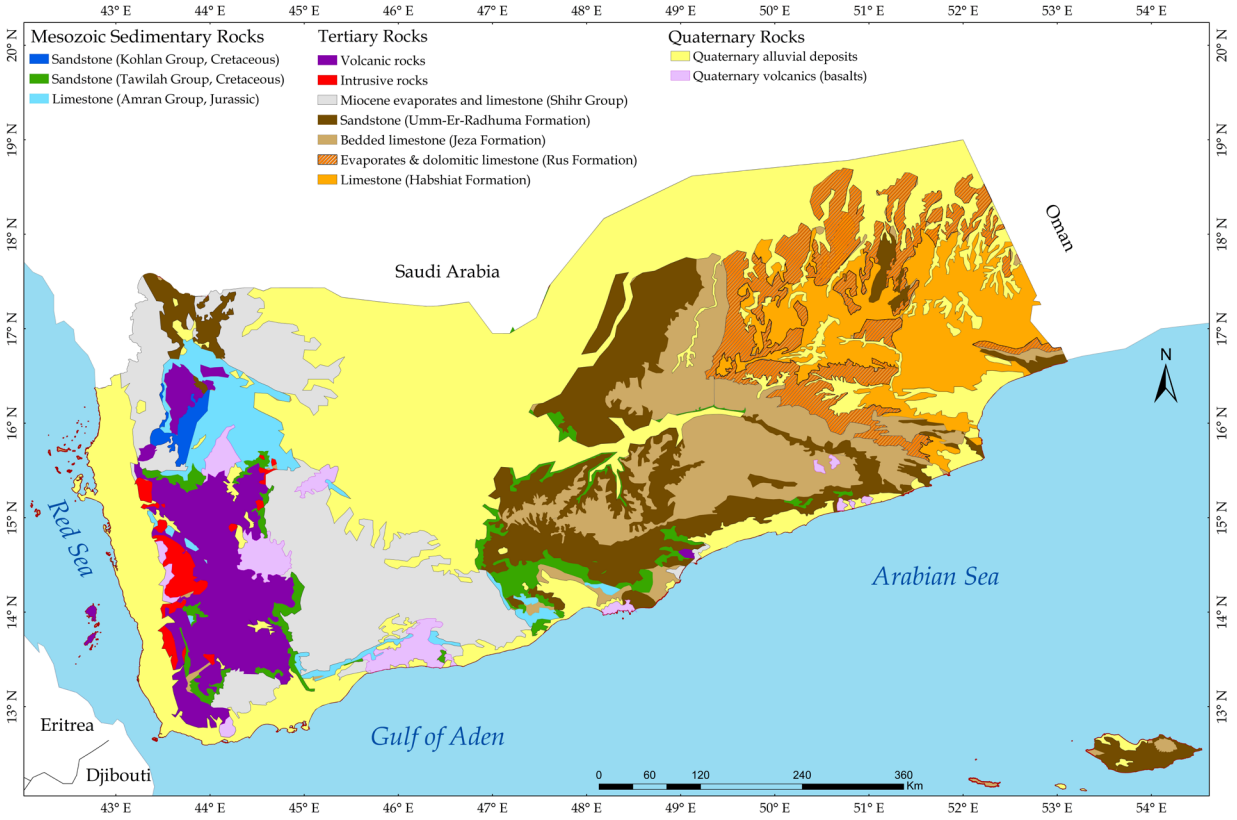

Figure 2. Simplified geological Map of Yemen (Van der Gun & Ahmed 1995).

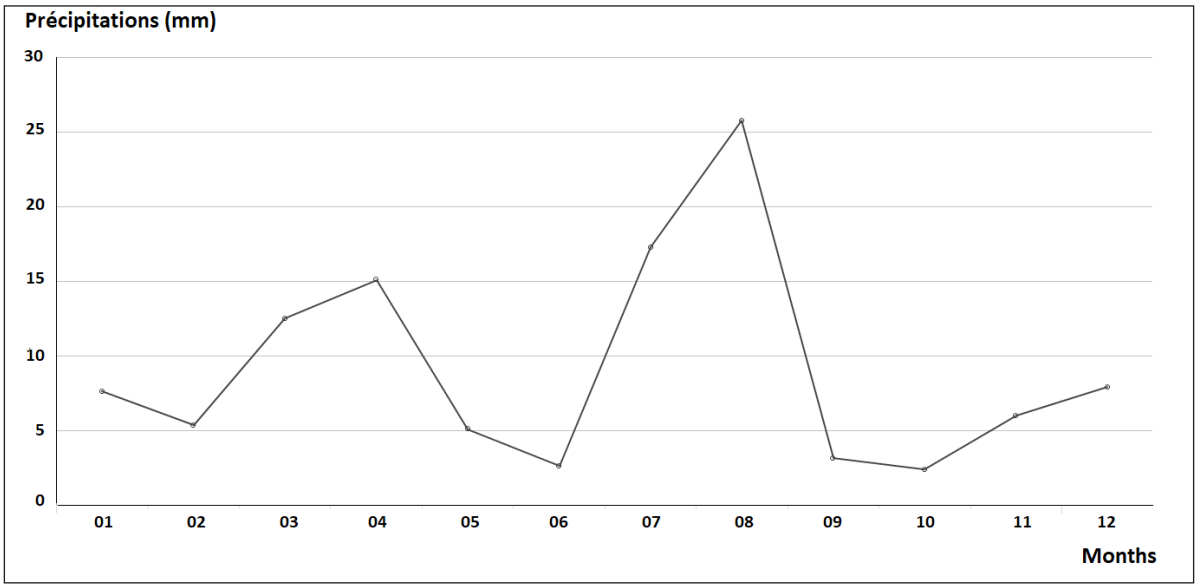

Figure 3. Monthly variation of precipitations in Yemen (Hadramawt watershed).

