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Evaluation of urban sustainability through the metabolic study of nutrient food flows: The case of the Grand Nador, Morocco, city-region.

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Ph.D. Thesis

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Abstract

For the first time in history a majority of the global population live in urban areas. In the coming decades, most of the world's population growth is expected to be absorbed by coastal urban areas -specifically in small and medium cities and urban peripheries- of the developing world.

In the last decades, anthropogenic food-related activities and urbanization have been identified to contribute altering the natural nitrogen (N) and phosphorus (P) nutrient cycles, as well as exhausting P-mineral resources. These alterations have caused a myriad of pollution and environmental problems resulting from nutrient accumulation and loss to the soil, waters and air. Both macronutrients are critical for regional and global food security, by virtue of being essential inputs for agricultural food production.

In an increasingly urbanized world, urban areas and their development are at the centre of all discussions on sustainability and/or sustainable development. Yet, the role played by cities as drivers of environmental change at multiple scales, e.g. as agents in the flow of energy and materials, stays poorly recognized, and thus grossly understudied, remaining even more scarce (even least available) when it comes to studies of cities in developing countries. The latter are significantly constrained by limited data availability, access, and data collection resources.

The notion of Urban Metabolism (UM) provides a conceptual framework to study how a city functions, and hence, a way to address the sustainability of a city.

The present research, focused in the city-region of Grand Nador in northeast Morocco as a case study, aimed to study the role played by urban areas as agents in the metabolism of food by, on the one hand, examining the circulation of the major nitrogen (N) and phosphorus (P) food-related flows by using the analytical method of Substance Flow Analysis (SFA), and on the other hand, contextualizing the politico-historical development of the urban region. N and P flows were estimated using mainly data from official statistical databases, published literature and unpublished reports authored by municipal and regional level institutions. Besides, approximations, surrogates and proxies were used, as well as the adoption of different assumptions and estimation methods. As a result of data limitations, an uncertainty analysis was performed to enhance the reliability of results.

The results displayed the linearity of the N and P food-related flows studied, elucidating the openness of the food metabolism in the urban system of Grand Nador. Results also showed the strong insights of the significant influence that urban histories, namely the sociopolitical and historical context in which a region develops, have on its structure, functioning and metabolic flows. Different existing options towards more-balanced nutrient management and to reduce and enhance nutrient N and P recirculation in Grand Nador are discussed. Likewise, new lines of further research are advanced.

Keywords: Urbanization, Urban metabolism, food, nitrogen, phosphorus, Substance Flow Analysis (SFA), environmental impacts, Sustainability, Grand Nador.

Resumen

Por primera vez en la historia de la humanidad, una mayor proporción de la población global vive en áreas urbanas. En las próximas décadas, se espera que la mayor parte del crecimiento mundial previsto sea absorbido por las zonas urbanas costaneras del mundo en desarrollo, específicamente en las ciudades pequeñas y medianas así como en las zonas periféricas.

En las últimas décadas, tanto las actividades humanas de producción y consumo de alimentos, cómo el fenómeno de la urbanización, se han identificado como actividades que contribuyen a alterar los ciclos naturales de los nutrientes del nitrógeno (N) y del fósforo (P), así como de promover el agotamiento de los recursos minerales del fósforo, generando impactos medioambientales negativos resultantes de la acumulación y pérdida de nutrientes en la tierra, el agua y en la atmosfera. Ambos macronutrientes son básicos para la seguridad alimentaria regional y global al ser insumos esenciales para la producción agrícola de los alimentos.

En un mundo cada vez más urbanizado, tanto las áreas urbanas como su desarrollo se encuentan en el centro de todas las discusiones sobre sostenibilidad y desarrollo sostenible. Sin embargo, el papel que desempeñan las ciudades como motores de cambio ambiental a múltiples escalas, p.ej. como agentes en el flujo de energía y materiales, permanece poco reconocido, y por lo tanto poco estudiado, siendo aún más escasos los estudios sobre ciudades en los países en desarrollo, debido a su limitada disponibilidad, acceso y recolección de datos.

La noción de metabolismo urbano (UM) proporciona un marco conceptual para el estudio del funcionamiento de las ciudades, y consecuentemente, una aproximación al análisis de la sostenibilidad de las mismas.

La presente investigación, centrada en el caso de estudio de la ciudad-región de Gran Nador, en el noreste de Marruecos, tiene por objetivo el estudio del papel que desempeñan las áreas urbanas como agentes en el metabolismo de los alimentos. El estudio, por un lado, analiza la circulación de los principales flujos de nutrientes de los alimentos, el nitrógeno (N) y el fósforo (P), mediante la aplicación del método de Análisis del Flujo de Sustancias (SFA). Por otro lado, contextualiza el desarrollo sociopolítico e histórico de la región urbana de estudio. Los flujos de N y P se calcularon mediante el uso,principalmente, de datos procedentes de bases de datos estadísticas oficiales, literatura publicada e informes no publicados elaborados por las instituciones municipales y regionales de la zona. Además, se utilizaron distintas aproximaciones y "proxies", así como la adopción de diferentes supuestos y métodos de estimación. Finalmente, se realizó un análisis de incertidumbre para mejorar la fiabilidad de los resultados.

Los resultados muestran la linealidad de los flujos de N y P analizados, evidenciando así la apertura del metabolismo de los alimentos en el sistema urbano de Gran Nador. Los resultados también sugieren los fuertes indicios en relación a la influencia significativa que las historias urbanas, es decir, el contexto sociopolítico e histórico en que se desarrolla una región o área urbana, tienen sobre la estructura, el funcionamiento y los flujos metabólicos de la misma área urbana. Posteriormente, el estudio presenta distintas opciones existentes hacia una gestión más equilibrada de los nutrientes, a la vez que para reducir la pérdida y acumulación y aumentar la recirculación de los nutrientes de N y P en Gran Nador. Finalmente, el estudio introduce posibles nuevas líneas de investigación para avanzar con el presente estudio.

Palabras clave: Urbanización, metabolismo urbano, alimentos, nitrógeno, fósforo, Análisis del Flujo de Sustancias (SFA), impactos ambientales, sostenibilidad, Gran Nador.

Table of Contents

Acknowledgements v

Abstract vii

Resumen viii

Table of Contents 11

List of figures 13

List of Tables 14

List of abbreviations 15

Preface 17

- Background 17
- Research questions, objectives and working hypotheses 19
- Methodology 20
- Structure of the thesis 22
- References 24

Chapter 1.-Urban Metabolism: A review of recent literature on the subject 33

- Introduction and background 33
- What does urban metabolism mean? A historical perspective of the concept 35
- Contemporary understandings of urban metabolism 37
- Commonalities and controversies on urban metabolism 42
- Methodological approaches toward the biophysical notion of urban metabolism 44
- Conclusions 45
- References 45

Chapter 2.- The political and historical roots of Grand Nador 53

- Introduction 53
- Description of the study area 55
- The political-historical roots of Grand Nador 61
  - Migratory movements: rural to urban and international labor migration 66
  - The dynamics of city development 70
  - Land market and real estate. Land property speculation as engine and consequence of the urban explosion 72
- The current situation of Grand Nador 75
- Discussion 77

Conclusion ... 80
References ... 81
Chapter 3.- Assessment of Nutrient flows for the urban metabolism of food in Grand Nador, Morocco ... 89
Introduction ... 89
Objectives of the Grand Nador Case Study ... 93
Methodology ... 94
Description of the study area ... 94
Methodology ... 95
Data collection and sources ... 97
System Analysis. Model description and estimation of nutrient flows ... 97
System boundary definition and description ... 97
Model description ... 98
Estimation of nutrient flows. Developing the substance flow model ... 101
Uncertainty analysis ... 133
Results ... 136
Discussion ... 144
Nutrient reduction and recirculation options ... 144
Uncertainty ... 152
Limitations of this assessment and future research ... 153
Conclusion ... 155
References ... 157
Conclusions ... 173
References ... 180
Appendices ... 181

List of figures

Figure 1.: Administrative division of the Oriental Region and its geographic situation and the Grand Nador area of study.. 55
Figure 2.: Administrative division of the Nador and Driouch provinces by Decree nº2-09-319 on 11th June 2009; and shaded in red the urban and rural communes that make up the Grand Nador area of study. 56
Figure 3.: Geographical location map of the Nador region, with the coastal Bou-Areg Plain, the inland Gareb plain and the lagoon of Nador in Morocco. 57
Figure 4.: Location map of the coastal Bou-Areg Plain and Gareb plain of Morocco. 57
Figure 5.: Aerial photo of the lagoon of Nador or Marchica lagoon in Morocco. 58
Figure 6.: View of the civil town of Nador corresponding to the years 1909 (left) and 1911 (right) 61
Figure 7.: Panoramic view of Nador on the day of its occupation by the Spanish troops, 17th September 1921. 62
Figure 8.: Photography of the railroad station of the Spanish Rif Mines Company, 1921. 63
Figure 9.: Location map of the iron mining deposits of Ouichane and the mining railway lines for the exploitation of the iron deposits by the Spanish Rif Mines Company, 1921. Also showing the geo-economic strategic enclave of Nador by the Spaniards. 64
Figure 10.: Map of the building construction evolution in Nador since independence to last decade. 67
Figure 11.: Time-line of the birth and growth of the Nador city and its urban agglomeration. 75
Figure 12.: Flow diagram representation of the system analysed. 100
Figure 13.: Irrigated perimeters of Bou-Areg and Gareb under the administration of the Moulouya Regional Office of Agricultural Development – ORMVAM, and the principal irrigation channel. 103
Figure 14.: Irrigated perimeters under the administration of the Moulouya Regional Office of Agricultural Development – ORMVAM- and the Grand Nador area of study. 104
Figure 15.: Location of three depolluting initiatives/programs developed in the region of Grand Nador and supported by the Royal initiative and compelled by national legal frameworks: The WWTP of Nador, the sanitary landfill and the new inlet of the Nador Lagoon. 125
Figure 16.: Flow diagram representation of the Consumption and Waste management processes analysed. 127
Figure 17.: NITROGEN flow diagram of the Urban food metabolism of Grand Nador in 2010. 138
Figure 18.: PHOSPHORUS flow diagram of the Urban food metabolism of Grand Nador in 2010. 139
Figure 19.: Nitrogen and Phosphorus Waste Management Sub-process flow diagram of the Urban food metabolism of Grand Nador in 2010. 140

List of Tables

Table 1. Contemporary interpretations and current debates on the concept of urban metabolism across different disciplines from biophysical and political economy sciences. 42
Table 2.: Data on population density and urban population on 1994, 2004 and estimates for 2010, at the different administrative levels of country, region, province and the area of study. 60
Table 3.: List of companies forming the fishing processing industry of Nador, specifying its main activity and production capacity. 118
Table 4.: Definition of uncertainty level/intervals adapted to the present study. 136
Table 5.: Calculated average inputs and outputs of N and P of Grand Nador agricultural production land in 2010. 141
Table 6.: Average flows in tonnes year^{-1} of nitrogen and phosphorus in livestock production in Grand Nador in 2010. 142
Table 7.: Average flows in Kg year^{-1} of nitrogen and phosphorus and their uncertainty intervals, in Grand Nador in 2010. 154

List of abbreviations

AND:	Atmospheric Nitrogen Deposition.
BIP:	Biodiversity Indicators Partnership.
BNF:	Biological Nitrogen Fixation
a.a.p:	average annual precipitation.
DM:	Dry Matter.
FAO:	Food and Agriculture Organization of the United Nations.
FU:	Feed Unit
GDP:	Gross Domestic Product.
GN:	Grand Nador.
GW:	Ground Water.
HH:	Household.
LCA:	Life Cycle Analysis.
MFA:	Material Flow Analysis.
MMFA:	Mathematical Material Flow Analysis.
MMS:	Manure Management system.
N:	Nitrogen. In this study referred to as total nitrogen that is normally denoted as TN.
Nr:	Reactive nitrogen.
N_2:	Diatomic nitrogen.
NOx:	Nitrogen Oxides.
N_2O:	Nitrous Oxide
NH_3:	Ammonia nitrogen.
ORMVAM:	Regional Office of Agricultural Development of the Moulouya administration.
OSW:	Organic Solid Waste.
P:	Phosphorus. In this study referred to as total phosphorus that is normally denoted as TP.
Pdct.	Product
SA:	Study Area.
SFA:	Substance Flow Analysis.
SWM:	Solid Waste Management.
UM:	Urban Metabolism.
WW:	Wastewater
WWTP:	Wastewater Treatment Plant

Preface

Background

Cities are the primary habitat for over half of the global population (Girardet, 1996; UN-WUP, 2011), and this figure is expected to rise to 60 percent by 2030 (Decker et al., 2000) and up to 70-80 percent by 2050 (UNEP, 2013). Moreover, across the globe, urban areas have grown dramatically not only in size and density but also in complexity, i.e. in their social structures, economic systems, geopolitical settings, and technological advances (Decker et al., 2000; Kennedy et al., 2007; Satterthwaite, 2007).

On a global scale, cities, on just 2 percent of the earth's land surface, command economic growth, with 80 percent of global GDP, and use over three-quarters of the world's resources discharging similar amounts of wastes to the environment (Baccini, 1997; Barles, 2010; Girardet, 1996; UNEP, 2013). According to UNEP (2013), urban areas currently account for 60-80 percent of global energy consumption (Zangh et al., 2014), 75 percent of carbon emissions, and more than 75 percent of the world's natural resource consumption.

Hence, cities are not only important drivers for socioeconomic development, but also hot spots of human pressures on ecosystems that drive environmental change at multiple scales (Glasow et al., 2013; Grimm et al., 2008; Sekovski et al., 2012; UNEP/MAP, 2012). As population density and economic activity increase, so do pressures on the structure and functions of ecosystems and on the services provided by them (Bai, 2007; Decker et al., 2000; Huang et al., 2012; Niza et al., 2009). Urban production, consumption and waste discharge not only alter land use and cover, biodiversity and hydro systems locally to regionally, but also affect local to global biogeochemical cycles and climate (Grimm et al., 2008). Yet, urban settlements also offer important economies of scale accommodating large numbers of people in a limited space and providing them with jobs, housing, and a myriad of services (Girardet, 1996; Satterthwaite, 2007).

Therefore, in an increasingly urbanized world, cities need to be part of the global problem-solving process to sustainability challenges (Girardet, 1996; Grimm et al., 2008). Accordingly, urban areas and their development are at the centre of all discussions on sustainability and/or sustainable development (Baccini, 1997). As stated by UNEP (2013) cities must therefore be seen as the building blocks of sustainable development.

Since urban areas are complex networks whose unique structure and functioning can result into very different levels of energy, water and materials consumption (UNEP, 2013), it is imperative to first gain a clear understanding of the functioning and processes of the urban system, as well as their impacts and their urban lifestyles implications (in terms of consumption and discharge patterns) in order to achieve more circular urban systems, and to increase compatibility with their surrounding environment while reducing impacts on the local to the global environment (Baccini, 1997; Decker et al., 2000; Girardet, 1996).

Some examples of biophysical analysis on energy (Baynes and Bai, 2012, in Melbourne, Australia; Browne et al., 2012, at Limerick city-region in Ireland; Zhang et al., 2014, in Beijing, China), water (Amores Barrero et al., 2013, in Tarragona, Spain; Erni, 2007, in Kumasi, Ghana; Mahgoub et al., 2010, in Alexandria, Egypt; Rozos and Makropoulos, 2013, in Athens, Greece), food (Barles, 2007, in Paris, France; Faerge et al., 2001, in Bangkok, Thailand; Forkes, 2007, in Toronto, Canada; Neset et al., 2008, in Linköping, Sweden; Qiao et al., 2011, in Beijing and Tianjin, China) and waste flows (Belevi, 2002, in Kumasi, Ghana; Cherubini et al., 2008, in Rome, Italy; Damanhuri et al., 2009, in Bandung and Cimahi cities, Indonesia; Kalmykova et al., 2012, in Gothenburg, Sweden; Liang and Zhang, 2012, in Suzhou, China; Montangero et al., 2007, in Hanoi, Vietnam; Qu et al., 2012, in Suzhou, China) have been carried out by several authors in different city-regions. Yet, as acknowledged by authors like Barles (2010) and Decker et al. (2000) the role played by cities in environmental transformations, e.g. as agents in the flow of energy and materials, remains poorly recognized, and thus grossly understudied. Likewise, local, global and differed impacts in both space and time are also poorly recognised (Barles, 2010).

In this regard, food production has been acknowledged by several authors (Bouwman et al., 2005; Childers et al., 2011; Cordell et al., 2009; Fowler et al., 2013; Galloway et al., 1995, 2003, 2004; Matsubae-Yokoyama et al., 2009; Neset et al., 2008; Smil, 1993; Vitousek et al., 1997, 2002) to be one of the major anthropogenic activities that have contributed to alter the natural nitrogen (N) and phosphorus (P) nutrient cycles causing a myriad of pollution and environmental problems resulting from nutrient accumulation and loss to the soil, waters and air.

Therefore, one of today's main societal challenges, in the context of food security, is to respond to the increasing demand for food and agriculture's growing need of nutrients without exhausting P mineral resources, and reducing N and P negative environmental impacts.

Urbanization has been identified as a key driver in altering the biogeochemical cycles of N and P (Grimm et al., 2008; Liu et al., 2008; Qiao et al., 2011) by promoting the shift from a society relying on nutrient recycling (the traditional closed rural or traditional city cycle of nutrients) to a society totally dependent on external nutrient inputs (the open urban cycle). That is, on the one side, the majority of the global population is urban, thus certainly living at a significant distance to the agricultural land where their food is produced and leading to nutrients loss in waterways via urban sewers or as sludge in landfills instead of being recycled back to agricultural land (Cohen, 2006; Cordell et al., 2009; Ma, 2014; Neset et al., 2008). On the other hand, urban diets are associated with animal rich products, which require significantly higher N and P inputs for their production (Neset et al., 2008; Qiao et al., 2011), as well as larger areas for their production (Neset, 2005).