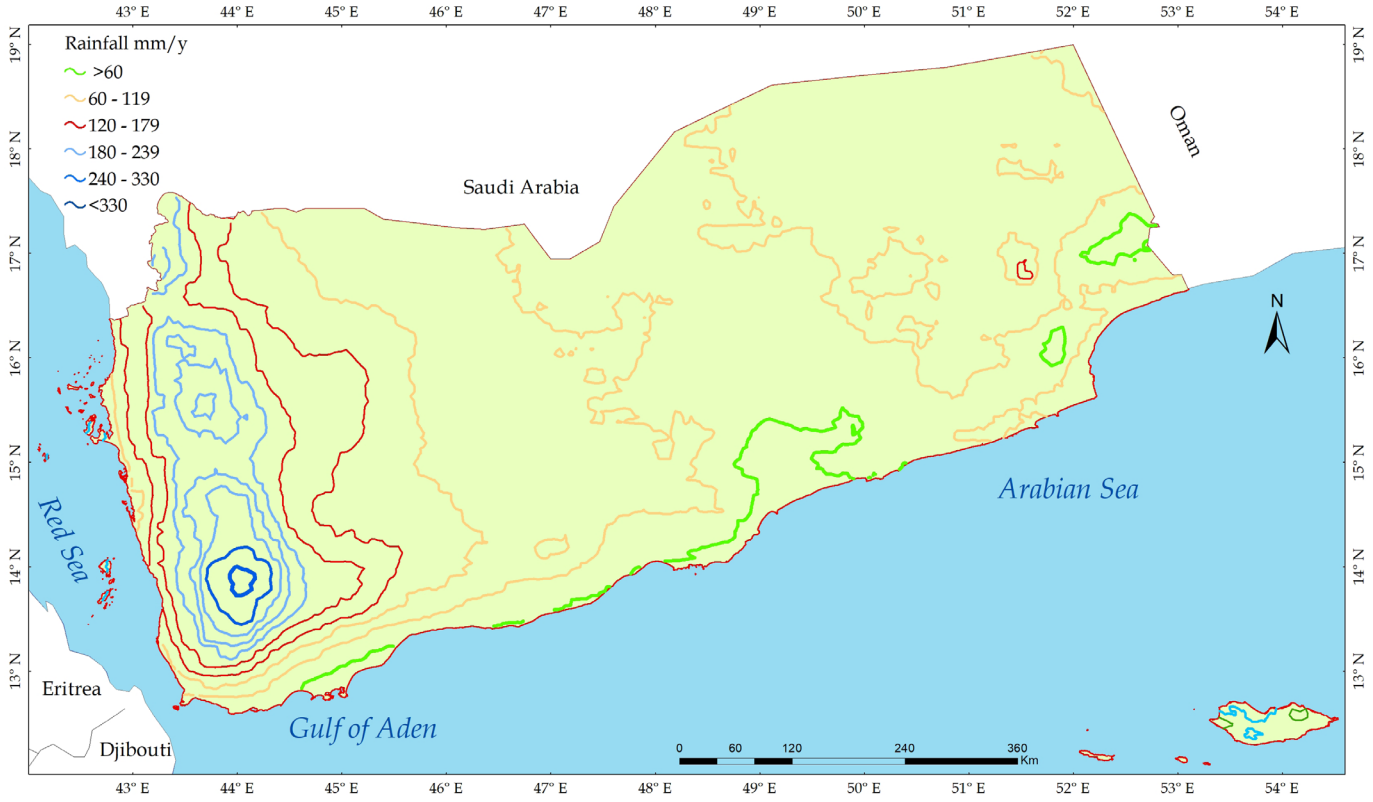

Figure 4. Spatial distribution of the annual rainfall in Yemen.

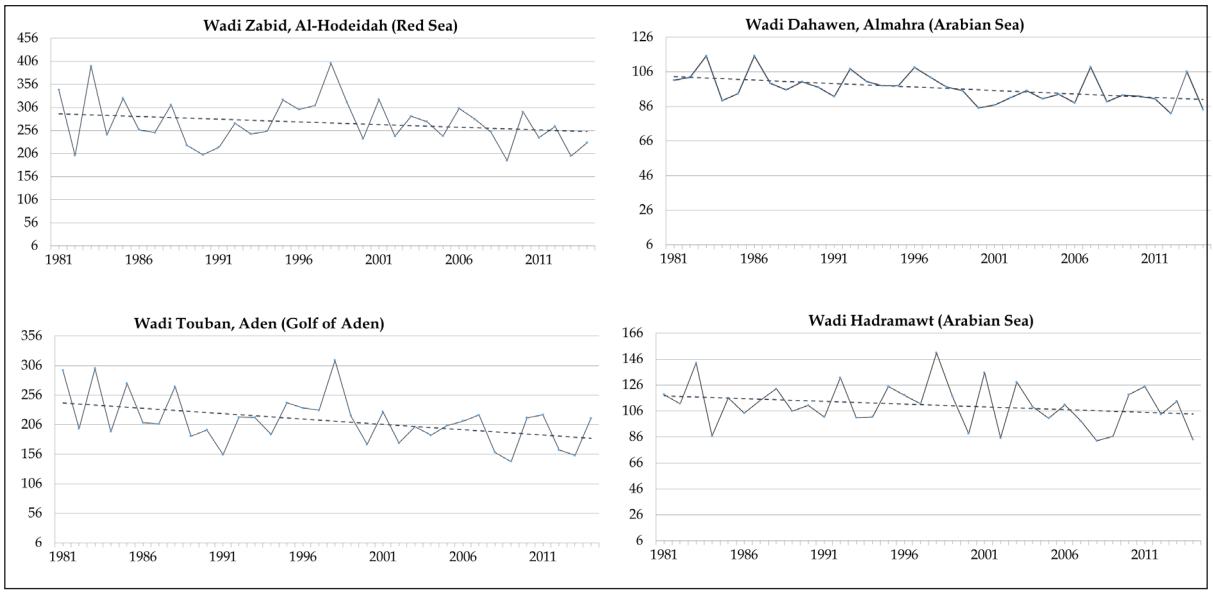

Figure 5. Rainfall trend in Yemen: annual average precipitations (1981-2014) in four rivers.

mainly built by sea and wing dynamics, and behave like North-African estuarine gueltas (Dakki *et al*. 2020), as brackish to hypersaline stagnant water.

Human context: heavy pressures on wetlands, amplified by frequent droughts

Human activities constitute a key issue in conservation strategies, since they play a decisive role in wetland loss, more especially in arid emerging countries that know a rapid increase of their population, while recurrent droughts deplete their water resources. In Yemen, the population increased five-times between 1955 and 2019 (Fig. 6); its growth rate registered between 2014 (CSO 2014) and 2016 (Worldmeters 2019) is 3.2% (i.e. 26.25 to 27.58 million), with alarming values in major cities, which have absorbed large numbers of rural emigrants. The average population density is about 55.6 people/km² (CSO 2014), with large spatial variation (e.g. 1.1 and 388 people/km² respectively in Almahra and Ibb regions).

This explosive growth means a high increase of both water demand and pollution; however, the deficit between available resources and consumption is continuously increasing, i.e. 400,000 m³ in 1990 and 900,000 m³ in 2000 (Ward *et al.* 2000).

In this arid agricultural country, thousands of water derivations have been managed for millennia along the riverbanks and from springs; their increasing number often dry up the riverbeds on long distances. Damming was also a traditional approach in this country, as illustrated by the old Ma'rib dam, but the increased water demand has forced the government to adopt and intensified damming politics. The number of dams has increased concomitantly to recurrent droughts, from 60 in 1970 to 240 in 1990 (Charbonnier 2009), exceeding now more than 600 dams (MAI 2016), mainly concentrated in the western highlands of the country.

Similarly, the groundwater exploitation has led to their rapid depletion, mainly in the western part of the country where the great majority of the population resides (NWRA 2005). The decrease of the water table level was estimated between 1.0 and 3.0 meters/year in Al-Hodidah, Ta'iz and Amran regions, but in Sana'a region, it reached 6-8 m/year. Recently, the water extraction was extended to fossil deep aquifers, which have been also depleted in some zones, such as Amran and Ta'iz basins, after what agriculture has been stopped.

This evolution is ecologically translated into a recurrent hydrologic stress in all wetlands depending from riverine waters, most of them being frequently dried, sometime for several years. As most of the human agglomerations are close to rivers (Fig. 7), water pollution is still increasing due to continuous growing of urban effluents and to different development poles. Being the final recipient of watersheds, estuarine wetlands are certainly suffering from all these impacts.

Status of the major wetland types present in Yemen

Considering the former description, we must conclude that wetlands are relatively diversified in Yemen, despite the aridity of this country. This diversity is presented hereafter, through a simplified classification borrowed from the Ramsar Convention scheme (Navid 1989), where all factors described above are reflected. However, this presentation is mostly focused on their characteristics, representativity and distribution in the country.

Coastal and marine wetlands

As formerly explained, Yemen coastline is 2,500 km long and belongs to three different seas, with different sizes, hydro-sedimentary dynamics and ecological factors: (1) the *Arabian Sea*, which is largely open on the Pacific Ocean and its coastal wetlands are submitted to its high hydrodynamics; (2) the *Gulf of Aden*, where salinity increases from East (35.5 mg/l) to West (37.5 mg/l) and the coastal wetlands are influenced by upwellings (surface waters relatively cold); and (3) the *Southern Red Sea*, which width decreases from the North (270 Km) to the Bab Al-Mandeb stretch (20 Km). This latter regulates the water exchange between this sea and Gulf of Aden, isolating the Red Sea flora and fauna from the other marine communities and enriching them in endemic forms (EPA 2009).

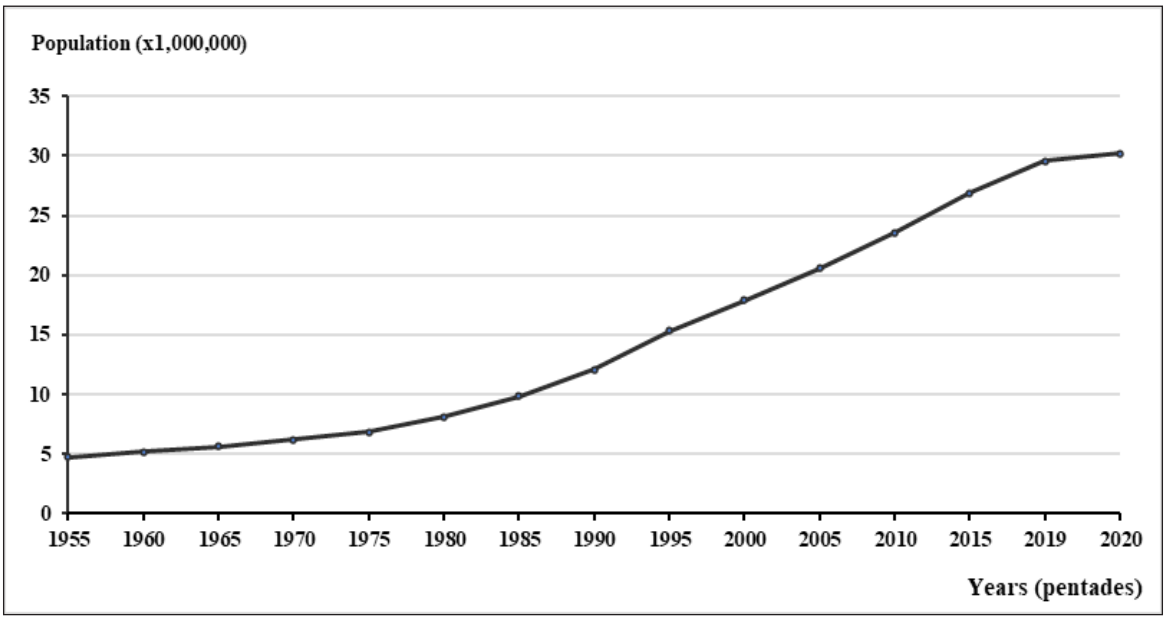

Figure 6. Yemen population growth during 1955-2020 period (Worldmeters 2019).