Moreover, most of the world's population growth in the coming decades is expected to be absorbed by coastal urban areas in low- and middle-income nations (Glasow et al., 2013; Kilcullen, 2012; McGranahan et al., 2007; Satterthwaite, 2007; UN, 2009, p.1). Urban settlements in coastal lowlands are densely settled and expand very rapidly (McGranahan et al., 2007). Additionally, the bulk of urban growth is specifically occurring in small and medium cities and urban peripheries or peri-urban areas of the developing world, where simultaneously, the process of urbanisation is far more heterogeneous and complex, encompassing problems of poverty, inequality, informality, rapid urbanisation and spatial fragmentation (Lerner and Eakin, 2011; Watson, 2009). The relevance of both fast-increasing trends, mutually reinforcing each other, translates into major, potentially worrisome environmental consequences associated with urban growth. The southern Mediterranean basin is cited as a clear example of this urban-littoralization trend (Kilcullen, 2012; Kramsch, 2007; UNEP/MAP, 2012). Yet, as acknowledged by authors like Montangero (2006) studies in developed countries remain scarce as they are significantly constrained by limited data availability and data collection resources.

This thesis studies the nutrient (N and P) food-related flows of the urban agglomeration of Grand Nador (GN), in northeast Morocco. The Grand Nador city-region provides an interesting case for such an investigation since, in addition to its location, in the coast of the southern Mediterranean basin, GN forms part of the world's lower-middle-income economies, according to the World Bank data classification (http://data.worldbank.org/country/morocco?view=chart). Moreover, the region has been undergoing a fast process of urban growth in the last decades and concentrates almost all of the regional economy, which is an important source of environmental imbalances (Nakhli, 2010). Besides, in ecological terms, GN is bounded to the Northeast and Southeast by the locally known Sebkhat Bou Areg, or the lagoon of Nador, whose ecological value is not only acknowledged at national level, as part of the Sites of Biological and Ecological Interest (SIBE, in french), but also internationally as a RAMSAR site since 2005. Besides, GN shelters other highly original yet fragile biodiversity natural domains. These values make the coast of GN a place with important environmental, economic and social challenges (SDAU-GN, 2012).

Research questions, objectives and working hypotheses

My general research questions are:

- Do food chains in urban systems influence the possible openness and linearity of the N and P cycles? And if so, to what extent?
- Do urban histories have an influence on metabolic flows? And if so, in what ways?

The general objective of this thesis is to gain insight on the environmental, social and economic interactions that shape urban phenomena, and, more generally, on the relations between society and nature in urban areas, with the final aim to manage the urban environment in more compatible ways with sustainability.

Given the myriad of aspects and complexity of the urban phenomenon, I will approach this general objective focusing on how human production, consumption and waste regarding food in urban areas affect nutrient flows. More specifically I will examine the circulation of food nutrients, i.e., nitrogen and phosphorus, in urban areas. Moreover, since the period of analysis was established for one year, I needed a politico-historical study of the region to provide a context for the narrative that follows.

As said before, my case study will be the Grand Nador (GN) urban region of Morocco. The specific objectives of the present research are as follows:

- To determine how and to what extent the urban history of Nador has influenced metabolic flows.
- To assess the suitability of the conceptual framework provided by urban metabolism to study the urban flow system of Grand Nador.
- To identify and quantify the major N and P food-related flows in the urban agglomeration of Grand Nador for the four processes studied: production, processing, consumption and disposal.
- To elucidate whether the nutrient system studied is cyclic or linear, i.e., the degree of openness of the N and P cycles.
- To assess possible ways by which to increase the efficiency in use and the degree of recovery for the cycling of N and P in order to reduce nutrient emissions to the environment.

The general working hypotheses on which I base the present study are:

- Changes in food consumption habits associated with urban growth determines the nature and intensity of nutrient flows, and nutrient flows follow linear and not circular pathways.
- Urbanization processes in history shape cities' unique structure and functioning which, in turn, determine the nature and intensity of nutrient flows.

Methodology

The notion of urban metabolism (UM) forms the conceptual framework of this dissertation, and the study of the metabolic nutrient food-related flows of the Grand Nador city-region has been approached by employing the predominant biophysical conception of urban metabolism. In this regard, different methodological approaches are used to account for and analyse the urban metabolic process from a biophysical perspective. Material Flow Analysis –MFA-, Substance Flow Analysis –SFA-, Input-Output analysis (and PIOT-physical input-output tables), eMergy (energy flow) analysis; Ecological footprint analysis, Ecological network analysis, MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism) and LCA – Life Cycle Analysis, are among the main tools used to conduct physical environmental accounting, based on the study, in variable depth, of material and energy flows.

Substance Flow Analysis (SFA) has been the analytical method used to develop the present study, based on system perspectives, its core principle is the mass balance principle, in which the modelling of material and energy flows is governed by the laws of conservation of matter and energy (Barles, 2010; Daniels and Moore, 2002; Hammer et al., 2003).

Studies that can be classified as SFA applications have been conducted since the 1920s, first in ecology, and later on in biogeochemical cycles, including human interference, and on flows in economic systems. More harmonized SFA efforts began in the 1990s (Van der Voet, 2002).

A number of SFA studies (or that could be classified as such) of nitrogen and phosphorus flows have been conducted through different systems at various geographical and temporal scales such as the global scale (Bouwman et al., 2005, 2009; Childers et al., 2011; Cordell et al., 2009; Dawson and Hilton, 2011; Fowler et al, 2013; Galloway and Cowling, 2002; Galloway et al., 2004, 2008; Liu et al., 2008; Smil, 2000, 2002c; Villalba et al., 2008), country or national level (Antikainen, 2007; Antikainen et al., 2005; Chen et al., 2008, 2010; Cooper and Carliell-Marquet, 2013; Cordell et al., 2013; Ma, 2014; Ma et al., 2012; Matsubae-Yokoyama et al., 2009; Risku-Norja and Mäenpää, 2007; Saikku et al., 2007; Senthilkumar et al., 2012; Sokka et al., 2004; Thaler et al., 2013), at regional scale (Boyer et al., 2002; Faerge et al., 2001; Kalmykova et al., 2012; Metson et al., 2012b; Montangero, 2006; Vladimirovna, 2013; Wu et al., 2012; Yuan et al., 2011) and at city scale (Erni, 2007; Forkes, 2007; Li et al., 2010; Ma et al., 2008; Neset, 2005; Neset et al., 2008; Qiao et al., 2011; Yuan et al., 2011), even some studies have been conducted at smaller geographical scales, such as household level (Baker et al., 2007), or specific production sector, like the rainbow trout aquaculture in Finland (Asmala and Saikku, 2010).

Data collection included the compilation of official national/regional and local statistical data, mainly from the official statistics of the Moroccan Haut-Commissariat au Plan and from international institutions (e.g. Faostat), scientific publications -case study and general literature-based values, e.g. nutrient content in food-, and databases, external studies, institutional and business reports and other grey literature, and environmental monitoring data when existing and accessible. Data was also derived from expert estimates and knowledge by interviews with the major actors involved, as well as from unpublished reports provided by the experts working at the institutions interviewed. All these data and sources provided the basis for the calculations of the nutrient food-related flows.

In developing countries, as it is the case of Morocco, data at municipal level is not always collected and systematized. Besides access to in-situ specific data was difficult to reach, sometimes not available and most of the time non-accessible.

As a result of data limitations, the present study had to rely mostly on data from different nature of sources and of varying quality as input for modelling. Namely, data used were based on single measurements only, rescaled, extracted from another region, process, year or systems and transformed to apply to the investigated system. Likewise, the adoption of assumptions and estimation methods provided by other authors in their case studies or by other institutions, were also used. Therefore, wherever it was possible data cross-check with values in the literature was done or more than one source was consulted. Moreover, interviews with local experts, together with personal visits to the facilities/sites allowed qualitative assessments of the data.

Structure of the thesis

This thesis is organized in three parts: introduction, main body and conclusions. The main body is in turn divided in two chapters. The introduction focuses on the conceptual and methodological framework of this work, with an attempt at substantiating its focus. This Chapter has been published in the SCOPUS-indexed journal Documents d'Anàlisi Geogràfica 2014, vol. 60/3 (http://dx.doi.org/10.5565/rev/dag.134). Two main chapters follow, each one presented as a complete work with its own findings and both based in the study of the urban agglomeration of Grand Nador. Chapter 2 explores the political and historical context in which the urban agglomeration of GN has developed. Conversely, Chapter 3 develops the accounting analysis of the nutrients in food-related flows of the area of study. The last Chapter summarizes the main conclusions of this research.

The first chapter introduces the notion of urban metabolism in general terms to continue with the concept's historical roots or intellectual antecedents. Contemporary understandings of urban metabolism as approached and applied across the different disciplines of urban ecology, industrial ecology, ecological economics, political ecology and urban political ecology are extensively presented. The commonalities and controversies of the different disciplinary conceptions of UM are discussed. Focusing on the most widely used conception of UM today, the diversity of methodological approaches towards the biophysical notion of UM are presented.

Unlike most theses, there is no separate Methodology Chapter. The study that follows has been developed within the framework of the EU 7FP MEDINA project. Therefore, a literature review on the current different methodological approaches used to account for and analyse urban metabolic processes was developed to provide a methodological framework for the study. The studies of Daniels and Moore (2002), Hammer et al. (2003), Loiseau et al. (2012), Huang et al. (2012), and Zhang (2013) were of great help. Together with other case studies in the literature, they provide guidance on the specific potential difficulties, constrains and peculiarities found at the city-region scale of analysis, as well as alternative ways to overcome them. Extrapolation of data and different estimation methods were among the most used methodological solutions. Yet, the decision process to choose the method to be used in the study was primarily marked by the specific requirements of the MEDINA project, and the fact that the case study was to be carried out in a developing country like Morocco. In anticipation of possible difficulties in the collection and access to data, jointly with the short time period available to field work, I considered more appropriate to choose a generally accepted method, and not to add more uncertainty and lack of robustness to my results than that given by my input data. Therefore, the primary methodological framework of MFA was chosen since it provides great scope for the generic application and advancement of environmental accounting and systems analysis. Yet, as N and P nutrients were the target of study SFA was the finally chosen and applied method of analysis.

Chapter Two describes the area of study and introduces the political and historical context in which the urban agglomeration of Gran Nador has developed. This section specially emphasizes the factors of migration, city development dynamics and land market and real estate as key drivers in Grand Nador's urban growth. The Chapter intends to reveal the role that sociopolitical and historical factors play on the structure, functioning and processes of urban systems, as fundamental to correctly understand and comprehend the city's structure and flows. Thereby, albeit exploratory and descriptive, the Chapter attempts to address the lack of proper politico-historical contextualization of the biophysical UM approach studies. However, the full integration of the sociopolitical and historical aspects and of their influence on cities' flows was not pursued in the depth desired. Besides data shortcomings, complete integration necessitates interdisciplinary work between sociopolitical and biophysical UM dimensions. Accordingly, this full integration job means the work of another complete doctoral thesis. The chapter ends with a brief discussion and a section of main conclusions.

In Chapter Three the assessment of nutrient flows for the urban metabolism of food in Grand Nador is presented. After introducing the significant role nitrogen and phosphorus nutrients play in food production, and the consequences derived from the increased use of N and P in the last decades, the specific objectives for this nutrient flows assessment are presented. The method applied and the data sources and collection used are also described. The chapter follows with the definition and description of the system boundary, the description of the model, and the estimation of nutrient flows, hence developing the substance flow model. As a result of data limitations, this chapter also includes an uncertainty analysis in order to enhance the reliability of results. After the presentation of the study results, the chapter discusses on different existing options to reduce and enhance nutrient N and P recirculation in Grand Nador. The chapter ends with a section of main conclusions.

Unlike most, if not nearly all, studies found in the academic literature, this chapter jointly studies the nutrients of N and P. In food, N and P are always connected (Antikainen, 2007). Besides, both nutrients also flow rather quickly through a society. Therefore, although the cycling of N and P differ relative to each other, because of this connection we consider advantageous to explore N and P in parallel. Furthermore, we focused on the study of N and P because both are required in relatively large quantities by plants and animals, crops reaction to N and P application is relatively large globally, and N and P accumulation and losses to air, soil and water systems have serious ecological and human health impacts (Ma, 2014; Sutton et al., 2013). Hence, chapter three is very long, especially compared to the other chapters of this thesis. Actually, it could have been divided into two or even three different chapters, i.e. one focused on the study of N flows, a second one on the study of P flows, and a third chapter integrating and comparing both N and P nutrients. Yet, I personally considered more enriching, and providing a more holistic view, the jointly analysis, besides it prevents from duplication and repetition.

The conclusions drawn in the final chapter integrates and underlines the main findings obtained in the previous three chapters, and interrelates them focusing on the metabolic performance and the sustainability of the system. The chapter closes the document with few personal final reflections and remarks learned on the topic studied.

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Chapter 1.-Urban Metabolism: A review of recent literature on the subject[1]

Introduction and background [2]

Cities are the primary habitat for a fast-increasing majority of the global population. Modern urban growth, beginning in the 19th and early 20th centuries in Europe and America as a result of the spread of industrialization and the associated rapid increase in the use of fossil fuels, is now a common trend all over the world (Girardet, 1996).

Cities have grown dramatically not only in size and density but complexity across the globe. This growing complexity is associated with their social structures, economic systems, geopolitical settings, and the evolution of technology (Decker et al., 2000; Kennedy et al., 2007; Satterthwaite, 2007).

According to the United Nations, over half of the world's population lives today in urban areas (UN-WUP-2011), and by 2030 this figure is estimated to increase to 60 percent (Decker et al., 2000). Urban areas in low- and middle-income nations will absorb most of the world's population growth between now and 2020 (Satterthwaite, 2007). Moreover, the majority of this urban population is located in coastal zones or in zones with a distinct coastal influence (Glasow et al., 2013). Recent studies show that low elevation coastal zones [3], although accounting for only about 2 percent of the world's land area, contain about 10 percent of the world's population and 13 percent of the world's urban population. On average, developing countries have a higher share of their population living in coastal lowlands (14 percent) than OECD countries (10 percent), with even greater disparities in the urban sphere (21 compared to 11 percent). Furthermore, urban settlements in coastal lowlands are densely settled and expand very rapidly (McGranahan et al., 2007).

In the Mediterranean region, more than one third of the population lives in coastal administrative entities totalling less than 12 percent of the surface area of the Mediterranean countries. The concentration of population in the coastal zone is higher in the southern countries than in the northern shores of the basin (UNEP/MAP, 2012).

The development of cities represents a fundamental change in human settlement patterns and entails a dramatic transformation of the physical environment (Hosier, 1993).

On a global scale, urban settlements occupying 2 percent of the world's land surface use over three-quarters of the world's resources and discharge similar amounts of wastes to the

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[2] The work carried out by the authors of Broto et al. (2012) and Rapoport (2011) was particularly useful for the writing of this review.

[3] According to McGranahan et al. (2007), the Low Elevation Coastal Zone is defined as a contiguous zone along the coast less than 10m above sea level.

environment (Baccini, 1997; Barles, 2010; Girardet, 1996). Hence, cities are not only important drivers for socio-economic development, but also sources of human pressures on ecosystems because of the environmental consequences associated with their development (Glasow et al., 2013; Sekovski et al., 2012; UNEP/MAP, 2012). As population density and economic activity increase, so do pressures on the structure and function of ecosystems and on the services provided by them (Bai, 2007; Decker et al., 2000; Huang et al., 2012; Niza et al., 2009). But cities also offer important economies of scale accommodating large numbers of people in a limited space and providing them with jobs, housing, and services (Girardet, 1996; Satterthwaite, 2007). Hence, the effective management of the environment and of the impact of cities on the wider environment is critical for a large proportion of the world's population.

Since cities play a significant role in the world's major environmental agenda, they also need to also be part of the global problem-solving process (Girardet, 1996). Accordingly, urban areas and their development are at the centre of all discussions on sustainability and/or sustainable development (Baccini, 1997), the latter understood as development without increase in the throughput of materials and energy beyond the Earth's carrying capacity for regeneration and waste assimilation (Goodland and Daly, 1996). Yet, urban areas remain largely unrecognised as agents in the flow of energy and materials, and therefore remain grossly understudied (Barles, 2010; Decker et al., 2000). Likewise, their local, global and differed impacts in both space and time are also poorly recognised (Barles, 2010). In addition, although at least some uUrban Mmetabolism (UM) studies at regional-local level exist (e.g. Kennedy et al., 2007; Niza et al., 2009; Browne et al., 2009) the literature is dominated by case studies from developed countries.

For cities to increase compatibility with the surrounding environment, first, a clear understanding of the functioning and processes of the urban system, and the impacts and implications of urban lifestyles (in terms of consumption and discharge patterns) is essential to face the social, environmental, and economic challenges of the near future and to manage the urban environment in a way that is more compatible with its hinterlands (Baccini, 1997; Decker et al., 2000; Girardet, 1996).

Therefore, there is an urgent demand to gain a better understanding of cities' functions, states and needs in order to achieve more circular urban systems. A concept that addresses this claiming demand is urban metabolism. UM provides a conceptual framework to study how a city operates and is constituted and therefore, is a means of assessing the impact performance of a city, a region, or a country.

This review attempts to reveal the increasing significance of UM as a rich and rapidly evolving field of research on urban environments. First, the concept of urban metabolism is introduced in general terms to continue with the concept's historical roots or intellectual antecedents. From here we move on to identify and present the diverse approaches on UM, as applied by different disciplines to study the performance of cities. Finally, the paper ends by focusing on the most widely used approach of UM today, i.e. the biophysical perspective, to briefly expose the diversity of methodologies used when studying the city.

What does urban metabolism mean? A historical perspective of the concept

The concept of urban metabolism has been used, in recent years, as a way of enhancing our understanding of the way in which environmental, social and economic factors interact to shape urban phenomena and processes. Thus, UM can be a productive and useful way to conceptualize how urban areas function, and a valuable concept for understanding urban processes and the relations between society and nature in urban areas (Rapoport, 2011).