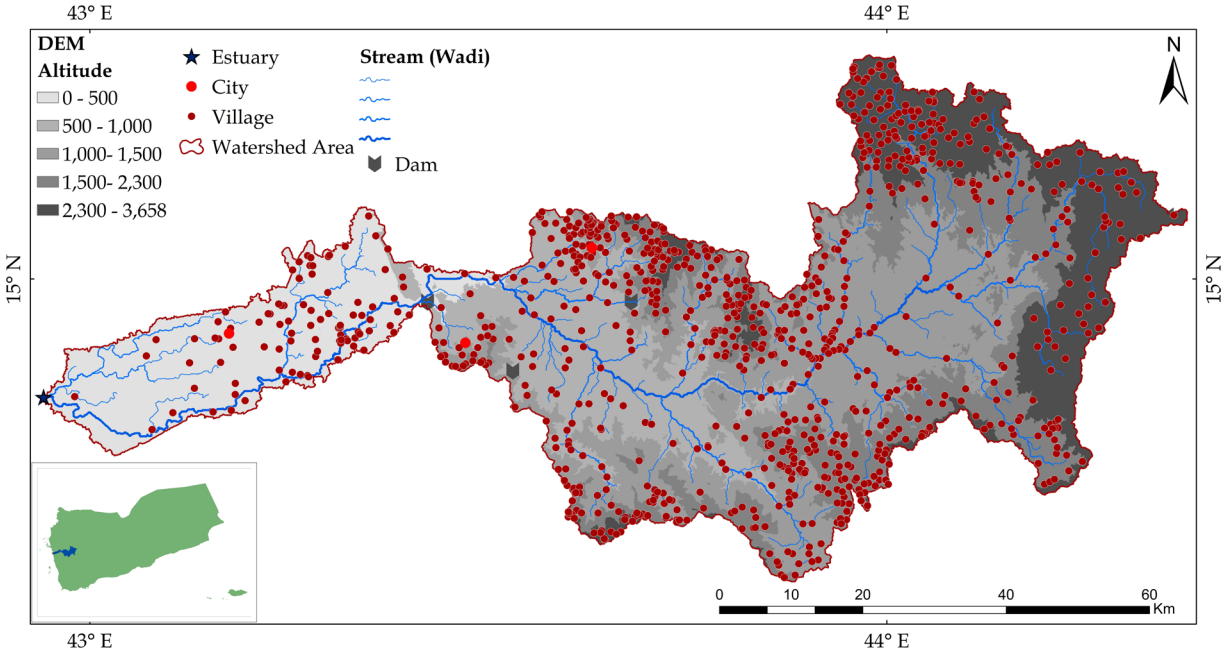

Figure 7. Superposition between human habitat and hydrographic network, an illustration of human pressures on wetlands (e.g. Wadi Al Mahiam).

Coastal open waters

Considering the former introduction, tidal and subtidal shallow waters in the three seas differ by their hydrodynamics, with clear decrease of the tide amplitude, depth and bottom slope from the Arabian Sea to the Red Sea.

Coastal beaches

These ecosystems include sediment coastal lands, flat or slightly sloping, submitted to sea tides and waves; they slightly vary in pace, mainly in relation with the coast slope the tide amplitude and the storm waves. In the western half of the country and Socotra, most of the coastline is close to foothills and its beaches are more or less narrow and sloping, frequently enriched with coarse sediments (gravel, pebbles and blocks), mainly when they are close to river mouths. Pure sandy beaches are relatively rare, but more frequent on the Arabian Sea coast.

Sea cliffs

These habitats correspond to vertical or sub vertical coastal lands, beaten by sea waves and spray. These landscapes, with variable height (generally exceeding 20 meters), have remarkable length, although they are frequently interrupted by estuaries. High sea cliffs play an important ecological role, mainly as refuges for particular forms of flora and fauna; this importance is amplified in Yemen by the high rate of endemic species (Sheppard *et al.* 1992).

Estuarine systems

These habitats correspond to sea inlets (lagoons and river mouths), relatively sheltered from marine hydrodynamics and more or less fed with inland waters. As the country is mainly mountainous, it holds a dense river network that generated more than 450 estuaries. Considering their extension, 89 % of them have an area of less than 50 ha; the remaining 47 estuaries that exceeds 50 ha are mainly in the Red Sea (43%) and the Gulf of Aden (36%). Sixteen estuaries exceed 200 ha and are also on the Red Sea side, and only three of them are on the Gulf of Aden or the Arabian Sea coasts. This latter receives the largest estuary (555 ha) in the country, Wadi Hadramawt (or Almasilah). The morphology of estuaries reflects the impact of large floods that happened during past wet periods, including the Holocene. Actually, the riverbeds are frequently dried up for several weeks or months, even for several years, and most of the river mouths took the form of a standing water pond. Therefore, they can be classified as *intermittently open/closed estuaries* (Whitfield 1992), due to sediment obstacles built between the sea and the river by marine hydrodynamics, sometime supplied by wind. However, the river floods transport coarse materials, enriching the estuarine substrate with gravels and pebbles, even in blocks, which contribute to consolidating the sediment dam. Outside of these floods, the ponds will be enriched with fine materials, including organic matter produced by biological processes, more especially in Red Sea inlets. Sandy habitats seem to be more abundant in the eastern half of the country (about 115 estuaries of the Arabian Sea).

This functioning scheme was well described in similar arid zones, as in North Africa (Dakki *et al*. 2020), where they are named 'estuarine *gueltas*', in Southern Asia (Ranasinghe & Pattiaratchi 2003), Australia (Roy *et al*. 2001), New Zealand (Lill *et al*. 2012) and more especially in South Africa, where they constitute more than 70% of the estuaries (Perissinotto *et al*. 2010, etc.) and benefited from abundant studied (Nozais *et al*. 2005, James *et al*. 2007, Snow & Taljaard 2007, Taljaard *et al*. 2009, Whitfield *et al*. 2012, Tweddle & Froneman 2015, Scharler *et al*. 2020, etc.).

Lagoons are intended here as sea inlets that are not fully open to the sea and receive few inland waters. The whole information used in this study is based on satellite images and punctual field visits, noting that the ecological studies dedicated to these ecosystems (EPA 2009) concern mainly Kalnsia and Ditwah lagoons on Socotra coast and the Mocha Lagoon in Ta'iz region (Red Sea). These ecosystems are

mainly represented on the Red Sea coast, where 26 inlets could be identified as lagoons, the two other seas show only six small inlets, the largest one (Almahra-Arwet) having a maximum surface of 65 ha. Some large shores, developed in the Gulf of Aden and the Arabian Sea coasts, show on their inland side a *sebkha* like landscape, which dries out seasonally and form vast salty flats, with scattered halophytic plants or blue-green algal crusts (EPA 2013).

Islands

These small lands entirely surrounded by sea waters, are particularly numerous along the Yemen coasts, about 186 islands (Al-Najar *et al.* 2008). The biggest Islands in the Red Sea are Zugur groups (120 km²), Kamaran (108 km²) and Big Hanish (65 km²), Socotra is however the largest Yemeni island on the southern margin of Arabian Sea (3,549 km²). It holds diverse ecosystems, including terrestrial habitats, and a rich flora and fauna, with high endemism rate (Tardelli & Baldini 2000, Al-Saghier 2002b …). Islands are ecologically remarkable by their coastal and marine habitats (cliffs, beaches, mangroves and coral beds), which are treated separately in this article.

Mangroves and Seagrass

These tropical sea-coast formations are common in the Red Sea, where they were identified in more than 130 km of coasts; they are organized in discontinuous belts, with some large formations in the north-western coast of Yemen (e. g. Midi to Alluhayah). More to the South (e.g. Al-Urj to Al-Hodidah or Bab Al-Mandab areas), these habitats are organized in well conserved thin belts around islets, but sometimes highly fragmented into small patches. Furthermore, the seagrass distribution is quite-continuous along the Red Sea coast (Barratt *et al*. 1987), while they are rare in the Gulf of Aden and the Arabian Sea.

Coral reefs/beds

These habitats make the Red Sea among the most famous coral areas in the world, both by their diversity, in terms of number of species and communities, and by their extension. This sea contains about 260 species of hermatypic corals, organized in large but discontinuous patches (Kemp 2000 and Sheppard *et al*. 1992). In Socotra Island, coral reefs are remarkable, while they are relatively rare in the Gulf of Aden. In addition to its high richness, the Yemeni Coral fauna is mainly remarkable with its high rate of endemism both in Socotra and the Red Sea (Sheppard *et al.* 1992).

Inland wetlands

River (Wadi) systems

This category includes all types of running waters, the local term *Wadi* refers to '*surface drainage channels essentially characterized by intermittent flow*' (Hall *et al.* 2008). These ecosystems are very widespread in Yemen, due to its mountainous reliefs (more than 450 watersheds). Most of them belong to nine wide watersheds, draining the western mountains and southern slopes. The appreciable rainfall at these highlands ensures some regular flow to the mountainous wadis, but these acquire intermittent regime when moving downstream, taking then the form of a chain of separate ponds. Their waters arrive to the sea or to the desert only during high floods (NBSAPY 2005), which floods carry a great quantity of alluvial deposits, with variable sizes, allowing agriculture on hillside terraces and riparian farms, even in high altitudes.

Surface water temperature, as a highly determinant ecological factor in the longitudinal organization of river communities, have been poorly studied, but punctual measures show high values: i.e. 27 to 35°C (exceptionally 40°C) at dry season between elevations of 230 m and 1254 m (Minissale *et al.* 2007). These values translate a determinant role of insolation combined to flow lowering in warm running waters. Consequently, as demonstrated in other dry lands (e.g. Dakki 1987), the Yemeni river communities are exposed during dry seasons to extreme thermal conditions in addition to the severe hydrologic stress.

The global warming, expressed in Yemen by frequent droughts, generates heavy loss in running water's biodiversity. On another hand, the riverine natural vegetation was dramatically destroyed in medium altitudes, due to the excessive occupation of the riverbanks. In the mountains, as well as in the plains, dams contribute to this regression by drying these riverbanks for long periods. However, vegetation is still relatively abundant at several canyons, that have been dug during the Quaternary pluvial periods (i.e. Hadramawt, Ayhaft, Dirhur, Al-Guedam north of Sana'a) and continue to deepen with violent floods. Because of their inaccessibility, canyons therefore play a significant role as reservoirs for aquatic biodiversity (Scholte 1992).

Springs

These small habitats correspond generally to groundwater emergencies, characterized by a low thermal amplitude and low concentration of organic matter. They are abundant in the western highlands and are responsible for the permanent and semi-permanent flow of some torrents. Most of these habitats have been transformed in a way to facilitate their use for drinking and irrigation. Thermal springs are relatively widespread in the western mountains and the southern littoral; at least 65 sites are known, mostly in the Tertiary and Quaternary volcanic areas (Kamra 2006 and Al Kubati *et al.* 2017). Their water temperature ranges between 40°C and 96°C (Minissale *et al.* 2007), giving them low chance to hold living communities, except some endemic phreatic invertebrates. The other springs, considered in geological literature as cold, have hot waters (30-35°C), in the sense that they are very selective of living communities. The lowest temperatures measured in springs and wells (21-27°C) are favorable to subtropical thermophilic fauna rather than to the Palearctic one (Dakki 1987 and Abd El-Mageed *et al*. 2013).

Lakes and ponds

In Yemen, freshwater lakes are practically absent, mainly because of the scarcity of large natural depressions and the dominance of the arid climate. However, intermittent pools are significantly frequent, as a consequence of the dry climate and intensive evaporation. The crater lake of Bir Ali near the coastal village of Bir Ali, is the only natural permanent lake; its brackish water reaches 28°C in dry season, indicating no volcanic influence (Mohammed *et al*. 2018).

Artificial wetlands

Throughout history, wetlands of Yemen as well as in other arid countries, have provided essential services to the local populations, thus their management and transformation date back to thousands of years. The traditional uses of these ecosystems were mostly sustainable, in the sense that they generate soft modifications. However, the recent exponential increase of the population intensifies the use of ecosystems with modern techniques that led to their deep transformation.

Artificial reservoirs

It includes large artificial reservoirs and small ponds, mainly created for agriculture, domestic use and aquifer recharge. According to the Ministry of Agriculture and Irrigation, 615 dams have been constructed in the upper lands until 2015, with different sizes and objectives. Most of the dams are in the western and central parts of the country, where more than 77% of the population lives. It should be reminded that Yemen has a long history in river damming and its ancient civilizations (like Ma'in, Saba and Himyar, which existed before the 12th century BCE) were mainly dependent of the great dam of Ma'rib, in such a way that their civilization disappeared when this dam collapsed. The new Ma'rib reservoir has a capacity of 400 million m^3, while the others reservoirs have a total capacity of 62.5 million m^3 (MAI 2013). This means a very high domination of small reservoirs that are relatively benefic at least in terms of recharging superficial aquifers (FAO 1997). Most of these reservoirs have small extension and are in deep valleys; therefore, their capacity to hold waterbirds is supposed to be relatively low (Al-Safadi 1995); many other reservoirs are exposed to intense insolation, which is highly favorable to evaporation and to eutrophication with frequent algae blooms (Charbonnier 2009).

Oases

These ecosystems, highly important in different international conventions, are considered as artificial because of their absolute domination by human habitats and activities. In Yemen, as in other dry and desert countries, oases take place on large river banks that benefit from renewable fertile soils (provided by the river) and from both surface and underground waters, making them as key agricultural lands. Oases have been managed for millennia; however, their vegetation and hydrological regime have recently been destroyed and depleted. In Yemen, most of the cities were originally in oases, as well as numerous villages that are actually growing up. However, the luxurious vegetation of oases, generally artificial and dominated by palm trees, offers very attractive habitats to breeding and migrating birds. The presence of large oases in Yemen, both at foothills and in mountains, amplifies this role (Almhab & Busu 2011).

Sewage wetlands

Wastewater treatment started only recently in Yemen, and less than twenty sewage stations have been created, but this number is expected to increase. Some famous treatment areas (as Ta'iz, Aden, Dhamar …) created large mud pans and marshes where several species of flora and fauna exist, including waterbirds. For example, sewage ponds in Aden including inter-tidal mudflats and a stretch of sandy beach and salt pans, are considered as important wetlands especially for migrant birds (e.g. Shobrak *et al*. 2003).