Concerns about UM are not entirely new and, after having been overlooked for many years, have once again become central in urban environmental matters (Barles, 2010). The term "metabolism", developed in the early 19th century to characterize chemical changes within living cells, was broadly applied in the following fifty years, in the field of biology and in what would become biochemistry, to represent processes of organic breakdown and combination, within individual organisms (at a cellular scale) and between organisms and their environment. Ever since, metabolism has lived a dual existence in the natural sciences, applying both to processes through which bodies change and reproduce themselves and to more holistic conceptions of ecosystem relations (Fischer-Kowalski, 1998; Foster, 1999, Wachsmuth, 2012).

In the 1970s, the ecological approach to UM was largely influenced by H.T. Odum's (1983) conceptualization of energy flows. H.T. Odum, working in the field of systems ecology, pioneered the application of the notion of biological metabolism to describe metabolism in terms of solar energy equivalents (or *eMergy*) (Holmes and Pincetl, 2012). The entire ecosystem was taken as a unit of analysis, in order to study and model an entity, its environment, and the interactions between the two (Rapoport, 2011). H.T. Odum's eMergy analysis represents an attempt to apply a biophysical value theory to both ecological and economic systems to study the energetic flows in the metabolism of socio-economic systems (Holmes and Pincetl, 2012), since it recognizes the variation in the quality of different forms of energy (fuels, electricity, solar) that accomplish different amounts of work. This is based on H.T. Odum's (1996) claim that the different types of energy flows are organized in an energy transformation hierarchy, *Transformity*, which measures energy quality. This argument connects with the entropy concept, understood as a measure of dispersion, determined by the second law of thermodynamics. Hence, solar energy equivalents are used as a universal metric (Kennedy et al., 2011).

However, long before H.T. Odum, urban metabolism in the 19th century, although not using the term at the time, was applied by agricultural chemists to understand the cycle of organic matter and nutrients in order to encourage exchanges between the city and agriculture, that is, by using urban population excreta from cities as a new agricultural fertilization source in the production of food (Barles, 2010). The fertiliser revolution and the mobilization of new raw materials that made urban excreta useless led to the end of this peculiar form of urban chemistry, but at the same time, paved the way for urban metabolism (Barles, 2010). Thus, the biological concept of metabolism has influenced understandings of, and approaches to, urban metabolism in urban ecology, industrial ecology and ecological economics (Rapoport, 2011).

Also in the 19th century, the concept of metabolism entered the social sciences via Karl Marx. Marx had been influenced by Justus von Liebig, a German soil chemist who used the concept of metabolism to describe the material exchanges and interdependent relationships between human society and nature (Fischer-Kowalski, 1998; Martinez-Alier, 1987; Wachsmuth, 2012). It was in this sense that Marx's use of the expression "metabolism between man and earth" referred specifically to the cycles of plant nutrients (Martínez-Alier, 1987: 220-221) in terms of fertility conditions, agricultural production systems and urbanization. By applying the notion of UM, Marx described first the human transformation of nature through the labour process, and secondly the capitalist system of commodity exchange. Marx was also first to use the concept of social metabolism to question the apparent separation between human beings and their environment, the society-nature duality, which Marx coined as "metabolic rift" (Wachsmuth, 2012). The term "metabolic rift" comprises the characterization of the social and environmental implications of industrial agriculture and urbanization, referring to the notion that human beings in capitalist society have become estranged from the natural conditions of their existence (Foster, 1999).

Specifically, Marx regarded urbanization as a key process leading to "metabolic rift" because of the reduced interaction between humans and the Earth resulting from the migration of people from rural to urban areas or because of the growth in long-distance trade in food and clothing (Martínez-Alier, 1987; Wachsmuth, 2012). The implication of this perspective is that environmental crises unfold in relation to historical and spatial patterns of inequality that, in the context of increasing urbanization, manifest themselves within the city (Broto et al., 2012). In short, Marxian conceptions of metabolism have influenced understandings of, and approaches to urban metabolism in the fields of ecological economics, political ecology and urban political ecology (Rapoport, 2011).

With reference to the concept of metabolism applied to the economy, according to Martínez-Alier (2004, 2013) the first precursors appeared at the end of the 19th century. Podolinsky's work on agricultural energy flows and Marx's and Engels' interest in the interactions between the human economy and the natural environment, both expressed the concept of metabolism. In this sense, the significance of identifying and tracing physical flows of material and energy through the human economy has been recognized for several decades (Ayres and Kneese 1968, 1969; Georgescu-Roegen, 1971; Leontief 1970, 2002; Wolman 1965).

In 1965, the engineer and geographer Abel Wolman published the first explicit application of the metabolism concept to the urban sphere. Wolman modelled the metabolism of a hypothetical American city of one million people in response to deteriorating air and water quality, and used metabolism as a method of analysing cities and communities through the quantification of inputs –water, food, and fuel, and outputs –sewage, solid refuse and air pollutants, while tracking their respective transformations and flows. Wolman defined metabolic needs as ''all the materials and commodities needed to sustain the city's inhabitants at home, at work and at play'' (Wolman, 1965:179; Decker et al., 2000; Kennedy et al., 2007).

A wave of empirical studies of the metabolism of various cities ensued (Boyden et al., 1981; Duvigneaus and Denaeyer-De Smet, 1977; Hanya and Ambe, 1976; Newcombe et al., 1978).

After this initial popularity, several decades elapsed before a renewed interest in urban metabolism was expressed, in the late 1990s, within the context of two emerging concerns: first, the capacity of the planet to feed and maintain a growing population and, second, the destructive power of humans due to the Earth's finite, limited and unique characteristics (Barles, 2010; Kennedy et al., 2007; Rapoport, 2011). The study by Kennedy et al. (2011) presents a chronological review of some 15-20 comprehensive studies on UM, in addition to numerous related studies, from the first study by Wolman in 1965 to the current period. Likewise, Zhang (2013) presents a review of UM studies applied to cities, and introduces studies on UM approached from different perspectives such as the expanding field of household or community metabolism (Liu et al., 2011; Moll et al., 2005).

Therefore, contemporary work employing the concept of UM tends to draw on either biophysical or political economy sciences. Additionally, different disciplines, in their diverse approaches to UM, draw on various branches of systems theory (Gandy, 2004; Rapoport, 2011). While UM studies in the fields of ecological economics and industrial ecology rely on thermodynamics, world system analysis, initially developed by Immanuel Wallerstein (1974), is the basis for ecological economics and to a lesser degree for political ecology. Likewise, urban ecologists draw on complex systems theory (Rapoport, 2011).

Contemporary understandings of urban metabolism

As introduced in the previous section, the notion of UM is understood and employed differently across the disciplines of urban ecology, industrial ecology, ecological economics, political ecology and urban political ecology. It must be emphasized that the writing of this section has been fundamentally based on Broto et al. (2012) and Rapoport (2011). Thus, this section briefly introduces the most prominent interpretations of UM by the five disciplines (see also table 1 as a summary).

As Broto et al. (2012) and Rapoport (2011) state, urban ecology understands *the city as an ecosystem* in the biological sense, seeing the city as both a 'system' and a 'natural' entity. The concept of UM is loosely based on an analogy with the metabolism of organisms. Cities are similar to organisms in that they consume resources from their surroundings and excrete wastes outwards (Decker et al., 2000; Kennedy et al., 2011). The city is seen as an ecosystem embedded in a larger system, and the metabolism notion is used to describe the interactions between the numerous subsystems of an urban region, in an attempt to understand how cities process energy or matter in relation to their surroundings. Hence, the application of a systemic approach to the analysis of human-environment relations enables the full complexity of urban systems to be effectively captured and interpreted (Broto et al., 2012).

Accordingly, urban ecologist proponents argue that by emulating the cyclical and efficient nature of natural ecosystems, that is, by shifting from a linear to a circular metabolism, in which outputs are recycled back into the system to become inputs, urban settlements will become viable and sustainable in the long term (Rapoport, 2011).

However, it is important to note Golubiewski's (2012) observation questioning the suitability of the UM framework in applying the concept of the city as a biophysical system. By underlining the essentials of both foundational ecology and biology disciplines, she unveils "a weakness of UM as the tendency to conflate organism and ecosystem, often using the terms interchangeably" (Golubiewski, 2012:757). Hence, by drawing parallels with the biology of individual organisms, UM inconsistently applies the analogy that "has the effect at times of conflating concepts, limiting analyses, or fostering misleading interpretations" (Golubiewski, 2012:757).

In this vein, a group of scholars working in the subdiscipline of systems ecology have developed research to understand *cities as socio-ecological systems*, i.e. urban ecosystems (Golubiewski, 2012). According to these scholars, working from complex system theory, "urban ecosystems are complex, dynamic biological-physical-social entities, in which spatial heterogeneity and spatially localized feedbacks play a large role" (Pickett et al., 2008:148). There is an attempt, therefore, to understand complex systems approaching system dynamics from different perspectives, such as eMergy or solar energy equivalents (H.T. Odum, 1996), Network theory (Fath et al., 2007; Ulanowicz, 1987), Hierarchy Theory (Allen and Starr, 1982; Zellmer et al., 2006) and complexity and Thermodynamics (Schneider and Kay, 1994). Likewise, the work by Giampietro et al. (2009) has contributed to the metabolic studies from the perspective of complex systems theory.

Broto et al. (2012) and Rapoport (2011) associate the notion of UM developed in industrial ecology with the analysis of *material and energy flows in the city*. UM studies in this field focus on quantifying the flow of particular materials and/or energy in an urban system. The goal is to optimize metabolism with the final aim of making cities less dependent on their wider hinterlands, since being self-sufficient, in terms of resource generation and waste disposal, is considered the hallmark of a sustainable UM (Barles, 2010; Baccini, 1997; Brunner, 2007). Though the aim is similar to that pursued by urban ecologists, the rationale behind the approach of industrial ecologists is that, through the systematic recording of all physical flows to and from an urban area, it becomes possible to describe the relationship between the environment and an urban system (Rapoport, 2011). The lack and the imperative need to systematically account for physical flows through the economy have also been advocated by ecological economists (Murray et al., 2005; Naredo, 2006; Carpintero, 2005).

By optimizing economy-environment relations, or their metabolism, industrial ecologists attempt to identify and reduce the loss of materials in order to lessen environmental impacts, and to develop symbioses by shifting from a linear to a circular metabolism. In other words, the discipline seeks to develop methods that improve metabolic efficiency or to reduce the amount of resources used per unit of economic output. This is a process usually referred to as *dematerialization or decoupling* (Carpintero, 2005). At this point, industrial ecologists and ecological economists share the interest in the relationship between economic growth and resource consumption, by applying the same notion as *the material basis of the economy* (Adriaanse et al., 1997; Carpintero, 2005; Broto et al., 2012; Naredo, 2006).

In this regard, ecological economists use UM to analyse potential existing measures to break the links between urbanisation, economic growth and resource consumption with the focus of concern on depletion of natural resources and environmental damage (Carpintero, 2005; Naredo, 2006; Rapoport, 2011).

However, ecological economics differs significantly from the industrial ecology discipline in the way in which it draws on the use of systems theory. Here, the notion of metabolism is applied to a view of an economic sector that is subject to the laws of thermodynamics (Rapoport, 2011). In other words, the metabolism idea is related to the hegemony of the laws of thermodynamics on economic flows (Broto et al., 2012). Quoting Daly and Farley (2004:70) the economy is seen as embedded in an "ordered system for transforming low-entropy raw materials and energy into high-entropy waste and unavailable energy. The urban is presented as a key form of organization of the current economic system".

In the research debate on how to break the link between urbanization, economic growth and resource consumption, a group of ecological economic scholars who regard the unending capital accumulation as the main cause of continued resource depletion and environmental damage, advocate for alternative models to dematerialization theories: the steady-state economy (Czech and Daly, 2004) and de-growth theory (Martínez-Alier et al., 2010b; Schneider et al., 2010).

The steady-state economy as presented in Czech and Daly (2004) entails an economy that undergoes neither growth nor recession, but finds a stable size at a stable level of throughput, consistent with the ecological principle of carrying capacity, and dependent on technological progress to increase the efficiency ratio of production throughput.

De-growth theories according to Schneider et al. (2010:512) propose "an equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global level, in the short and long term", or actually limiting the scale of production and consumption.

The ecological economics and political ecology disciplines share a common interest in the unequal social and ecological distributional flows and structural inequalities that unfold with the functioning of cities. However, their particular focus of concern differs, creating and applying different conceptions of UM. These scholars relate urban agglomeration resource demands to the structural inequalities and ecological conflicts occurring in the world regions supplying these resources (Hornborg, 1998; Martínez-Alier, 2009).

Within ecological economics there is some interest in studying *the economic drivers of rural-urban relationships*, as named by Broto et al. (2012). However, when building on world systems theory, two slightly different perspectives appear.

The first perspective seeks to explain the connections between urban flows and inequality by supporting the idea that cities are both centres of capital accumulation and dissipative structures or systems sustained through increasing resource exchanges with their peripheral environments (usually corresponding to rural underdeveloped regions). This ever-increasing exchange process reveals in itself the main cause of the creation of continual structural inequalities between urban areas and their periphery in the world system (Broto et al., 2012). As Broto et al. (2012) explain, in this approach UM is applied to analyse the way in which urban areas impact upon and are impacted by broader global systems. Therefore, the underlying ecological conditions of human economies determine this unequal distribution of resources. This relates to and builds on Harvey's proposals of the "uneven geographical development" of capitalism (1982:373), which emphasizes the significance of the politics of space and the role of space in social reproduction, mainly in the urban context, as well as the property rights in land markets shaping the physical landscape of spatial accumulation driven by the capitalist mode of production.

The second perspective departs from the idea that the fast increasing metabolism of cities, that is, their enlarging constant demand for resources and generation of waste, is related to the proliferating number of ecological conflicts in "commodity frontiers", commonly situated far from cities (Martínez-Alier et al., 2010a). Since urban metabolic processes rely on areas beyond their boundaries, these processes produce and reproduce inequality through conflicts around the social and environmental costs of resource extraction (Broto et al., 2012). Therefore, as suggested by Martínez-Alier (2010a:153), the metabolism analysis should focus on "the manner in which human societies organize their growing exchanges of energy and materials with the environment".

An alternative debate, —by proponents from the urban ecology and ecological economic disciplines— which follows the ecology argumentation and builds on complex systems theory, seeks to understand *cities as socio-ecological systems*, whose processes are influenced by human agents and socio-economic factors (Golubiewski, 2012). This approach advocates for metabolism studies that not only elucidate the magnitude of the heterotrophy of the city, but contextualize the city's consumption of resources within the analysis of the structures (agents or funds) using these flows, and the functions performed by the consumption of these flows, i.e. the purpose of this consumption (Sorman and Giampietro, 2012). Therefore, these approaches not only analyse the external constraints, namely supply and sink side limits, but also "study the internal relation of structures and functions associated with the metabolic pattern of society" (Sorman and Giampietro, 2012: 4).

Furthermore, political ecologists and political geographers interested in social and distribution impacts in cities, analyse the urban inequality of material and nonmaterial flows, and the role that infrastructure networks and spatial patterns of urbanization have in creating and reproducing patterns of urban inequality within the city (Broto et al., 2012; Monstadt, 2009).

An inferred suggestion from these types of studies is that different parallel metabolisms for the same resource might coexist in the same city. For example, water may be supplied by networked infrastructure to the urban elite but also by water vendors to poor urban citizens with limited access to water supply networks (Bakker, 2003a). Thus, infrastructure networks are central to the understanding of metabolic circulation in cities, since through their analysis, socioeconomic inequalities may be disclosed (Broto et al., 2012).

In association with studying the impact of urban flows on inequality the analysis of their governance, and/or control also becomes relevant. That is, understanding how power relationships shape urban flows and how urban flows are influenced by broader social power relationships (March, 2013; Rapoport, 2011). In this sense, the control of metabolic flows is essential for the reproduction of structures of power (Broto et al., 2012).

Urban political ecologists focus on understanding the way in which urban metabolic flows and the networks that mediate them are controlled by and socially mobilized to serve particular purposes, usually in the interest of the elite to achieve or maintain social power positions, and often at the expense of marginalised populations (Otero et al., 2011; Swyngedouw and Heynen, 2003). This work has displayed the role of politics, the urban elite, neoliberal reforms and international finance institutions in governing urban resource flows (Bakker, 2003b; Broto et al., 2012; March and Saurí, 2013; Otero et al., 2011). In addition, governance that commands individuals and institutions on urban flows may be contested or subverted by daily practices of individuals and groups and local political economies of cities, and hence also requires an analysis (Bulkeley et al., 2011 in Broto et al., 2012; Monstadt, 2007). Nevertheless, understanding the way in which these infrastructure networks reproduce power structures is particularly complex since in modern cities many networks are out of sight and therefore invisible to citizens (Kaika and Swyngedouw, 2000).

Political ecologists and urban political ecology scholars, assuming the notion of the interdependence between ecosystem function and human activity, particularly in urban areas, build on the idea that resource flows interact reflexively with the social world to reimagine relations between social, technical, economic, and ecological forces in urban areas to hence create new conceptions of UM (Heynen et al., 2006; Swyngedouw, 2006). In doing so, they contribute to the idea of *resignifying the city* (Broto et al., 2012).

For political ecologists UM is conceived as consisting of a number of dynamic, interconnected, and mutually transformative physical and social processes (Heynen et al., 2006) whose flows are shaped by the historical context in which they emerge and the urban practices around them (Gandy, 2004). This conception of UM, built on Marx's idea of metabolism, explores the complex interweaving of social and biophysical processes occurring in cities that transform nature into commodities, and which produce new forms of nature (Gandy, 2004), emphasizing the conception of urbanization as the outcome of historical change by political contestation (Broto et al., 2012; Gandy, 2006).

From this perspective finally, urbanization is seen as "a process by which new and more complex relationships of society and nature are created" (Keil, 2003:729); or as defined by Swyngedouw (2006:35) "urbanization is conceived as a social process of transforming and reconfiguring nature". Hence, a scientist model is replaced by a historically driven conception of urban nature which is rooted in the political dynamics of capitalist urbanization as a contested and multi-dimensional process of urban change (Gandy, 2004).

From this approach, the characterization of metabolism also adopts a critical political stance, since, despite being a process of exchanging resources, humans can control their input into this exchange. In this regard, a key remark is that metabolisms have the potential to express people's drives, desires, and imaginations, but they do so in a dialectic way, that is, through the interplay of structure and agency (Swyngedouw, 2006). This reveals a large diversity in the mechanisms shaping these flows, which are seen as being shaped by a wide array of policies, designs, and management styles alongside forms of cultural production, routine interactions and everyday practices (Broto et al., 2012).

Yet, due to their inherent critical emphasis, the normative and practical applications of this approach are not as obvious as urban ecology and industrial ecology methods. The emphasis of these critical perspectives on UM is raising new questions, which require further theoretical development and methodological innovation through enhanced interdisciplinary dialogue on the future of sustainable cities (Broto et al., 2012).

Table 1. Contemporary interpretations and current debates on the concept of urban metabolism across different disciplines from biophysical and political economy sciences.

	Discipline				
Interpretations/ current debates	Urban Ecology	Industrial Ecology	Ecological Economics	Political Ecology	Political Geography
The city as an ecosystem	X				
The city as material and energy flow or material and energy flows in the city		X			
The material basis of the economy, or breaking the links between urbanization, economic growth and resource consumption		X	X		
The city as a socio-ecological system	X		X		
Economic drivers of rural-urban relationships, and the production and reproduction of inequality			X	X	
The reproduction of urban inequality and the governance of urban flows			X	X	
Resignifying the city: urban metabolism and social, technical and ecological relationships				X	X

Source: author's elaboration mainly from Broto et al. (2012) and Rapoport (2011).

Commonalities and controversies on urban metabolism

The notion that urban areas operate as metabolic systems has not only already made a significant impact on urban scholarship, but has also led to expanded conceptions and reconceptualizations of UM across different disciplinary fields (Rapoport, 2011).

Each disciplinary approach adds and contributes to the understanding of the relations and interactions between environmental, social and economic factors in shaping urban phenomenaon (Rapoport, 2011). Actually, the analysis of the scholars' work on UM, across the diverse range of disciplines, discloses shared common concerns, such as the relationships between social and natural systems, cities and their hinterlands (both immediate and global) and sustainability and social justice in urban areas (Rapoport, 2011).

Yet, the different disciplinary conceptions of UM introduce a set of analytical dilemmas about the crossing points between the sociopolitical and the biophysical dimensions of urban space (Gandy, 2004). Likewise, in an attempt to seek interdisciplinary approaches, confusion about or misuse of jargon and theory within multidisciplinary research, by making connections across disciplines, may foster misleading interpretations and prevent interdisciplinary problem-solving and knowledge-building research (Golubiewski, 2012:760). Besides, significant variation exists in the extent to which these different disciplinary perspectives proceed from theory into practice (Rapoport, 2011).

The prevailing interpretation of UM today is the biophysical quantitative and accounting perspective (Kennedy et al., 2011) measuring the exchange and transformation of energy and matter between a city and its environment (Moles et al., 2008). This interpretation draws mostly on approaches from the field of urban and industrial ecology which are seen as tools both for identifying environmental problems and designing more efficient urban planning policies (Baccini, 1997; Barles, 2009; Niza et al., 2009).

According to Holmes and Pincetl (2012), UM is defined as a multi-disciplinary and integrated platform that examines material and energy flow in cities, as they are shaped by various social, economic and environmental forces. Factors such as urban structure, form, climate, quality and age of building stock, urban vegetation and transportation technology can influence the rate of a city's metabolism. These studies contradict works that interpret UM in a political or qualitative historical context (Kennedy et al., 2011).

Major criticisms of urban and industrial ecology interpretation claim that though necessary, these quantitative and technological approaches are not sufficient. It is argued that these predominant conceptions of UM depoliticize the urban sphere, since they are unrelated to social and historical contexts, paying little attention to political changes as well (Gandy, 2004; Monstadt, 2009; Rapoport, 2011; Swyngedouw, 2006). In this regard, they fail to explain the changing nature of the contemporary city within an increasingly globalized urban system (Gandy, 2004) based on the underlying capitalist economy. Another objection insists on the shallowness of the analysis to provide the fundamentals for effective urban policy and planning interventions (Fischer-Kowalski and Hüttler, 1999). Yet another criticism observes the shortcomings in better integrating the spatial characteristics and their influence, and the lack of methods to perform long-term analyses (Rapoport, 2011). Therefore, criticisms of biophysical approaches primarily target the integration of sociopolitical and historical factors and spatial characteristics into urban metabolism analysis.

Alternatives to overcome the observed shortcomings comprise extending the metabolism model to consider the links between urban and environmental quality, urban drivers, patterns and lifestyles and metabolic flows (Minx et al., 2011 in Rapoport, 2011; Newman, 1999).

Likewise, attempts are also made to better integrate the social aspects of and influences on material and energy flows, as well as to understand how spatial characteristics influence the relationship between the built environment and ecosystems (Barles, 2010; Rapoport, 2011).

Methodological approaches toward the biophysical notion of urban metabolism

Urban metabolism, involving 'big picture' quantification of the inputs, outputs and storage of energy, water, nutrients, materials and wastes for an urban region (Kennedy et al., 2011), can be a productive and useful way to conceptualise how urban areas function and to determine their spatial relationships with surrounding hinterlands and global resource webs (Rapoport, 2011; Kennedy et al., 2007). At the same time, UM studies can elucidate basic trends in human resource use (Decker et al., 2000), by analysing relevant energy and material pathways at different scales, which might lead to the design of adequate and more efficient urban planning policies towards a more circular pattern of UM, vital to sustainable development (Holmes and Pincetl, 2012; Moles et al., 2008; Niza et al., 2009).

Different methodological approaches are used to account for and analyse urban metabolic processes (Barles, 2010). The studies of Daniels (2002), Daniels and Moore (2002), Hammer et al. (2003), Loiseau et al. (2012), Huang et al. (2012) and Zhang (2013), provide a comprehensive review and a classification of both research methodologies and UM studies conducted through these different methods. Material Flow Analysis -MFA- (Brunner and Rechberger, 2004; Niza et al., 2009; Zhang et al, 2013), Substance Flow Analysis -SFA- (Antikainen et al., 2005), Input-Output analysis (and PIOT-physical input-output tables) (Liang et al., 2012), eMergy (energy flow) analysis (Huang et Hsu, 2003; Liu et al., 2011); Ecological footprint analysis (Holden, 2004; Muñiz and Galindo, 2005), Ecological network analysis (Li et al., 2012), MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism) (D'Alisa et al., 2012) and LCA –Life Cycle Analysis- (Chester et al, 2012), are among the main tools used to conduct physical environmental accounting, based on the study, in variable depths, of material and energy flows (Eurostat, 2001; Loiseau et al., 2012). The substantive use made of the organicist "analogies" of the human-environment relation, as well as the metabolic viewpoint closely linked to the acceptance of "material balance" principles, in which the modelling of material and energy flows is governed by the laws of conservation of matter and energy, are major features shared by most of these studies (Daniels and Moore, 2002; Barles, 2010). Yet, the significant internal variation across the above-mentioned metabolism techniques, from methodological to conceptual variations, makes integration difficult, and justifies the reason behind why a unique, clearly defined methodology with standard criteria and a consistent set of operational tools to conduct UM is still lacking (Daniels and Moore, 2002; Loiseau et al., 2012). Moreover, as Huang et al. (2012) observe, M/SFA applications continue to grow, and are increasingly combined with other research methods to analyse the increasingly complex material/substance flows resulting from socioeconomic development. Hence, in general terms, MFA provides the methodological groundwork, mostly because it is the primary methodological framework that offers great scope for the generic application and the harmonization, integration, and advancement of environmental accounting and systems analysis (Daniels and Moore, 2002). In most of these cases, the UM approach is primarily used as the basis of an accounting framework. Nevertheless, part of the methods introduced move beyond classic MFA-style analyses.

Furthermore, at a regional-local scale, a uniform and standardised methodology does not exist yet either (Hammer et al., 2003; Loiseau et al., 2012; Niza et al., 2009). Therefore, studies on a regional scale use previously published methods for assessing cities' circular metabolism patterns which necessarily required modifications and further improvements (Moles et al., 2008).

Conclusions

Urban areas sustain over half of the world's population today, and all future scenarios point towards an increase in this trend. The concentration of population and socioeconomic activities within a reduced geographic space not only entails important economies of scale but also pressure on the structure and function of ecosystems and on the services provided by them, potentially producing ecosystem impacts from the local to the global scale but varying both in space and time.

Therefore, for cities to alleviate their ecological and environmental impacts, the interactions between societies (i.e., their living patterns in terms of resource consumption and waste discharges) and the biosphere, considered two interdependent systems in co-evolution, need to reach a certain balance. Accordingly, the fundamental previous step is to create a better understanding of the processes, structures and functions of urban systems and the impacts and implications of urban lifestyles.

The notion of urban metabolism provides a conceptual framework to study how a city functions, and hence, a way to assess a city's compatibility with the surrounding environment. Nevertheless, different field disciplines from the social and natural sciences interpret and approach the concept differently, revealing the complexity and multiple dimensions of the same urban phenomenona, and point to the need for interdisciplinary dialogue to develop theoretical and practical approaches to urban metabolism with the aim of making progress in urban sustainability research.

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Chapter 2.- The political and historical roots of Grand Nador

Introduction

In the previous chapter, the importance and global trend towards urbanization [4](understood as the increasing propensity for humans to live in cities) and specifically towards littoralization (as the tendency for these cities to concentrate on coastlines) were introduced. It was also observed that almost the entire increase in population growth in the coming decades is expected to be absorbed by urban areas in low- and middle-income nations (Satterthwaite, 2007; UN-WUP, 2009, p.1), which on average have a higher share of their population living on coastlines. Therefore, on top of the fact that cities are the primary habitat for over half of the global population (UN-WUP, 2011), world's population growth in the near future will be absorbed to a large extent by coastal urban areas in the developing world (Glasow et al., 2013; Kilcullen, 2012; McGranahan et al., 2007). The southern Mediterranean basin is cited as a clear example of this urban-littoralization trend (Kramsch, 2007; UNEP/MAP, 2012).

The relevance of both fast-increasing trends, mutually reinforcing each other, translates into major, potentially worrisome environmental consequences associated with urban growth, i.e., as population density and economic activity increase, so do pressures on the structure and function of ecosystems an on the services provided by them (Bai, 2007; Decker et al., 2000; Huang et al., 2012; Kilcullen, 2012; Niza et al., 2009). Yet, as acknowledged by authors like Barles (2010) and Decker et al. (2000) the role played by cities in environmental transformations, e.g. as agents in the flow of energy and materials, remain poorly recognized, and thus grossly understudied.

The notion of urban metabolism may enhance our understanding of how environmental, social and economic factors interact to shape urban phenomena. Urban metabolism may assist us in conceptualizing the functioning and processes of urban systems, and the impacts and implications of urban lifestyles, with the final aim to manage the urban environment in ways more compatible with its hinterlands, and with the wider environment (Baccini, 1977; Decker et al., 2000; Girardet, 1996; Rapoport, 2011).

The urban agglomeration of Grand Nador (GN), in Northeast Morocco, provides an interesting case for such an investigation (see Figs. 1 and 2). In addition to its location, in the coast of the southern Mediterranean basin, GN forms part of the world's lower-middle-income economies according to the World Bank data classification. Moreover, the region has been undergoing fast urban growth and concentrates almost all of the regional economy which is an important source of environmental imbalances (Nakhli, 2010).

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[4] Although there is a clear distinction in bibliography between the terms urbanization, cities, urban areas and urban agglomerations, these terms are used indistinguishably in the following document. Hence, when referring here to urban areas and the urban environment, we refer to a common perception of the 'city-region', understood as dense population, organized social life, lack of or minimal contact with nature and large scales of production and consumption.

The urban agglomeration of GN is bounded to the Northeast and Southeast by the locally known Sebkhat Bou Areg, or the lagoon of Nador, whose ecological value is not only acknowledged at national level, as part of the Sites of Biological and Ecological Interest (SIBE, in french), but also internationally as a RAMSAR site since 2005. Moreover, the "Marchica" lagoon has already been the subject of several projects, such as MedWet Coast and SMAP III aimed at the conservation and improvement of the quality of its waters and its natural character. Yet, GN is also home of other environmentally remarkable sites like the sandy belts beaches of Kariat Arekmane and Beni Nsar, the Gourougou mount, the massif of Béni Snassen and the irrigated perimeter of Bou-Areg (Nakhli, 2010; SDAU-GN, 2012). Therefore, the agglomeration of GN shelters highly original yet fragile biodiversity natural domains, with the the lagoon of Nador at the top of the list in ecological terms. These values make the coast of GN a place with important environmental, economic and social challenges (SDAU-GN, 2012).

However, as introduced in previous sections (see Chapter 1), our study develops by approaching and employing the predominant biophysical conception of UM.

Major criticisms of quantitative and accounting perspectives of UM, by political and urban ecologists, primarily target the lack of integration of sociopolitical and historical factors into the UM analysis (Gandy, 2004; Monstadt, 2009; Rapoport, 2011; Swyngedouw, 2006).

The present chapter introduces the political and historical context in which the urban agglomeration of Gran Nador has developed. Albeit exploratory and descriptive, the chapter intends to address one major criticism regarding urban metabolism that is, the lack of proper historical, political and economic contextualization of the approach, asserting, as claimed by Swyngedouw (2006) and Gandy (2004), the significance of the historically driven conception of urban nature which is rooted in the political dynamics of capitalist urbanization. This review also attempts to reveal the role that sociopolitical and historical factors play on the structure, functioning and processes of urban systems, as fundamental to correctly understand and comprehend the city's structure and flows. In this chapter, first, the area of study is described. Second I continue with the political-historical roots of Grand Nador. This section specially emphasizes the factors of migration, city development dynamics and land market and real estate as key drivers in Grand Nador's urban growth. The chapter ends with a brief discussion and a section of main conclusions.

However, the full integration of the sociopolitical and historical aspects and of their influence on cities' flows was not pursued in the depth desired. Besides data shortcomings, (both scarcity and very limited means of collection and/or access), complete integration necessitates interdisciplinary work between sociopolitical and biophysical UM dimensions. In the attempt to seek this interdisciplinary approach, by making connections across disciplines, authors such as Gandy (2004), Golubiewski (2012) and Rapoport (2011) advert to the difficulties and analytical dilemmas of interdisciplinary problem-solving and knowledge-building research. Accordingly, this full integration job means the work of another complete doctoral thesis. However, we greatly agree with Broto et al. (2012) and Holmes and Pincetl (2012) that enhanced interdisciplinary dialogue is necessary for the future study of more circular urban systems.

Description of the study area

The urban region of Grand Nador (GN), in the northeast of Morocco, constitutes part of the administrative province of Nador belonging to the Oriental region of this country (see Figs. 1 and 2). With an area of 1,491 Km^2 (ASRO, 2011; PNC, 2010) and an estimated population of 451,779 in 2010 (RGPH, 2004; PPMM, 2007) (population density of 303 inhabitants/Km^2, see table 1) the Grand Nador is formed by fourteen communes (six urban or municipalities and eight rural) (see Figs. 1 and 2).

The climate of the region is typically Mediterranean, with hot, dry summers and mild or warm winters. The average temperature fluctuates between 16.7 and 18.3 ºC. In terms of precipitation, seasonal contrasts are found between heavy rainfall episodes, often in the form of thunderstorms, especially between the months of November and April and the irregular and modest pattern of 300 mm a year of rain on average (El Yaouti et al., 2009; Khattabi et al., 2007; SDAU-GN, 2012; Zerrouqi et al., 2011). The region is also under the influence of the Saharan pressure systems , which are at the origin of hot dry winds (Chergui and Sirocco). The Rif Mountains and the Béni Snassen range attenuate, respectively, the Atlantic disturbances and the hot, dry winds from the desert. The general wind conditions are west-southwest from November to May and east-northeast from May to October. These winds have a great influence on the direction and strength of marine surface currents (SDAU-GN, 2012).

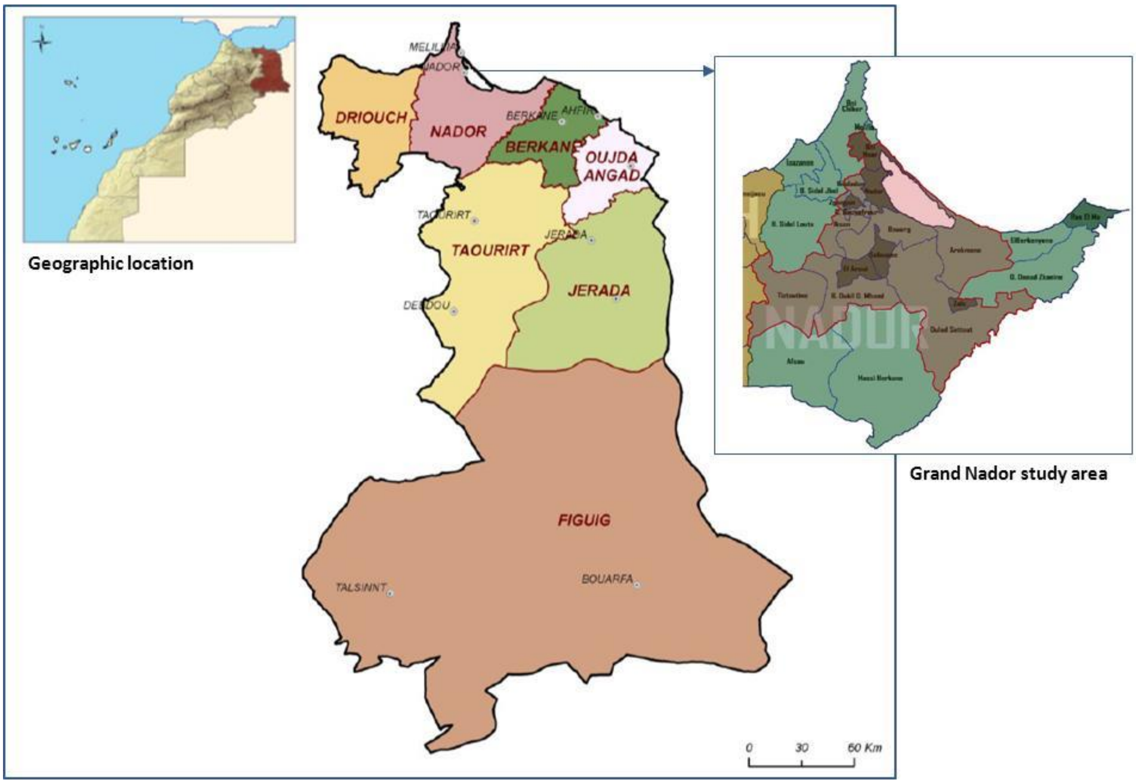

Figure 1.: Administrative division of the Oriental Region and its geographic situation and the Grand Nador area of study. Source: Ministère de l’Energie des Mines de l’Eau et de l’Environnement. Secrétariat d’Etat chargé de l’Eau et de l’Environnement. Département de l’Environnement. Edited by: DEPP\ONEM\SBDE in EEIRO (2013).