Channels

These artificial wetlands are very abundant, but small and traditionally concentrated in mountainous valleys, where they ensure domestic waters and more especially irrigation water for small agricultural terraces (Mohammed *et al*. 2018). Nevertheless, some large channels exist, mainly located in Coastal areas, the most popular one being in Mukalla city.

Salt pans

In Yemen, salt exploitation played an appreciable role in improving local people income, particularly on sea borders. Several salt pans were managed on the coasts of the Red Sea and the Gulf of Aden, the most famous salt production being in the Al-Hodidah region (mainly Alsaleif coast). However, salt pans are progressively abandoned since the 1990s and their number is decreasing in the whole country (Al-Najar *et al*. 2008), reducing their function as habitats for migrant, wintering and breeding waterbirds.

Several estuarine habitats were transformed, at least partly, in saltpans that are treated here as artificial ecosystems, although their area has been accounted in the estuaries.

DISCUSSION: MAJOR ORIGINALITIES OF YEMEN WETLANDS

The first major output of this overview concerns the high diversity and abundance of the Yemen wetlands, which have been demonstrated and justified. This result, unexpected in an arid country that evolves as a large island, is mainly explained by the diversity of orographic and marine situations and by the country's position at the crossroads of three biogeographic regions. Indeed, hundreds of wetlands have been identified, dominantly in riverine, marine and coastal domains, while lacustrine systems are quasi-absent.

Rivers hold, as well as in other arid zones, a high number of permanent puddles, named *gueltas* in North-Africa (Dakki *et al*. 2020), which hydrology is strongly linked to large floods that alternate with long droughts. These habitats extend to the river mouths, as these are in majority intermittently open/closed estuaries (Whitfield 1992, Whitfield *et al*. 2012).

This study focused also on the remarkable endemism that gives a high patrimonial importance to the flora and fauna of the country. Several studies focused on endemism in islands and in the Red Sea, but this aspect remains unstudied in running waters and springs, habitats as endemism hotbeds in arid zones (e.g. Dakki 1987). Indeed, the country evolves at least since the early Quaternary in insular context, amplified since the Arabian Desert appears.

In addition, Yemen is located in a major crossroads of bird migration between Eastern Europe and Western Asia to the North and Eastern Africa to the South. The data on this aspect are still relatively poor (Porter 1993, Shobrak 2003, Al-Obaid et al. 2017), but the habitat composition of the coastal wetlands and artificial reservoirs permit to suppose that they constitute determinant staging habitats for a high number of waterbirds.

Despite this importance, the Yemen wetlands undergo heavy human impacts. In fact, this country historically constituted a land of agriculture and fishing, mainly thanks to its river waters and seas. These were widely used since millennia, but this use became recently unsustainable because of an exponential population growth, combined with frequent droughts, political instabilities and a conservation policy context very lacunar.

The precipitation trend is until now clearly negative and don't seem improving in the near future; this means that the water scarcity is the major challenge that will face an eventual conservation strategy for wetlands. Actually, river damming and derivation and groundwater pumping are highly prior in facing this scarcity, but they transformed hundreds of river sectors, including estuaries, and impoverished their aquatic biodiversity.

CONCLUSION

The present article offers a large overview of the wetland diversity and characteristics in Yemen, and describes the natural and human factors that determine these characteristics, including dysfunctions. Facing the great rarity of academic studies, this work was achieved mainly thanks to satellite data, technical reports and unpublished information.

With this overview, it becomes easy to launch a national wetlands' inventory, as a major step in the assessment of their patrimonial values, their services and their dysfunctions and in planning their management, whether for conservation purposes or for sustainable use.

Compared to the whole Arabian Peninsula, Yemen shows the highest richness in wetlands and should therefore play a major role in conserving the regional aquatic biodiversity. This role is essential especially because of the originality (in terms of richness in endemics) of its flora and fauna. It is therefore clear that a high priority should be given to wetland conservation in this country. Indeed, despite their great value, these ecosystems benefited from poor conservation efforts (Harvey 1999, Shobrak *et al*. 2003, Al-Sagheir 2002b …) and few biological studies (i.e. Almhab & Busu 2011, Al-Safadi 1991, 1992, 1995), meanwhile they remain under heavy human and natural pressures.

In the actual political context, marked by instabilities that amplify poverty and justify more water use, a wetland conservation strategy has few chances to emerge, and even less for being implemented, only with national initiatives. It is to say that international organizations are called to give more attention to these wetlands and to help in gathering and publishing scientific data and in conserving habitats.

The poverty of the ecological knowledge on Yemen wetlands is another challenge that the country has to meet, for improving the conservation processes, mainly in inland water ecosystems. We are convinced that their aquatic communities will reveal many great surprises, mainly their relationships with European, African and Asian communities.

Abbreviations

GIS: Geological Information System, MEA: Millennium Ecosystem Assessment, EPA: Environmental Protection Authority, DEM: Digital Elevation Model, DID: Directorate of Irrigation and Dams, MAI: Ministry of Agricultural and Irrigation, NWRA: National Water Resources Authority, PERSGA: Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden, FAO: Food and Agricultural Organization, CSO: Central Statistical Organization.

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REFERENCES

Abd El-Mageed A, El-Kamel A., Abbady A. *et al*., 2013. Natural radioactivity of ground and hot spring water in some areas in Yemen. *Desalination,* 321, 28-31. https://doi.org/10.1016/j.desal.2011.11.022

Al Kubati M. Al Qraafi Fahd, Mattash M. *et al*., 2017. Geothermic characters of the most promising geothermal filed for power generation in republic of Yemen. *International Journal of Scientific & Technology Research*, 6, 55-63.

Almhab A. & Busu I. 2011. *The approaches for oasis desert vegetation information abstraction based on medium-resolution Landsat TM image: A case study in desert wadi Hadramut, Yemen*. Faculty of Geoinformation Science and Engineering, University of Technology, Malaysia, 1-5.

Al-Najar A., Aldeeb A. & Ahmed A., 2008. Geological and Tourism Study for Coastal Areas in Yemen. PHD Thesis, Aswan University, Egypt, 1-427. [Original version in Arabic].

Al-Obaid S., Samraoui B., Thomas J., El-Serehy H.A., Alfarhan A.H., Schneider W., O'Connell M., 2017. An overview of wetlands of Saudi Arabia: Values, threats, and perspectives. *Ambio*, 46, 98–108.

Al-Safadi M.M., 1991. Freshwater macrofauna of stagnant waters in Yemen Arab Republic. *Hydrobiologia,* 210, 203-208.

Al-Safadi M.M., 1992. Freshwater fishes of Yemen. *Proceedings of the Egyptian Academy of Sciences,* 42, 265-271.