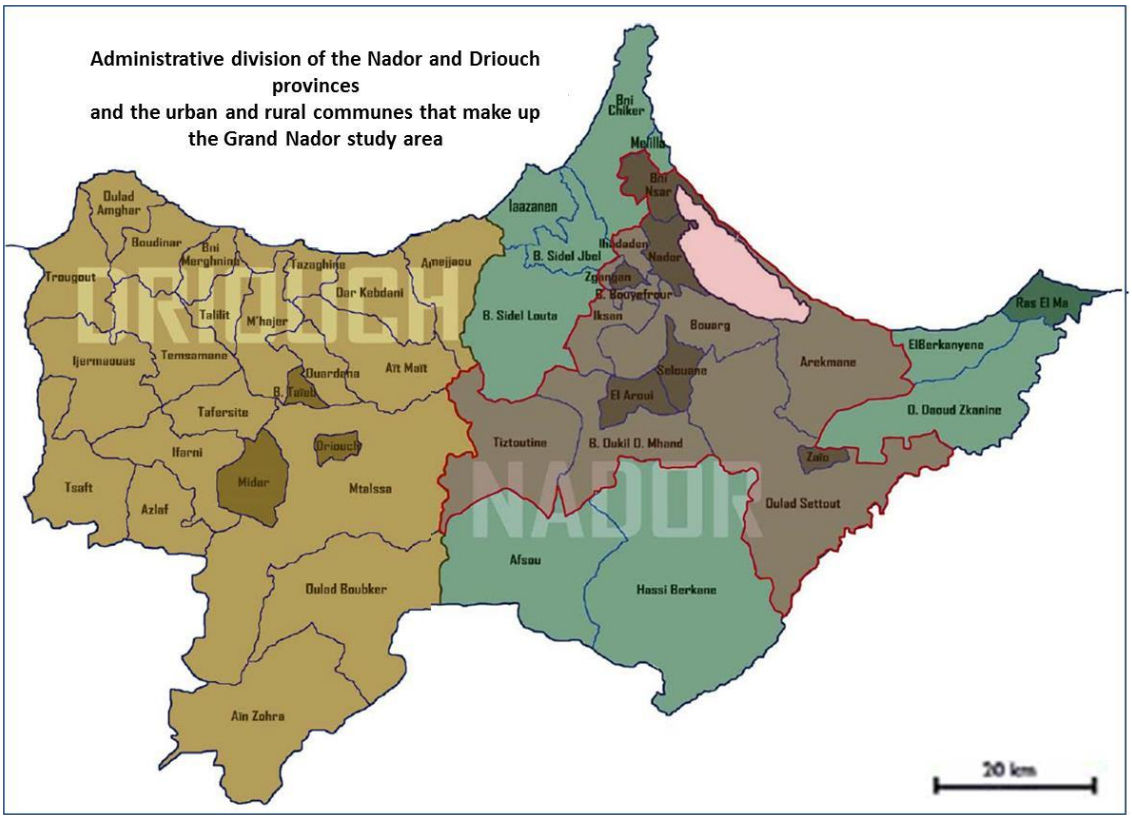

Figure 2.: Administrative division of the Nador and Driouch provinces by Decree nº2-09-319 on 11th June 2009; and shaded in red the urban and rural communes that make up the Grand Nador area of study. Source: Monographie Économique de Nador. Année 2012. Chambre de Commerce d'Industrie et de Services de Nador (CCISN) (Personal contact with M.H. Jaroudi, October 2013).

Morphologically this is a very heterogeneous area with a succession of mountains, basins and plains (see Figs. 3 and 4). GN is located on the Gareb Bou-Areg plain, more specifically in the subsiding basin of “Gareb Bou-Areg”. The coastal plain of Bou-Areg is bounded to the south by the Selouane passage that connects this plain with the Gareb plain (see Fig.4). The area is surrounded by the natural barriers of the Gourougou and the Bni Bouifrour volcanic massifs to the northwest and west, respectively, and by the Kebdana range to the east, which separates the Moulouya’s lower valley from the Bou-Areg basin. To the northern border of the plain Bou-Areg is limited by the so-called Nador Lagoon, locally known as Marchica Lagoon or Sebkha Bou Areg (El Yaouti et al., 2009; Khattabi et al., 2007; Re et al., 2013; SDAU-GN, 2012).

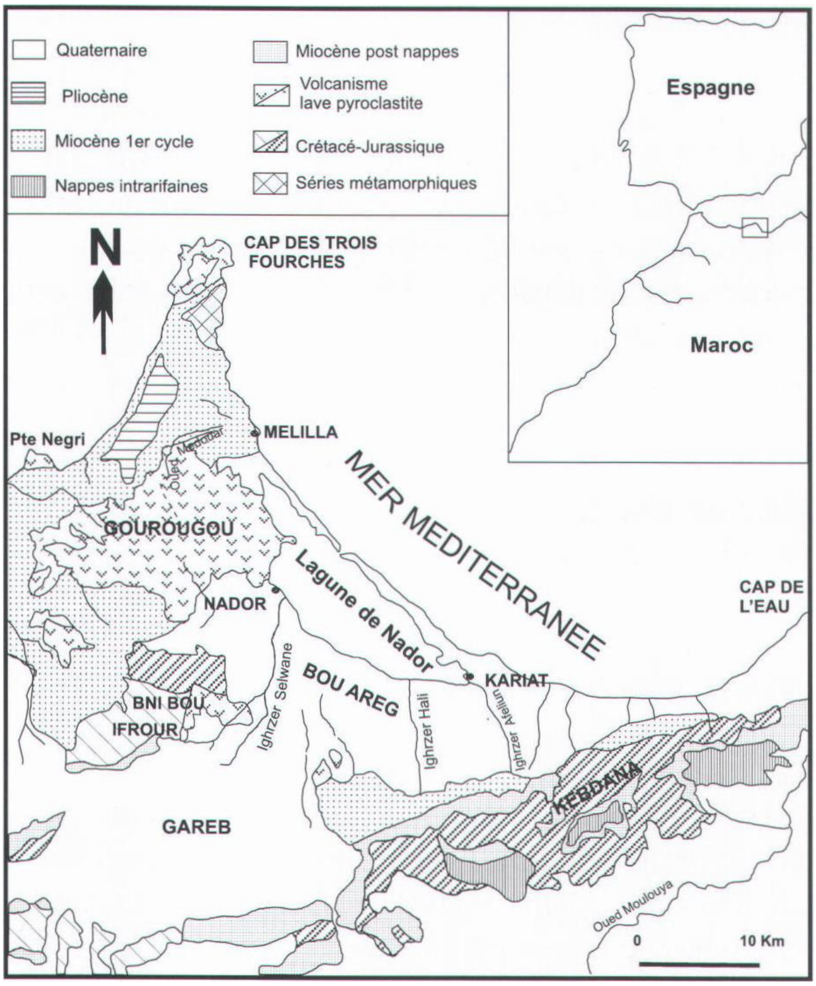

Figure 3.: Geographical location map of the Nador region, with the coastal Bou-Areg Plain, the inland Gareb plain and the lagoon of Nador in Morocco. Source: Mahjoubi et al. (2003).

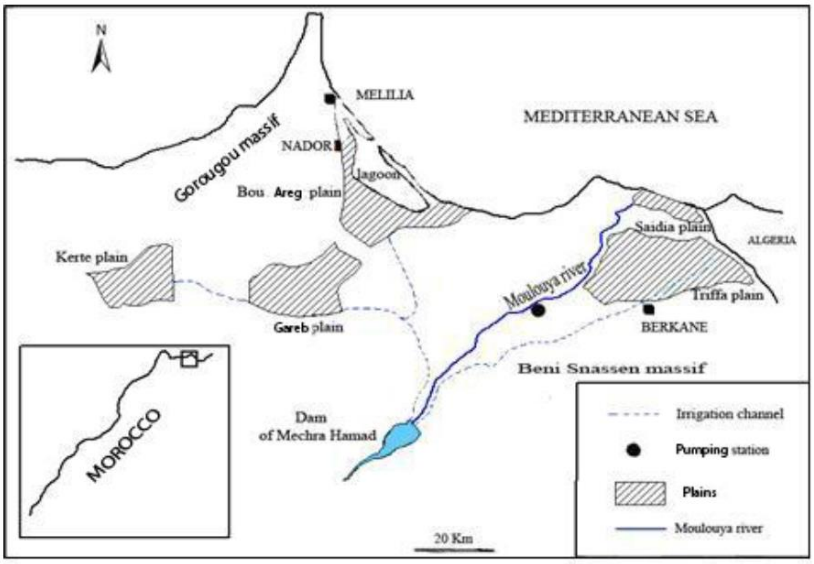

Figure 4.: Location map of the coastal Bou-Areg Plain and Gareb plain of Morocco. Source: El Mandour et al. (2010).

The Nador Lagoon, recognized as a Site of Biological and Ecological Interest (SIBE, in French) and classified as a RAMSAR site since 2005, is the only lagoon in the Mediterranean coast of Morocco, and the largest in extension in the country (surface area of ca. 115 km^2; 25 Km length and 7 Km width) (González et al., 2007; SDAU-GN, 2012; Zerrouqi et al., 2011). Most importantly, as a coastal lagoon, it is a high productive, yet a complex and delicate ecosystem which is threatened by several anthropic pressures (González et al., 2007; Pastres et al., 2013). The city of Nador, the most populated of the study area is located in the coastline of the Marchica lagoon (see Fig.5)

Figure 5.: Aerial photo of the lagoon of Nador or Marchica lagoon in Morocco. Source: Bab Africa website (2015).

The Nador lagoon contains predominantly seawater, which enters through the pass connecting the lagoon to the sea, yet it is also fed by surface waters, and represents the main outlet of the Bou-Areg aquifer. The lagoon watershed consists of many small streams with intermittent flow, some of which often serve as sewage outflows for urban areas upstream (González et al., 2007). There are only a few permanent rivers, such as the Selouane river, with the largest flow of the watershed (and also with large amounts of raw sewage entering the lagoon), the Bouaroug or Caballo river, whose mouth is located at the south of the city of Nador, and begins in the Gourougou massif, and the Afelioun river, located at the southeast end of the lagoon (Khattabi et al., 2007; Re et al., 2013; SDAU-GN, 2012). Some streams discharge directly into the lagoon of Nador contributing, together with the underground water flow, to freshwater and sediment inputs, while others do not reach the lagoon because of flow losses due to evaporation or infiltration into the aquifer (Khattabi et al., 2007; Re et al., 2013).

The lagoon also receives irregular water inflows from excess irrigation through the irrigation channel Bou Areg, whose final stretch drains into the stream Sidi Amer (or Iyamniouen), as well as waters coming from the local irrigation channel network (El Yaouti et al., 2009; Re et al., 2013). In addition to surface water, sewage and wastewaters inputs, treated or untreated, are also present, collected by the small streams/rivers, and carried by the storm waters. They are mainly associated with the urban and suburban settlements on the lagoon shore and with the inland urban centers of the area. In sum, freshwater inputs to the lagoon depend on runoff, groundwater levels, drainage and irrigation waters, and urban effluents (Khattabi et al., 2007; Re et al., 2013).

As in the case of the Mediterranean and Atlantic Moroccan coasts, this physical setting has facilitated an intense process of littoralization (Côte and Joannon, 1999; Liziard and Voiron-Canicio, 2012). In recent decades, the strong concentration of population has turned the coastline into the major axis around which the entire structure of the activities of modern Morocco and the most important urban centers develop (Nakhli, 2010). Yet, the coastal area has been exposed to many forms of environmental pressures such as urbanization growth, industrial activity effects, intensification of agricultural activities and loss of agricultural land, the destruction of dunes or the pollution of terrestrial and marine ecosystems (Nakhli, 2010). In particular, the Grand Nador area concentrates a steel large-scale industrial complex accompanied by, rapid and unplanned urbanization, most of which is located on the edges of the Marchica Lagoon (Nakhli, 2010) (see Figs. 5 and 10).

According to Nakhli (2010), at national level, marine waters in Morocco receive directly around 98 percent of industrial and agricultural effluent and 52 percent of urban domestic waste from coastal cities. Therefore, the Moroccan coast in general, and GN in particular, are suffering strong ecological and environmental pressures, in a context of extreme fragility of the ecosystems (Nakhli, 2010). Yet, as Nakhli (2010) explains, the management of these coastal zones is inefficient and handicapped by the multiplicity of institutional intervening parties and by the fragmentation of sectorial policies.

Therefore, our study area (see Figs. 1 and 2) is subjected to the anthropic pressures of population and urban growth. Besides, since it concentrates almost all of the main activities of the regional economy, the GN area also receives the influence of many industrial sites such as the Port of Beni Nsar, the international airport of Mont-Aroui, the harbour and airport free zones (*zones franches portuaires et aéroportuaires*), etc. This growth dynamics is supported by many new and ambitious economic projects (creation of new industrial units and the creation of an industrial park in Selouane) (González et al., 2007; Nakhli, 2010; SDAU-GN, 2012).

The Oriental region is the 2nd largest region of the kingdom of Morocco (82,820 km^2, equivalent to 11.6 percent of the Moroccan territory). Administratively is organized by the Oujda-Angad prefecture and 6 provinces: Jerada, Berkane, Taourit, Figuig, Nador and Driouch (see Fig.1). The province of Driouch was established by Decree No.2.09.319 in June 2009, as part of the formerly Nador Province (EEIRO, 2013). According to the 2004 General Census of Population and Housing (RGPH, 2004) the Driouch Province had a rural-urban population distribution of about 80-20 percent (EEIRO, 2013).

This population is unevenly distributed. The provinces of Nador (before division), Berkane and Oujda Angad Prefecture, on less than 12 percent of the Oriental area, concentrate roughly 77 percent of the region's population (EEIRO, 2013). The areas belonging to the administrative provinces of Nador and Berkane form the most dynamic region in terms of urban growth (Nakhli, 2010).

Despite having a lower annual growth (0.8 percent) than the national average (1.4 percent) the Oriental region is undergoing a strong urbanization process and significant pressures on the demand for suitable land for residential construction occur (EEIRO, 2013). Under this regional population dynamics, the phenomenon of littoralization has accelerated the concentration of population in the different urban centers. In sum, around three quarters of the Oriental population live along the Mediterranean coast in less than one tenth of the territory (EEIRO, 2013).

The province of Nador (after the division of 2009) leads the area with 26.4 percent of the total population of the region in 2004 maintaining the same proportion than in 2010 (26.7 percent) (EEIRO, 2013).

The urban population of Grand Nador represents 68.6 percent of the total population of Nador province (after 2009), and 97 percent of the total urban population of the Nador province.

Table 2.: Data on population density and urban population on 1994, 2004 and estimates for 2010, at the different administrative levels of country, region, province and the area of study.

	Population (RGPH 2004)	Surface (Km^2)	Population density (Inh/Km^2) (RGPH 1994)	Urban population (%) (RGPH 1994)	Population density (Inh/Km^2) (RGPH 2004)	Urban population (%) (RGPH 2004)	Population density (Inh/Km^2) (RGPH E 2010)	Urban population (%) (RGPH E 2010)
Morocco	29,891,708	710,850	36.68	51.47%	42.05	55.08%	44.81	57.73%
Oriental Region	1,918,094.	82,820	21.36	55.18%	23.16	61.70%	24.05	65.50%
Driouch & Nador	728,634	6,130	111.57	35.99%	118.86	50.70%	123.65	56.30%
Nador	505,647	3,070	144.66	53.44%	164.71	64.10%	174.27	70.50%
Grand Nador (Study Area)	427,129	1,491	242	62.82%	286.47	73.40%	303	76,90%

Source: RGPH 2004, HCP-Projections 2005-2030.

Currently, the region is experiencing significant economic transformations after the Royal Initiative for the Development of the Oriental Area and the associated development of major infrastructural and sectorial projects (EEIRO, 2013).

In sum, this region of fourteen aggregated communes has been selected as the case study not only because of its main economic activities (industry, commercial, agriculture) and assets or transport infrastructures (port, airport, train and main road network), but also because of the presence of the Nador Lagoon, the largest Moroccan lagoon recognized to be a site of biological and ecological interest (SIBE) (Zerrouqi et al., 2011). Hence it may represent an interesting example of how economic activities are affecting a sensitive natural environment and the steps taken to remediate the subsequent impacts.