Al-Safadi M.M., 1995. A pilot study of lake Ma'rib, Yemen. *Hydrobiologia*, 315, 203-209.

Al-Saghier O. 2002b. Survey for the Breeding Seabirds in Red Sea of the Republic of Yemen. *PERSGA Report.* Jeddah, 1-35.

Barnard P. & Thuiller W., 2008. Introduction Global change and biodiversity: Future challenges. *Biology Letters* 4, 553-555.

Barratt L., Dawson-Shepherd A., Ormand, R. *et al.* 1987. *Yemen Arab Republic Marine Conservation Survey*. Volume 1, Distribution of habitats and species along the YAR coastline, IUCN, Red Sea and Gulf of Aden Environmental Programme/ TMRU, UK, 1-23.

Bruland G.L., 2008. *Coastal wetlands: function and role in reducing impact of land-based management.* Natural Resources and Environmental Management Department, University of Hawaii Manoa, USA. 1-39. Available at: http://www.ctahr.hawaii.edu/brulandg/publications/CWM_Chapter04.pdf [Accessed: February 7th2016].

Charbonnier J., 2009. *Dams in the western mountains of Yemen: a Himyarite model of water management*. Proceedings of the Seminar for Arabian Studies, 39, 81-94.

CHIRPS. 2015. *Climate Hazards Group.* UC Santa Barbara. Available at: http://chg.geog.Uc sb.edu/data/chirps/ [Accessed April 21th 2016].

Crooks S., Herr, D., Tamelander J. *et al.* 2011. *Mitigating Climate Change through Restoration and Management of Coastal Wetlands and Near-shore Marine Ecosystems: Challenges and Opportunities.* Environment Department Paper 121, World Bank, Washington DC, 1-47. Available at: http://siteresources.worldbank.org/ENVIRONMENT/Resources/MtgtnCCthruMgtofCoastalWetlands.pdf [Accessed: June 14th 2015].

CSO (Central Statistical Organization), 2014. *Central Statistical Organization Yearbook 2014*. Ministry of Planning, Yemen, 1-127. [Original version in Arabic].

Dakki M., 1987. Ecosystèmes d'eau courante du haut Sebou (Moyen Atlas): études typologiques et analyses écologique et biogéographique des principaux peuplements entomologiques. *Travaux de l'Institut Scientifique, Rabat, Série Zoologie*, 42, 1-99.

Dakki M., El Fellah B. & Qninba A. 2020. Rivers' natural reservoirs: new inputs to the classification of Mediterranean and Saharan wetlands. *Bulletin de l'Institut Scientifique, Rabat, Série Sciences de la Vie*, 1-14.

Davidson N.C., 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. CSIRO Publishing. *Marine and Freshwater Research,* 65, 10, 936-941. Available at: http://dx. doi.org/10. 1071/MF14173 [Accessed: September 18th 2018].

Duffy, J.E., 2006. Biodiversity and the functioning of seagrass ecosystems. *Marine Ecology Progress Series*, 311, 233-250.

Elasha B.O. 2010. *Mapping of Climate Change Threats and Human Development Impacts in the Arab Region*. UNDP, Regional Bureau for Arab States, Arab Human Development Report, Research Paper Series, 1-49.

EPA (Environmental Protection Authority), 2004. *First National Report to the Convention on Biological Diversity*. Ministry of Water and Environment, Yemen, 1-88.

EPA (Environmental Protection Authority), 2009. *The 4th National Report: Assessing Progress towards the 2010 Target - The 4th National CBD Report.* Ministry of Water and Environment, Yemen, 1-100.

EPA (Environmental Protection Authority), 2013. *Yemen's Second National Communication under the United Nations Framework Convention on Climate Change.* Environmental Protection Authority, Yemen, 1-68.

Erwin K., 2008. Wetlands and global climate change: the role of wetland restoration in a changing world. *Wetlands Ecology Management,* 17, 71-84. Available at: https://www.wetlands.org/wp-content/uploads/2015/11/Wetlands-and-Global-Climate-Change. pdf. [Accessed: October23th 2015].

FAO (Food Agricultural Organization), 1997. *Irrigation in the Near East Region in Figures*, FAO, Rome, 1-320. Available at: http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/W4356E/w4356e0z.htm [Accessed October 24th 2015].

Geukens, F., 1966. *Geology of the Arabian Peninsula, Yemen:* U. S. Department of the interior stewartl. UDALL, Secretary Geological survey. B1-B22. Available at: https://pubs.usgs.gov/pp/0560b/report.pdf [Accessed September 13th 2018].

Hall M, Al-Khulaidi A.W. & Miller A.G. *et al.* 2008. Arabia's Last Forests under Threat. Plant Biodiversity and Conservation in the Valley Forest of Jabal Bura'a (Yemen). *Edinburgh Journal of Botany*, 65, 113–135.

Harvey D. 1999. Wildlife conservation initiatives in Yemen. Al-bab, Available at: https://al-bab.com/wildlife-conservation-initiatives-yemen [Accessed: May 18th 2019].

Hushulong Q. 2012. *The problems of wetlands in our country and the researches.* International Conference on Future Electrical Power and Energy Systems. Energy Procedia, 17, 462-466.

James N.C., Cowley P.D., Whitfield A.K. & Lamberth S.J. 2007. Fish communities in temporarily open/closed estuaries from the warm -and cool- temperate regions of South Africa: A review. *Reviews in Fish Biology & Fisheries*, 17, 565-580.

Kamra A.A., 2006. Yemen Geothermal Resources. *GRC Transactions*, 30, 637-642. Available at: http://pubs.geothermal-library.org/lib/grc/1025103.pdf [Accessed: June 11th 2017].

Kemp, J.M. 2000. Zoogeography of coral reef fishes of the Gulf of Aden. *Fauna of Arabia*, 18, 293-321.

Lill A.W.T., Closs G.P., Schallenberg M. & Savage C. (2012). Impact of berm breaching on hyperbenthic macroinvertebrate communities in intermittently closed estuaries. *Estuaries and Coasts*, 35, 155-168.

MAI (Ministry of Agricultural and Irrigation), 2013. *Annual Report.* Yemen. 1-78. [Original version in Arabic].

MAI (Ministry of Agricultural and Irrigation), 2016. *Annual Report.* Yemen. 1-56. [Original version in Arabic]

McCartney M., Rebelo L-M., Senaratna Sellamuttu S. *et al.*, 2011. *Wetlands, agriculture and poverty reduction*. IWMI Research Report, International Water Management Institute, Colombo, 137, 26 pp. DOI: 10.5337/2010.230.