The political-historical roots of Grand Nador

The origins of the current urban agglomeration of Grand Nador, and specifically of the modern city of Nador, date back to the Spanish military occupation campaign of 1909, by which and as a result of the Spanish ratification to the Anglo-French agreement “Entente Cordiale[5]” in 1904 the Spanish government began to increase its influence over this eastern Rif area (Berriane and Hopfinger, 1999; Bravo, 2009; Bravo et al., 2005; Symes, 2006; Moreno, 2013; SDAU-GN, 2012). The “Entente Cordiale” was the preceding agreement to the official recognition of a French and Spanish protectorate status over Morocco by the signature, in 1912, of the Treaty of Fez followed by the Franco-Spanish Treaty (Symes, 2006; Madariaga, 2010). Prior to 1909, according to Bravo (2009), Nador consisted of a few scattered houses around a marabout[6] and a kasbah (see Fig.6)

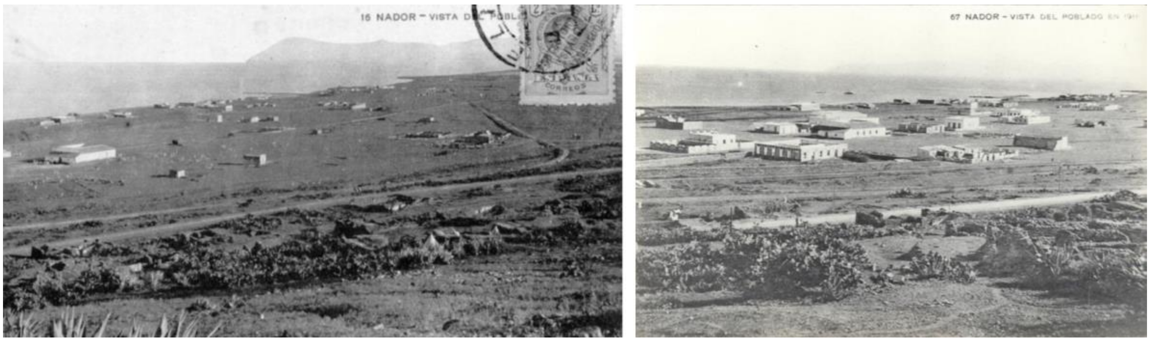

Figure 6.: View of the civil town of Nador corresponding to the years 1909 (left) and 1911 (right). Source: Bravo et al. (2005).

Nador was chosen by the Spaniards first and foremost for military and colonial-economy strategic reasons. On the one hand, Nador offered the topographical favorable conditions for both a military base and a residential area. Nador’s boundaries, consisting of the Mar Chica, the Atalayón Peninsula, the Gourougou massif and the plain of Bou-Areg, still define the present landscape and largely determine the spatial and structural evolution of the city and its agglomeration (Berriane and Hopfinger, 1999). On the other hand, the mining interests on the iron deposits of Ouichane in Bni Bouifrour, along with its proximity to Melilla (around 15 km away in the North) made Nador the perfect geo-economic strategic enclave for the Spanish (Berriane and Hopfinger, 1999; Bravo, 2009; Bravo et al., 2005).

With the establishment in 1912 of the Spanish Protectorate over northern Morocco (a strip of about 20,000 Km^2 which mostly comprised the mountainous Rif region) the Spaniards began to control this area. Although in theory the protectorate did not imply colonial occupation, in practice the northern part of Morocco (thus Nador) became a colony of Spain until the independence of Morocco in 1956 (Madariaga, 2010) (See Fig.7). Yet, the Treaty of Fez meant

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[5] The Anglo-French Agreement “Entente Cordiale” of 1904 gave Spain control of the very north region of Morocco in recognition of the Spanish controlled areas of northern Morocco for hundreds of years (the enclaves of Ceuta, Peñon de la Gomera, Alhucemas/Al-Hoceima and Melilla).

[6] According to Berriane and Hopfinger (1999) the marabouts were centers of religious education and the Kasbah were fortresses.

also the beginning of the Rif resistance against the Spanish colonial rule, triggering a conflict that would extend for the ensuing years.

Figure 7.: Panoramic view of Nador on the day of its occupation by the Spanish troops, 17th September 1921. Source: Bravo et al. (2005).

The uneasy relationship between the native population of the Rif and their Spanish rulers was not something completely new (Symes, 2006). Following Morocco's long tradition of power decentralization, the Riffian population enjoyed of a wide political and administrative autonomy at the local level. Actually, the inhabitants of the eastern Rif were only loosely connected with the Morocco Makhzen or central authority (Berriane and Hopfinger, 1999; Madariaga, 2010). Yet, despite attempting to remain in a state of administrative lawlessness, the area had never aspired to a political independence, i.e. the Rif population did not claim for an autonomous government. Rather it persistently demanded the administration of the Rif region by the Riffians (Madariaga, 2010). According to Madariaga (2010) the obedience or dissidence of the Rif tribes to the authority of the sultan was conditioned by several factors, among which tax collection and the sultan's resistance against foreign invasions (i.e., sultan's attitude towards foreign penetration) were of paramount importance. Therefore, historically, the Rif, with its Berber tribes, has been described as a region in continuous tension with the central authority and a main focal point of rebellion and contestation against authority (Madariaga, 2010; Suárez, 2015), image that was strengthened by its resistance to colonial rule during the Spanish protectorate and perpetuated throughout the postcolonial history of Morocco (Suárez, 2015). Simultaneously, Morocco's long tradition of power decentralization ended with the colonial administration of the Protectorates and was lately perpetuated, after independence, by the successive Moroccans governments (Madariaga, 2010; Suárez, 2015). Centralization of political power in Morocco was heavily enforced under the reign of Mohammed V (1957-1961).

This image of rebellion and disobedience of the Riffians against the central authority was underpinned by three particularly cruel episodes: the War of Melilla (1909), The Rif War (1911-1926) and the Rif Rebellion (1958-1959).

The War of Melilla, in 1909, arose from discrepancies between the locals and the Spanish Rif Mines Company and led the Rif tribes to attack the Spanish workers of the iron mines forcing the intervention of the Spanish army (Symes, 2006).

The Rif War (1911-1926) was originated by the Riffian population opposition to the Spanish colonialism leading to the so-called Battle of Annual (1921) commanded by the Rif leader Abdelkrim Al-Khattabi, in which the Spanish troops were defeated and the Republic of the Rif was declared. In 1926, the Franco-Spanish coalition managed to crush Abdelkrim's resistance and ended with the independent Rif Republic in a series of episodes that culminated in the landing of Al-Hoceima. By 1926-1927 the area was pacified, the Rif leader Abdelkrim surrendered and the previously lost territory was recovered (Madariaga, 2010).

Finally, in 1958, and after the Moroccan independence (1956), the Rif rebelled once more against the enduring marginalization and abandonment by the central power, and against the authority of the local leaders imposed by the Istiqlal Party which monopolized the power in Rabat (Madariaga, 2010). The King's Mohammed V response to the Rif uprising was brutal and violent and left deep scars in the collective memory of the Riffians and a lively and strong feeling of animosity towards the central power.

The economic interest of the Spanish rulers in Northeastern Morocco focused on the immediate exploitation and export of the region's existing resources, such as forest products and iron ore from the hinterlands of Nador, rather than to the development of basic infrastructure. Therefore, unlike French colonialism, public investment under Spanish occupation was mostly for the exploitation of natural resources and the maintenance of the colonial regime. In this regard, Nador benefited from its function as a relay station, hence the close link that existed between the development of the city and the exploitation of mineral resources. The most significant example of this policy was the construction of two mining railway lines for the exploitation of the iron deposits of Ouichane (see Figs. 8 and 9) (Berriane and Hopfinger, 1999; Bravo et al., 2005; SDAU-GN, 2012).

Figure 8.: Photography of the railroad station of the Spanish Rif Mines Company, 1921. Source: Bravo et al. (2005).

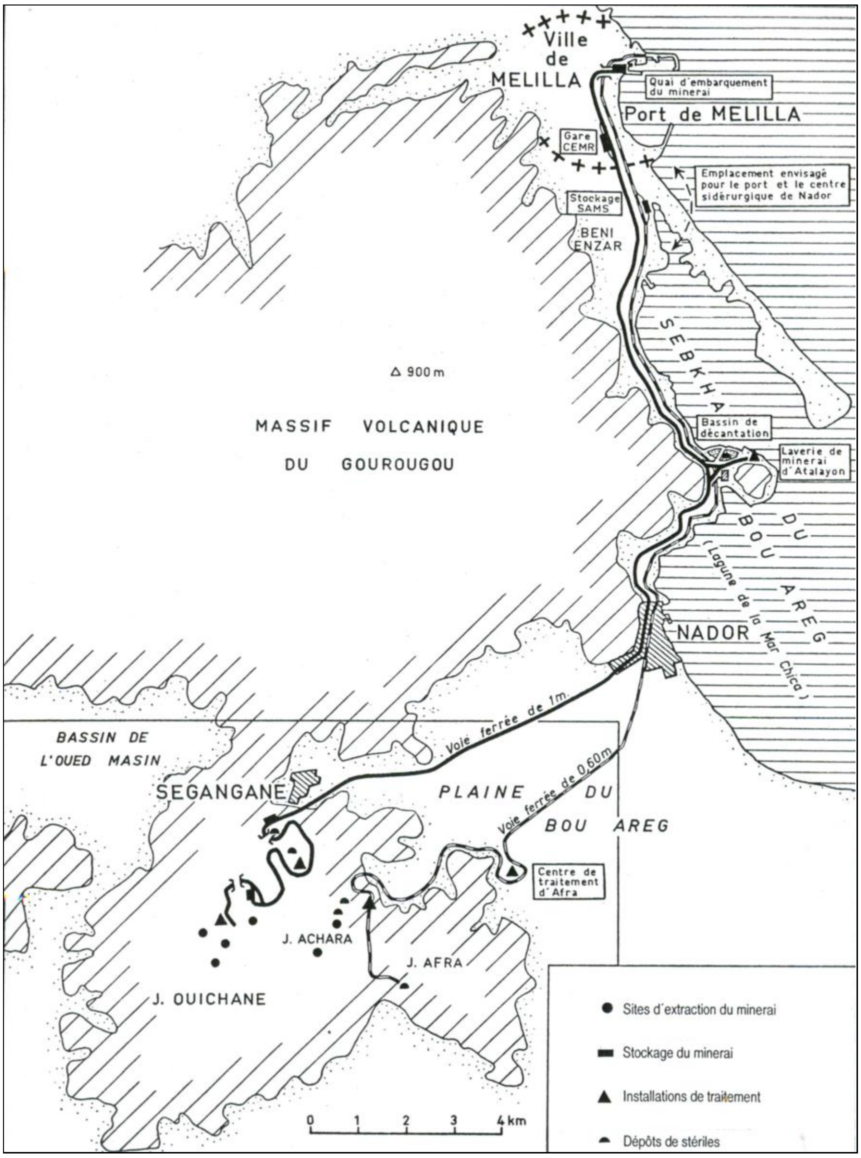

Figure 9.: Location map of the iron mining deposits of Ouichane and the mining railway lines for the exploitation of the iron deposits by the Spanish Rif Mines Company, 1921. Also showing the geo-economic strategic enclave of Nador by the Spaniards. Source: SDAU-GN (2012).

Hence, the Spanish colonial impact in terms of territorial and economic development was fairly negligible, explaining thus not only an important delay with regard to basic infrastructure and services in the region, but also the lastingness of a dispersed habitat and a relatively late appearance, compared to other regions of the country, of the urban phenomenon. Moreover, these different investment efforts made in infrastructure and development partially led to economic imbalances between the two protectorate regions which still persist today. Furthermore, intra-regional disparities were and are still acute at the level of the Nador Province and largely at the Oriental region, exemplified by the sharp drop in capital equipment when moving away from the capital city of Nador (Berriane and Hopfinger, 1999).

Another consequence of poor investment was the establishment of an intense smuggling traffic developed in the Rif region, mainly with the nearby Spanish enclaves of Ceuta and

Melilla, which still continues today. Actually, Nador owes the complex organization of its space, probably unique in Morocco, to the Nador-Melilla nexus, that marked the urban and demographic structure of Northeastern Morocco until the end of the Spanish Protectorate (Berriane and Hopfinger, 1999; SDAU-GN, 2012). Hence, it has sometimes been said that during the Spanish colonialism Nador was just the shadow of Melilla.

However, during the 1920s and responding once again to the geo-economic and strategic location, the Spanish rulers decided to transfer the majority of the administrative services from Melilla to Nador (Berriane and Hopfinger, 1999; SDAU-GN, 2012). In 1934, Nador was elevated to city status and became the capital of the Oriental-Kert region, the largest of the five regions under the Spanish Protectorate in Morocco (Berriane and Hopfinger, 1999; Bravo, 2009; Bravo et al., 2005). Its role as the capital of a regional administration, involving a considerable improvement in its infrastructure, coupled with a rising economic activity, promoted the rural exodus throughout the surrounding countryside towards Nador and resulted in a significant increase in population (Berriane and Hopfinger, 1999; SDAU-GN, 2012).

Therefore, during the first half of the twentieth century, three key factors drove the development and growth of the city: the military activity, the diversification and intensification of the commercial and economic activities of the civil population (that were to supply the army itself) and its designation as the capital of the Oriental-Kert regional administration, meaning hosting all the regional governmental agencies of the Spanish protectorate (Bravo, 2009; Bravo et al., 2005).

With the Independence (1956), the Rif region and particularly the eastern Rif suffered from political and historical prejudices that accentuated its marginalization relative to the economic and political decision-making of the central regions of the country and showing once more the nature of the complex relationships maintained between Riffians and the central government.

The state repression on the Rif territory was intensified in the Mohammed V reign (1957-1961) and was particularly severe under the Hassan II monarchy (1961-1999) who applied a policy of vengeance and punishment and left the Rif region largely neglected by the central government. Decades-long oppression and marginalization, with minimal investment rates, resulted into poverty rates among the highest in the country. This enduring asymmetries coupled with very little support from the center resulted in a lack of economic opportunities and forced Riffian people to resort to widespread cultivation of illegal drugs and smuggling, merely to survive (Suárez, 2015). Many Riffians chose to travel to Europe as migrant laborers, to the result that the majority of Moroccan migrants in Europe come from the Rif (Esveldt et al., 2000; Bilgili and Weyel, 2009; Suárez, 2015). The situation did not improve until the 1970s and 1980s, when the State invested in important infrastructures, such as the construction of the Beni Ansar port or the sugar industry (SUCRAFOR) in Zaïo that considerably boosted the regional economy (Berriane and Hopfinger, 1999). Yet, it was only in recent years, after the accession of Mohamed VI (1999) and the implementation of regional development plans, that the rejection of the central government by Riffians, so rooted by decades of neglect and contempt, started to diminish (Madariaga, 2010).

During the immediate years following independence (1956), and throughout the second half of the twentieth century, Nador sustained a tremendous and sudden acceleration of urban growth, coinciding with the decline of the mining activity. The city multiplied its population and built area (see Fig. 10). Lack of urban planning, self-construction and chaotic growth characterized this accelerated building period leading to the actual urban fabric typified by a total lack of cohesion and a spread of housing space in a fully saturated urban perimeter (Berriane and Hopfinger, 1999; Bravo et al., 2005; SDAU-GN, 2012) (see Fig.10). Among the key drivers explaining urban growth we must mention migration, city development dynamics, and land market and real estate usually all intertwined with each other in a manner that had no parallel in Morocco (Berriane and Hopfinger, 1999).

Migratory movements: rural to urban and international labor migration

Without being the main reason in explaining Nador's urban growth, migration, and especially international migration, have contributed in a significant ways to explain current growth processes (Berriane and Hopfinger, 1999).

The rural exodus to Nador, which began in large numbers in the 1960s, was triggered by the deficient basic infrastructures coupled with the few employment opportunities that rural villages could offer. Instead, Nador was comparatively much better equipped than the other cities and the surrounding rural centers of the region although it fared badly when compared to the majority of the cities of the country and to other regional capitals of equal size. Moreover, Nador offered more job opportunities for steady or even temporary employment. Rural migration to Nador grew further as a result of the international labor migration (Berriane and Hopfinger, 1999).

The Moroccan migration boom, which lead to Moroccans being among the most prominent diaspora groups in Europe, started with the so-called "guest worker" programs in the 1960s, that consisted of labor migration agreements between Morocco and several European governments to offset labor shortages abroad. Between 1963 and 1969, Morocco signed bilateral formal recruitment agreements with France (1963), Germany (1963), Belgium (1964), and the Netherlands (1969) (Bilgili and Weyel, 2009; Collyer et al., 2009).

Far from being simply a spontaneous process, Moroccan emigration to Europe was triggered by the Moroccan state for political and economic reasons. Actually, it was conceived as a strategic long-term national project for the economic development and political stability of the country (De Haas, 2005; 2007a). The state believed that by stimulating emigration from specific regions, such as the northern Rif Mountains, where a strong resistance and rebellious attitudes to the central authority had historically been dominant, migration could be a means to prevent political tensions and unrest. Likewise, it was argued that the remittances sent by migrants working abroad could improve the economic situation in the regions of origin, and thus contributing to the national prosperity and to prevent poverty (Bilgili and Weyel, 2009; De Haas, 2007a).

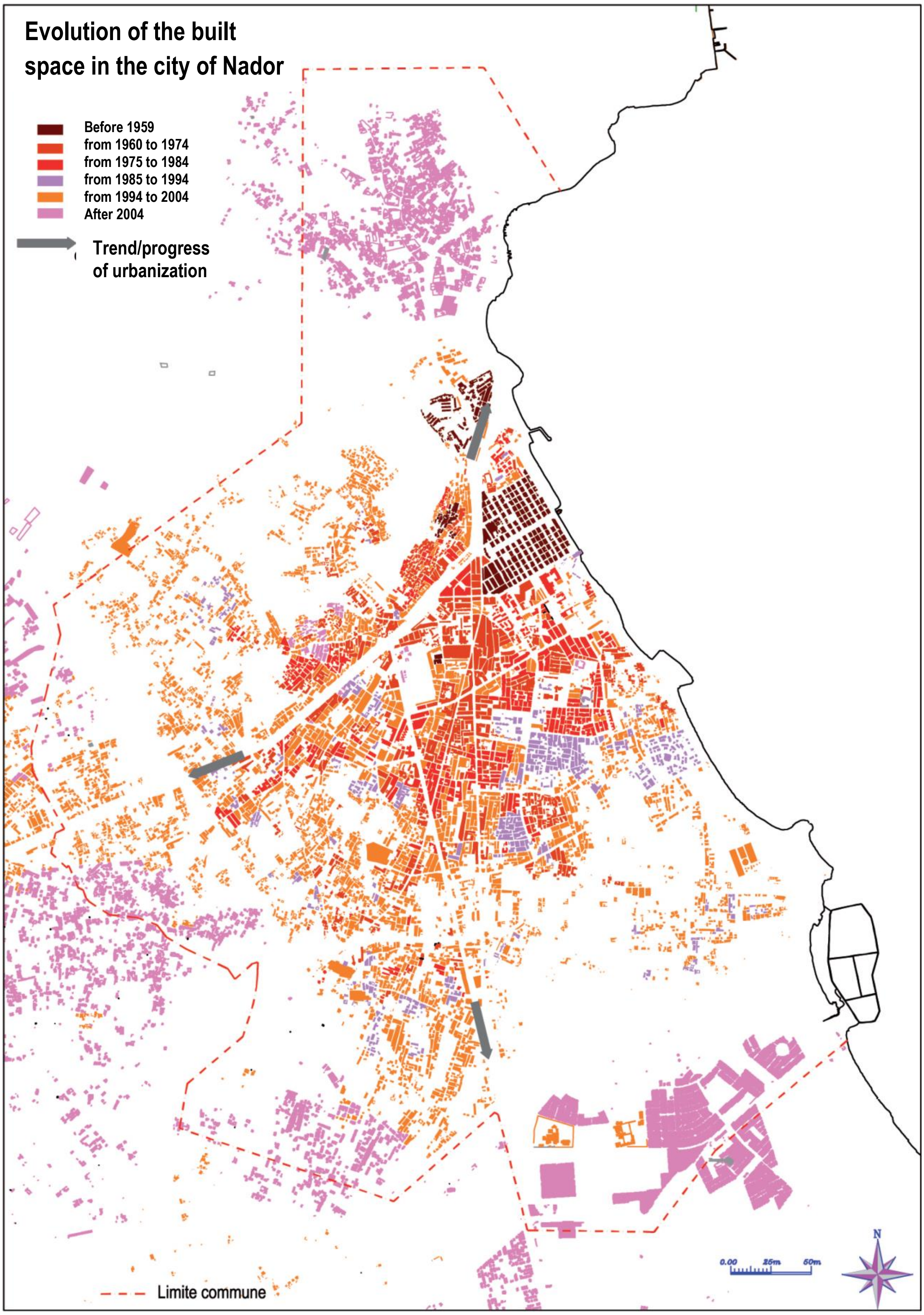

Figure 10.: Map of the building construction evolution in Nador since independence to last decade. Source: SDAU-GN (2012).

Therefore, the Rif, where insurrection and revolt took place after independence as a result of economic crisis, political discontent, and perceived discrimination, became one of the first migratory regions in the country (Berriane and Aderghal, 2008; De Haas, 2007b). The eastern Riffian labor migration to Europe began in the late 1960s and intensified in the early 1970s. Although starting comparatively late, from a quantitative point of view, Rif emigration to Europe quickly achieved a much more massive scale than in the rest of Morocco (Berriane and Hopfinger, 1999; Bilgili and Weyel, 2009; Collyer et al., 2009; Sasin, 2008). Besides, the Oriental Rif was also a region with established traditions of seasonal and circular migration within Morocco and towards Algeria (Bilgili and Weyel, 2009). As a region under the Spanish colonialism, the Riffian population did not speak French, partially explaining why the majority of the Rif migration was chiefly directed towards the large industrial regions of Northwestern European countries such as the Netherlands, Germany, and Belgium rather than to France, and was characterized by a strong spatial mobility (Berriane and Hopfinger, 1999; Bilgili and Weyel, 2009; De Haas, 2007b). In the case of Germany as a hosting country, there were connections dating back to German purchase of Riffian iron ore, and to the fact that, in the mid-1960s being in full economic expansion, Germany was running out of manpower. Hence the first employment contracts were signed between the miners of Ouichane and the mining companies of the Ruhr (Berriane and Hopfinger, 1999).

Until the mid-1970s Moroccan migration to Europe was essentially circular, from only some selective regions and organized by efficient migration networks. The Riffian emigrant community was male-dominant, had relatively low educational skills and a strong attachment to their families and their home country (Berriane and Aderghal, 2008; Bilgili and Weyel, 2009). Mostly, the (male) migrant was the family head, hence, generally he emigrating alone, moving his family to Nador or to one of the urban centers of the suburbs to ensure decent housing for his family, and provide his children with better conditions of schooling. The search for a better living conditions and a certain comfort, together with ensuring the future and stability of his family were the main motives to emigrate. Therefore, the emigrant's priority was to invest his first savings in a house in the city, followed by investing in a small business or a service to provide a source of income to his family that remained in the country. Housing and small businesses investment usually also responded to emigrant's aim to ensure a place to live in and work when he finally returned from abroad (Berriane and Hopfinger, 1999).

The 1973 oil crisis meant the starting point of return migration programs and a shift in the nature of Moroccan migration to Europe. The oil crisis caused economic stagnation and recession leading European countries to growing unemployment. No longer in need of low-skilled labor migrants, recruitment stopped, and the European countries successively closed their borders and implemented policies supporting family reunification and return. Yet, since the crisis had affected Morocco even more drastically than in Europe, causing both economic and political instability, return on a voluntary basis was therefore low and many of them preferred to stay in Europe permanently (Berriane and Aderghal, 2008; Bilgili and Weyel, 2009; De Haas, 2005, 2007b, 2009). Hence, the large-scale family reunification translated the nature of Moroccan migration to Europe from circular into more permanent settlement (Bilgili and Weyel, 2009; De Haas, 2007b).

In the late 1980s and early 1990s, family formation, i.e. marrying a partner in Europe, became for many Moroccans an important way, actually the only legal means, of migration to classic European destination countries. Family formation was also triggered by the fact that many second-generation Moroccans in Europe preferred to marry someone from their family's home country (Berriane and Hopfinger, 1999; Bilgili and Weyel, 2009; De Haas, 2007b). In recent years, Moroccan migration to Europe took an increasingly-undocumented nature, being Spain and Italy the most important destinations for irregular migrants, particularly because these were the countries that closed their borders the latest, and because in these countries it was possible to obtain a legal status after marrying in the destination country or through legalization campaigns (Berriane and Hopfinger, 1999; de Haas, 2007b).

In short, it was under the influence of massive international labor migration, and the resulting rural exodus, that Nador's urban expansion took place in the 1960's and especially in the 1970's. Other than being an important socio-economic process, migration had also intrinsically influenced the region's development and the livelihoods of the migrants and their families (in Bilgili and Weyel, 2009). De Haas (2009) argued that both return and circular migration constituted channels through which migrants contributed to Morocco's development.

The return migrants generally resettled in big cities and urban areas. Nador quickly became the preferred place of return and investment of a majority of Riffian emigrants. In addition, by being one of the most significant emigration regions in Morocco to Europe, Nador was also receiving relatively large inflows of remittances (Bilgili and Weyel, 2009; SDAU-GN, 2012). Migrant remittances significantly contributed to boost Nador's urban economy, particularly the construction sector, followed by trade and services. Migrants' investment represented an important share of total remittances, standing out housing as the main investment in the home country (either for the migrant and their family or for rental), which simultaneously was a sign of higher social status and success for migrants in the eyes of their community (Bilgili and Weyel, 2009; De Haas, 2007c). On the other side, migrant remittances constituted an important additional source of income in household budgets that was partly spreaded into the local economy through higher consumption (Berriane and Hopfinger, 1999; Bilgili and Weyel, 2009; SDAU-GN, 2012). In sum, migrant remittances directly improved the living standards of recipient households (Bilgili and Weyel, 2009; De Haas, 2007b).

According to Berriane and Hopfinger (1999), family economies worked through keeping the networks that linked members living abroad with those that remained in the country. These links were not only limited to money transfers, used in everyday consumption or in the construction sector, they also reflected the concern of migrant workers to create small projects, in the trade or services, in order to offer employment to their sons or relatives that stayed at the region of origin.

With regard to the construction sector, an internal migration movement from other regions of Morocco, was triggered to offset labor shortages at the local construction industry, under the double effect of demand from Riffian international migrants and the lack of local workforce (Berriane and Hopfinger, 1999; Bilgili and Weyel, 2009).

Still today, migration plays an important role in the Moroccan society, as the substantial volume of remittance flows remains indispensable for the Moroccan government. Actually, with the Moroccan migration boom, remittances were the biggest component of non-labor income and reached to account for an average 10 percent of the household budget in the country (Bilgili and Weyel, 2009; De Haas, 2005).

Therefore, in the early 1990s, and after some years of a rather complicated relationships with its migrants, the Moroccan state tried to foster a beneficial relationship with its citizens abroad by carrying out several measures and significant institutional developments to facilitate inflows of remittances in the origin country (e.g.: the creation of a ministry for Moroccans residing abroad and the establishment of the Foundation Hassan II for Moroccans Abroad) (Bilgili and Weyel, 2009; De Haas, 2005; 2007a). As a result of this, more positive attitudes and a more general liberalization of the Moroccan society in general, the Moroccan Diaspora expanded, a considerable increase in remittances was observed, and protection of emigrant rights were prioritized (Bilgili and Weyel, 2009; De Haas, 2005).

The dynamics of city development

Despite the strong links between migration processes and urban growth, the dynamics of development in Nador did not only depend on the migration effects, but also in more endogenous factors.

From Independence to the 1970s, the urban economy of Nador was almost exclusively based on remittances by labor migrants abroad, illegal activities, and the tertiary sector in general and trade in particular. Yet, Nador together with its Province were among the most marginalized and disadvantaged regions in terms of public infrastructure (Berriane and Hopfinger, 1999).

Migration to Europe significantly determined the economic life of the agglomeration of Grand Nador and helped to give the city its commercial vocation, since most of the commercial activities were initiated with migrant capital savings. Nador’s tertiary sector was based on administrative functions and commercial trade. After Independence, Nador maintained its administrative role, this time as the capital of the province of the same name, and became a small regional growth pole. Trade was, and it is still today, one of the main engines of Nador’s urban economy. Additionally, the size of the commercial sector in Nador was much higher than revealed by the official figures, on account of the smuggling trade with Melilla, that has attracted not only people from Nador and surroundings but also from all over Morocco and Algeria (until the closing of the Algeria-Morocco border in 1994) (Berriane and Hopfinger, 1999; SDAU-GN, 2012). Moreover, the distribution of contraband products through legal trade channels implied a growing interpenetration between legal trade and illegal trade from Melilla. Therefore, it has become increasingly difficult to isolate the legal from the illegal trade in Nador. Indeed, many, if not most of the traders in the legal system now offer a wide variety of goods entered illegally in the city (Berriane and Hopfinger, 1999; SDAU-GN, 2012).

In short, Nador's contraband activity owes its success to the close enclave of Melilla, a free port since 1863, that benefited from tariff exemptions by the Spanish Law of Economic and Financial Plan since 1955, and remained outside the Schengen law and therefore excluded from the common European tax policy, customs union and Common Agricultural Policy (Berriane and Hopfinger, 1999; SDAU-GN, 2012). Melilla enjoys from exemptions on customs duties and other taxes on goods entering the city. The Spaniards support Melilla's local economy by subsidizing consumer products, to the extent that the tax levied on essential goods, such as food products, is insignificant. Yet, given the small nature of its local market, and with about 30 percent of its population being Moroccans, Melilla targets the Moroccan market, hence the Spanish authorities have allowed the inhabitants of the province of Nador to travel to Melilla, simply by showing their identity card (SDAU-GN, 2012). It was estimated that more than 50,000 people commute daily to Melilla to stock up on Spanish products, which first pass through neighboring cities, including above all Nador before being routed to other Moroccan cities. Therefore, Melilla's trade has been essentially directed to the Moroccan domestic market at strong competitive prices. These price differentials are exploited by smugglers on both sides of the border (SDAU-GN, 2012). Thus, the existence of an international border between the cities of Nador and Melilla has done nothing but to help develop intense trade relations between the two entities that can hardly live without each other (Berriane and Hopfinger, 1999). However, the entry into force of the free trade agreement between Morocco and the EU (which began in 2000 to be fully accomplished by 2010) along with the realization of forthcoming projects (such as the "Nador West Med" project and the industrial park of Selouane), may contribute to the progressive decline of this trade in the nearer future, since imports of European products through the port of Melilla will no longer benefit from attractive prices compared with those to be imported from Nador (SDAU-GN, 2012).

Yet, although trade and emigration flows marked the economy of Nador, serious attempts to develop industrialization also existed. In the early 1970s, the State implemented some major projects that helped to set up the basic infrastructure for endogenous development. Likewise, individual initiatives of local actors, increasingly attracted by the production sector, contributed to develop the industrial sector of Nador (Berriane and Hopfinger, 1999).

The most significant efforts made to industrialize the region were basically the following four: the nationalization of the Rif Mines Company (1968); the modernization of agriculture in the irrigated perimeter of the Bou-Areg (1971); the creation of the sugar refinery Sucrafor (1971) based in Zaïo, that treats the sugar beet and cane produced in the irrigated area of Bou-Areg and which is still today one of the largest employers in the region, and the creation of the National Steel Company (SONASID) (1974), a heavy industry complex that consisted in the transformation of Ouichane iron, manganese from Bouarfa and anthracite from Jerada. In the 1980s the state also contributed to the fishing activity on the Mediterranean coast and in the lagoon, the creation of a rolling mill, the opening of an industrial zone in Selouane and the construction of the modern port in Beni Ansar. The development of the Beni Ansar port (1980) was directly related to the commercial vocation of the city and has since become one of the most important national fishing ports on the Mediterranean Morocco and a major regional hub for raw materials and agricultural and finished products. Finally, the canning industry has also grown remarkably. This increase has been accompanied by a product diversification: canned vegetables, fish and meat, exporting almost all of its production of canned vegetables to the European market (Berriane and Hopfinger, 1999).

The global impact of all these different activities form the different productive sectors of Grand Nador (divided into four industrial sectors: agro-food industries; textile industries; building materials industries, chemicals; mechanical, metal and electrical industries), even from those more or less legal activities of the informal sector, though could not be quantified, gave a strong economic boost to the city during the 1980s and 1990s and thus contributed to the population dynamics and urban growth of the region (Berriane and Hopfinger, 1999; SDAU-GN, 2012).

Finally, as acknowledged by Berriane and Hopfinger (1999) drug trade was another important source of external income into the Nador region, thus completing with what was known as the infernal trilogy of 'smuggling, drugs and emigration'.

Land market and real estate. Land property speculation as engine and consequence of the urban explosion

During the 1970s and 1980s, uncontrolled urbanization developed in pace with population growth. It expanded in the outskirts of the city center and was constantly gaining ground on areas previously occupied by intensive agriculture. The chaotic growth of the city jointly developed with an intense process of land speculation, that, in addition to benefit from various interests, escaped any attempt of tax collection (Berriane and Hopfinger, 1999). This intense land and property speculation activity was fed back by the large cash flow that entered in the form of remittances in Nador, which, as said before, became one of the main historic centers of departure of the intense emigration towards Europe (SDAU-GN, 2012).

Since Morocco's independence, land market in Nador, like in the rest of northern Morocco, had been very unstable. The Spaniards left northern Morocco without any official register of land property, nor did the Spanish hold a policy reform on land and property law (Berriane and Hopfinger, 1999). But since even earlier times, the former territory of Grand Nador had been subjected to a succession of several land legal texts that contradicted each other, thus resulting in a situation where regularization became and still is today a daunting and difficult task. This juristic-historical legacy has resulted in a very low land property registration rate, that is the transformation from a khalifien title to a titular land, because of the increasing amount of litigation cases in courts, and the numerous blockage claims, that occur during the procedures of transformation generating a huge apprehension on owners. Hence, owners preferred to enjoy an unsaved but uncontested property than starting a registration process through which opposition could arise (SDAU-GN, 2012).

This low registration rate stands still today as a major handicap to the development of a regulated/statutory construction activity, since according to articles 4 and 5 of the 25/90 law, relative to the lots, division and blocks of flats on housing estates and residential groups, authorization request is considered "inadmissible and/or unacceptable if the land is neither registered, nor in the course of registration". Hence, the fact of not accepting to examine any authorization request for the permission to subdivide or create groups of dwellings located on lands not covered by a land title, it actually means to deny the urbanization of almost all land object of a khalifien title. Thus, this constraint stimulated the multiplication of illegal operations of land subdivisions and underequipped housing on all existent unregistered land (SDAU-GN, 2012). In the absence of a unified land status, constructions have been built according to ownership's land, being in either urban or rural areas, and regardless of existing urban planning documents. In other words, what prevailed was the logic of the land property instead of that of urban planning. At any rate, this did not prevent the urban area of Nador from experiencing a strong expansion (SDAU-GN, 2012).

On the other hand, land also constituted a major obstacle in the process of lots and housing production because of its excessive price and rarity. The cost of the urban land was excessively high, not only in Nador and the other cities of the urban agglomeration, but also in the immediate outskirts of the urban centers. Besides, public lands are extremely rare. According to SDAU-GN (2012) these two factors in particular led to the phenomena of population densification and peripheral smears causing the disruption of the functioning of the urban fabric.

Therefore, this unregulated and very anarchic land situation, coupled with the excessive pressure from rural migration to Nador, and the increasing housing demand from Riffian emigrants (the construction fever driven by the European emigration demand), fostered the development of a fierce land speculation process. Actually, the very short and highly localized period within which housing demand had to be covered (during emigrants weeks off in summer) helped to trigger unprecedented land speculation, of which the emigrant became the main victim having to pay much higher prices than non-migrants for the same house or land (Berriane and Hopfinger, 1999). Moreover, Nador's smuggling activity with Melilla, together with its condition of a drug trafficking hub, also contributed to a highly sustained pressure on land prices. According to Berriane and Hopfinger (1999) land market transactions were also used for laundering drug money.

Therefore, the city expanded through a massive construction movement of spontaneous housing, built without official authorization and hence not registered in the official land records, in an undescriptive anarchy that went along with an unprecedented land speculation fever. Yet, it did not led to the emergence of spontaneous urbanizations of informal settlements, i.e. slums, commonly found in poor neighborhoods of other Moroccan cities. By contrast, the development of basic infrastructure to accompany the extension of the growing city could not follow at the same pace this rapid urbanization (Berriane and Hopfinger, 1999). Besides, since urbanization in Nador was partially raised on illegal constructions, in these areas it was virtually impossible to plan and implement any regulatory equipment well distributed in space (Berriane and Hopfinger, 1999).