MEA (Millennium Ecosystem Assessment), 2005. *Ecosystems and Human Well-being: Wetlands and Water-Synthesis.* World Resources Institute, Washington DC, 67 pp. Available at: https://www.Millennium-assessment. org/documents/document. 356. aspx.pdf [Accessed: August 13th 2016].

Minissale A., Mattash M.A., Vaselli O., *et al.,* 2007. Thermal springs, fumaroles and gas vents of continental Yemen: Their relation with active tectonics, regional hydrology and the country's geothermal potential. *Applied Geochemistry*, 22, 799–820.

Mohammed M., Frenzel P., Keyser D. *et al*., 2018. A humid early Holocene in Yemen interpreted from palaeoecology and taxonomy of freshwater ostracods. *Journal of Micropalaeontology*, 37, 167-180. Available at: https://doi.org/10. 5194/jm-37-167-2018 [Accessed: September16th 2018].

Navid D., 1989. The international law of migratory species: The Ramsar Convention. *Natural Resources Journal*, 29, 1001-1016, Available at: http://digitalrepository.unm.edu/cgi/viewcontent.cgi?article=2481&context=nrj [Accessed: March 23th 2015].

NBSAPY 2005. *National Biodiversity Strategy and Action Plan for Yemen.* UNDP/GEF/IUCN YEM/96/G31, Ministry of Water and Environment, Yemen, 70 pp. Available at: https://www.cbd.int/doc/world/ye/ye-nbsap-01-en. pdf [Accessed June 14th 2015].

Nozais C., Perissinotto R. & Tita G. 2005. Seasonal dynamics of meiofauna in a South African temporarily open/closed estuary (Mdloti Estuary, Indian Ocean). *Estuarine, Coastal and Shelf Science,* 62, 325-338.

NWRA (National Water Resources Authority), 2005. *Annual Report.* Ministry of Water and Environment. Yemen, 49 pp.

O'Connor N. & Crowe T., 2005. Biodiversity Loss and Ecosystem Functioning: Distinguishing Between Number and Identity of Species. *Ecology*, Ecological Society of America, 86, 7, 1783-1796.

Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. & Hanson C.E. (Eds.), 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the IPCC, Cambridge University Press, 811 pp. Available at: https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4_wg2_full_report.pdf [Accessed: May 14th 2015].

Perissinotto R., Stretch D.D. & Whitfield A.K. *et al*. 2010. Ecosystem functioning of temporary open/closed estuaries in South Africa. *In* Crane J.R. & Solomon A.E. (Eds). *Estuaries: Types, movement patterns and climatical impacts*. Nova Science Publishers, New York, ISBN 978-1-60876-859-2. 69 pp.

Porter R. 1993. Birds of Yemen. Al-Bab, https://al-bab.com/birds-yemen

Ranasinghe R. & Pattiaratchi C. 2003. The seasonal closure of tidal inlets: causes and effects. *Coastal Engineering Journal,* 45, 4, 601-627.

RAP (Rural Access Program). 2004. *Draft Sectoral Environmental Assessment.* SHEBA Engineering Services, Sana'a, 165 pp.

Roy P.S., Williams R.J. & Jones A.R. *et al.* 2001. Structure and function of south-east Australian estuaries. *Estuarine, Coastal and Shelf Science,* 53, 351-384.

Scharler U.M., Lechman K., Radebe T. *et al.* 2020. Effects of prolonged mouth closure in a temporarily open/closed estuary: a summary of the responses of invertebrate communities in the uMdloti Estuary, South Africa. *African Journal of Aquatic Science*, 45, 1, 1-10. DOI: 10.2989/16085914.2019.1689911.

Scholte P. 1992. *The birds of Wadi Rima, a permanently flowing mountain wadi in western Yemen*. Sandgrouse, 14, 2, 93-108.

Sheppard C.R.C., Price A.R.G. & Roberts C.M. 1992. *Marine ecology of the Arabian Region: patterns and processes in extreme tropical environments*. Academic Press, London, 359 pp.

Shobrak M., Alsuhaibany A. & Al-Saghier O. 2003. *Regional status of breeding seabirds in the Red Sea and the Gulf of Aden.* PERSGA Report, 74 pp.

Snow G.C. & Taljaard S. 2007. Water quality in South African temporarily open/closed estuaries: a conceptual model. *African Journal of Aquatic Science,* 32, 2, 99-111.

Stuip M.A., Baker C.J. & Oosterberg W. 2002. *The Socio-economics of Wetlands*. Wetlands International and RIZA, The Netherlands, 28 pp.

Taljaard S., Van Niekerk L. & Joubert W. 2009. Extension of a qualitative model on nutrient cycling and transformation to include microtidal estuaries on wave-dominated coasts: Southern hemisphere perspective. *Estuarine, Coastal and Shelf Science*, 85, 407-421.

Tardelli M. & Baldini R. 2000. Botanical Report on the Island of Socotra (Yemen). *Portugaliae Acta Biologica*, 19, 443-453.

Tweddle G.P. & Froneman P.W. 2015. Influence of mouth status on population structure of Southern African endemic estuarine-spawning ichthyofauna in a temperate, temporarily open/closed estuary. *African Journal of Aquatic Science*, 40, 2, 221-225. DOI: 10.2989/16085914.2015.1051940.

Van der Gun J. & Ahmed A. 1995. *The water resources of Yemen. a summary and digest of available at information.* WRY35 Technical Report, Ministry of Oil and Mineral Resources, Sana'a, Yemen. 106 pp. Available at: https://www.researchgate.net/publication/282665864 [Accessed: March 10th 2014].

Ward C., Ueda S. & McPhail A. 2000. *Water Resources Management in Yemen.* CDR_H2O_0112. World Bank, 39 pp. Available at: http://siteresources.worldbank.org/INTYEMEN/Overview/20150274/YE-Water. pdf [Accessed: March 4th 2014].

Whitfield A.K. 1992. A characterization of Southern African estuarine systems. *South African Journal of Aquatic Science*, 18, ½, 89-103.

Whitfield A.K., Bate G.C. & Adams J.B. et al. 2012. A review of the ecology and management of temporarily open/closed estuaries in South Africa, with particular emphasis on river flow and mouth state as primary drivers of these systems. *African Journal of Marine Science,* 34, 163-180.

Worldmeters, *2019. Yemen's Population from 1955-2050.* Dadax. Available at: https://worldpopulationreview.com/countries/yemen-population [Accessed: April 9th 2019].

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