The massive investment of emigration savings in producing an impressive housing stock led to a spectacular and rapid expansion of the built environment (see Fig.10). These big sums of money that glided among land and property speculation displayed the large volumes of capital, channelled through the banks, that were accumulated in Nador thanks to the migrants remittances (Berriane and Hopfinger, 1999). Actually, Nador and its province have been one of the leading cities and most active national regions in receiving savings from Moroccan citizens abroad (Berriane and Hopfinger, 1999; SDAU-GN, 2012). Yet, the extraordinary concentration of both bank entities and deposits in Nador and its Province, making the city the third financial center of the country after Casablanca and Rabat, far from being an economic indicator of wealth, was only an indicator of the money supply that circulated in the region. The banking network was essentially to collect the money, but not to benefit the city since funds instead of being redistributed locally as loans for investment were channeled for reinvestment to other regions (Berriane and Hopfinger, 1999; SDAU-GN, 2012).

The beginning of King Mohammed VI reign, in 1999, appeared to inaugurate a new era for Morocco. The gradual opening of civic and political space have characterised the country in the last decades (Madariaga, 2010). At the political level, the main government reform is the evolvement from a strongly centralized monarchy towards a political system dominated by the power of the parliament elected by democratic means, yet the King still today maintains a large proportion of the executive power (De Haas, 2009). Moreover, to develop Morocco’s economy, and raise the country to international standards (since its independence Morocco developed relatively strong partnership with the Western world, and the European Union is now one of Morocco’s main political partners), the King has set priorities in the government’s political agenda, which means essential reforms in many different fields such as justice, education, agriculture, industry, energy, and water (Bilgili and Weyel, 2009). Specifically, King Mohammed VI has made the economic opportunity for the Moroccan poor a cornerstone of his domestic policy and thus reduce the disparities between the Arab and the Berber population (Madariaga, 2010). Socially, decisive measures on human rights appear to have considerably improved Morocco’s record on this matter (Bilgili and Weyel, 2009).

With regard to the Oriental region , and thus GN, since 2003, the Moroccan Government has been channeling considerable sums of money. A number of cities and provinces received massive support for the development of agro-industrial, tourism, transport and logistics, and technology centers, with the aim to convert the Oriental Region into an economically strong gateway/interface between Africa, the Maghreb countries and Europe, by taking advantage of its direct access to the Mediterranean Sea (Runge et al., 2011).

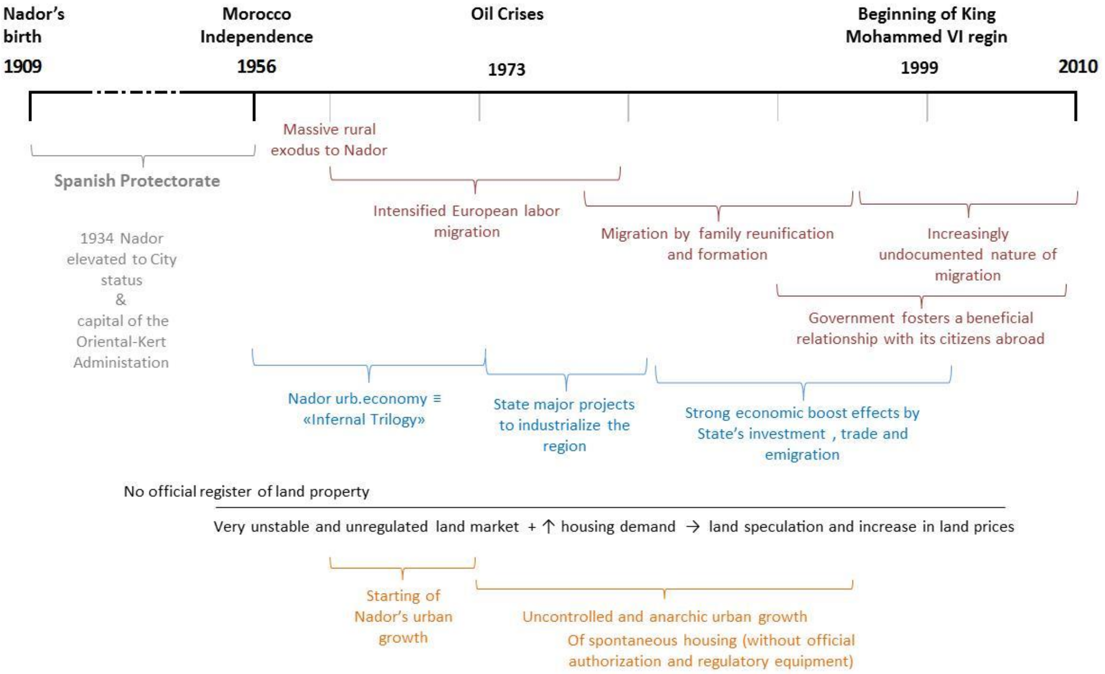

Figure 11.: Time-line of the birth and growth of the Nador city and its urban agglomeration. Source: Author's elaboration.

The current situation of Grand Nador

The spatial organization of Grand Nador today, itself a result of historical processes strongly marked by the Spanish colonial era, is characterized by the complexity of its urban structure, probably unique in Morocco. The Nador-Melilla nexus has been at the origin/root of this polynuclear urban complex consisting of several relatively urbanized municipalities and periurban communities with pronounced rural characters. Therefore we find a mix of urban and rural entities of uneven importance and functions.

The center of GN, with the city of Nador, the satellite municipalities of Beni Ansar and Zegangane, and the rural towns of Ihaddadene and Bni Bouifrour, concentrates the majority of the economic and financial activity, the social and administrative facilities, and most of the employment opportunities. It is thus a highly attractive area for the surrounding rural populations. Yet, the area is oversaturated and has no room for growth as it is enclosed between mountain ranges and the irrigated perimeter. The southeast peripheral area, made of by the satellite centers of Al-Aroui, Selouane, Zaïo, Arekmane and the rural communes of Oulad Settout, Bni Oukil Ouled M'Hand and Bouarg, is characterized by the existence of the most important agricultural irrigated perimeter of the province of Nador. It also contains the industrial park of Selouane and the Sucrafor factory, and the international Airport. Employment opportunities are high, and it is the direction towards which the agglomeration mostly expands. The western peripheral zone, consisting of the rural towns of Tiztoutine and

Iksane, is characterized by its rugged topography and its remoteness to Nador. It is the poorest area, with the lowest employment and a high rate of illiteracy (SDAU-GN, 2012).

Meanwhile, the city of Nador is structured in five more or less homogeneous areas. The historic core, in the form of a Spanish checkerboard, is the oldest entity and heart of the entire urban agglomeration. As administrative and business pole, it also concentrates financial activities and the essential urban facilities. The Southwest area, organized in continuity with the historical core, is home to several public administrations, as well as the education, cultural and service centres. Yet, some of the private lots of the area are still not connected to basic urban infrastructure networks. The Western peripheral area, keeps changing from agricultural to a spontaneous semi-dense to dense urban tissue, largely deprived of basic public urban facilities. The Northwest area is home to most of non-regulatory housing districts. Enclosed in the foothills of the Gourougou massif, its accessibility is a real problem. Characterised by an irregular dense urban fabric, the periphery remains completely devoid of basic urban facilities. It is the district where a low-income population lives. Finally, the Aviation district is the new modern area of the city, in progress of construction, is fully structured and equipped (SDAU-GN, 2012).

With regard to the rest of the urban satellite centers of the agglomeration, the same structure applies. That is, a central zone rather homogeneous and regular, of dense urban fabric on both sides of the road to Nador, and hosting some public administrations and equipment. In the peripheral area, located at either side of the central zone, the urban fabric of non-statutory housing becomes anarchic and largely devoid of basic public facilities. Although some of these districts are neither connected to the sewerage nor have a garbage collection system, public facilities are planned in new urbanistic projects. The other communities of GN are of rural character, in them both modern and typically rural constructions are found mixed together. In general terms, constructions are built in a very anarchic and scattered way. Likewise, most of the constructions are not connected to public facilities (SDAU-GN, 2012).

As said before, from the mid-1970s to the mid-1990s, Nador experienced a chaotic and uncontrolled urban growth, not only in the number of inhabitants but also in terms of its built space. In addition to the densification of the old districts, the development of a dense urban fabric, devoid of public infrastructure facilities, was originated largely at the expense of the fertile farmlands of the South and Southwest (SDAU-GN, 2012).

The physical constraints to urban growth, namely, the presence of the irrigated perimeter of Bou-Areg and the Gourougou massifs, together with very strong land speculation and the high price of land, not only resulted in a very large yet poorly planned urbanisation and the saturation of its urban space, but also forced the migration to the city outskirts reinforcing the development of the small and medium urban satellite centers (Beni Ansar, Zegangane, Selouane, Al Aaroui, etc.) (SDAU-GN, 2012).

These new urban areas, sheltering at the present the majority of the population, mostly consist of popular districts, that is, spontaneous constructions built without accordance with any regulated urban plan, on land devoid of public infrastructure facilities such as public sanitation. These districts are also characterised by the absence of a clear legal status of the land registered in the name of the original owner or of possible heirs (SDAU-GN, 2012). However, It must be noticed that in most cases, housing is of very good quality enjoying all elements of comfort. Therefore, in GN the problem of under-equipped housing is more related to the absence of basic infrastructure of non-regulatory districts, than to the existence of precarious housing, i.e. slums (SDAU-GN, 2012).

Therefore a clear disparity exists between the center and the periphery, both within the same municipality and between municipalities. The same duality manifests at the regional level, when comparing GN with the Oriental region. Indeed, the great dynamics in urban centers is opposed to a real lethargy in the rest of the GN, thus resulting in a distortion and a spatial imbalance especially between the city of Nador and the other municipalities. Globally, Nador and the surrounding municipalities (Beni Ansar and Zegangane) monopolize the absolute majority of the equipment and public facilities. In addition, when compared to the Oriental region the area of GN offers a better level of basic services and infrastructures (SDAU-GN, 2012).

Discussion

The urban growth sustained by Nador and its region calls for its explanation and effects. While the large sums of money coming from the so-called infernal trilogy "emigration, smuggling and drugs', and the associated money laundering, may quite easily explain the intensity and scale of the urbanisation movement, they do not explain the disorder and anarchy in which this urban growth develops, nor the obvious contradiction that manifests between an anarchic city, under-equipped and apparently poor, relegated among the most backward cities nationwide in its development, and the flows of know-how and money that overwhelm the city since the late 1960s, becoming a city considered among the most significant in banking and finance (Berriane and Hopfinger, 1999).

In short, although Nador accumulates many paradoxes, the most significant is the gap between a city under-equipped and apparently poor and the flows of know-how and money it receives (Berriane and Hopfinger, 1999). It is precisely this paradox that highlights the need to contextualize, both at the historical and sociopolitical level, the development of this urban growth for the full understanding of its metabolic characteristics.

Economic grievances and decades-long oppression and marginalisation inflicted to Riffians by the Moroccan government forced Riffian people to primarily operate from outside of the national economy, that is European labour migration, smuggling trade with Melilla and cultivation of illegal drugs, hence the development of the historical bases of Nador’s black economy, partly rooted in the Spanish colonial period. Therefore, since the Moroccan State turned its back to Nador’s region, Nador had to live of the outside in order to survive.

Troin (2011) demonstrates this same argument by conducting a spatial analysis of the Moroccan territory. The author explains that Morocco, in general terms, follows the classic center-periphery spatial model with a decreasing gradient from the Atlantic coast (model based on a qualitative division of a territory into functional regions). Yet this model gets in contradiction/conflict with the region of Nador, characterized as an extremely vital region literally located at the geographical periphery of the national territory.

The same author (2011) illustrates that the region of Nador is a clear example of a classic interface zone (model of spatial analysis based on the opening degree of regions to the outside world), given the intense international migration flows coupled with informal or illegal activities that it experiences. Nador plays a connection role; it becomes the exchange and crossing area between an international foreland and a national and local hinterland (either via the sea or the mountain). Therefore, the region of Nador represents a space of transit, endowed with a modern port and an international airport, it sustains its associated substantial international flows, which are both related to regular migratory ties towards Europe as to the smuggling movements with Melilla (Troin, 2011). Hence the flows of know-how and money received by Nador.

The fairly negligible Spanish colonial heritage in terms of territorial and economic development (infrastructure investment), together with the absence of a unified land property status and the accentuated marginalization and neglectedness in political and economic terms by the central power after independence, had important effects on the urban growth of GN, shaping the origins of the anarchic and underequipped development of the city-region. Marginalization by the state resulted in a total lack of investment in the region. Consequently, this also meant a lack of urban governance, particularly the absence and inadequacy of urban planning. This situation was aggravated by the unstable land market in Nador, that is, the low land property registration rate jointly with the land speculation process. The combination of these factors under the pressure of a high demand for housing stimulated the multiplication of illegal operations of land subdivisions on all existent unregistered land explaining the anarchic character of the urban expansion. Hence the massive presence of mostly spontaneous and informal housing. This situation produced two sets of problems. On one hand, the development of basic infrastructure to accompany the extension of the growing city lagged behind this rapid urbanization process, and on the other hand, construction without official authorization and lack of formal registration in official land records. Therefore in these areas it was virtually impossible to plan and implement any regulatory equipment adequately distributed in space, resulting in the underequipped housing development of Nador's city-region (Berriane and Hopfinger, 1999).

With regard to the last point, as Monstadt (2009) argues, networked urban infrastructures (e.g. water pipes, sewers, electricity and transport networks, power and sewage plants, waterworks, etc.) play vital economic and social functions in the fabric of contemporary cities. In particular, the quality and the degree of social and geographical access to networked infrastructures have a huge impact on distributional justice and social well-being in cities (Graham and Marvin, 2001, in Monstadt, 2009). As noticed in the previous section, the uneven distribution of public urban facilities in the agglomeration of GN, as well as within each urban area, follow a center-periphery spatial model with a decreasing gradient from the city of Nador, corresponding the later with the urban area that concentrates most of the functional activities of the whole region. Therefore, this uneven provision, access and use of these networked urban infrastructures aggravate socio-spatial inequalities, hence the apparently poor image of the agglomeration.

Furthermore, it can be said that the urban region of GN is a clear example of cities in developing countries confronted with environmental problems due to infrastructural deficits (Monstadt, 2009). From an environmental viewpoint, Monstadt (2009) explains that networked urban infrastructures are simultaneously root cause and key solving of many environmental problems in urban societies. They are actually a crucial physical interface between nature and society.

These sociotechnical network systems drive material flows in and throughout the city, structuring a large part of the material metabolism in modern urbanization, whose patterns, at the same time, are strongly dependent on the functioning of these technical infrastructure systems, and therefore vital in the promotion of urban sustainability (Monstadt, 2009). For instance, as will be further explained in the next chapter, Grand Nador's water supply and sanitation services are provided by the National Office of Electricity and Water Supply (ONEE in French). An important part of households, not only in rural communities but also in some urban districts, are still not connected to the collective water supply network, and even less to the sewerage network. Conversely, in central districts of urban areas households are better served. Because of the uneven connection to sewerage, this results in the proliferation of cesspools, and the presence of solid and/or liquid waste in open fields and in rivers/streams with its consequent high risk of water and groundwater contamination. Therefore, inequalities in the provision and access of these services not only involve different patterns of use and consumption, but also particular ways of disposal of with their corresponding possibilities and ways of environmental pollution. Urban governance, along with the development and renewal of these urban infrastructures becomes key in the regulation of a sustainable relationship between nature and societies (Monstadt, 2009).

One last dimension central to urban issues is food. Urbanization has a significant impact on food consumption patterns (Delisle, 1990; Ma, 2014; Qiao et al., 2011). Urbanization usually involves varying degrees of modernization and westernization which all impact on dietary habits. Modernization refers to lifestyles changes linked with socio-economic development; westernization, instead, refers to the adoption of lifestyles and behaviour that are typical of developed countries of the "Western world"(Delisle, 1990). Yet, as Delisle (1990) argues, urbanisation with its concomitant urban food consumption patterns and their evolution supposes far-reaching economic, nutritional and health implications, that constitute a key driver in altering the biogeochemical cycles (Grimm et al., 2008; Liu et al., 2008; Qiao et al., 2011) since urbanization promotes the shift from a society relying on nutrient recycling (the traditional closed rural cycle of nutrients) to a society totally dependent on external nutrient inputs (the open urban cycle). In other words, while in the past food was consumed close to its place of production, and the resulting animal manure and human excreta were applied to the same land, assuring a recycled nutrient flow by an approximately close loop, nowadays, these two activities are moving further and further away from each other, contributing to change the biogeochemical cycling of both N and P elements (Qiao et al., 2011; Kilcullen, 2012). Consequently, urban agglomerations, especially those with high population densities, become N and P 'hotspots' which cause large amounts of nutrients loss in waterways via urban sewers or as sludge in landfills because of the openness of urban systems (Cohen, 2006; Cordell et al., 2009; Ma, 2014; Neset et al., 2008).

As acknowledged by Kaye et al. (2006) urban ecosystems have been identified as sources of nutrient pollution to receiving waters in many areas worldwide. All this shapes one of today's main societal challenges, namely to respond to the increasing demand for food and agriculture's growing need of nutrients without exhausting P mineral resources, and reducing N and P negative environmental impacts.

Conclusion

Today's spatial organization and complexity of the urban structure of the city of Nador and its urban agglomeration, probably unique in Morocco, is the result of sociopolitical historical processes strongly marked by the Spanish occupation heritage in the first half of the 20th century and the marginalization policies followed by the ruling elite of the country after independence. The Nador-Melilla nexus has been at the root of this polynuclear urban complex, which created an urban doublet at first based in military matters and later on the smuggling trade.

However, Riffian historically rebellious and contestable character against the central authority, image strengthened by its resistance to colonial rule during the Spanish protectorate and perpetuated throughout the postcolonial history of Morocco, was the main cause of their political and economic oppression and marginalization, forcing the region to the opening to the outside world and to establish the foundations of its mostly "black" urban economy. Therefore, European labor emigration, intense smuggling trade with the nearby Spanish enclave of Melilla, and illegal drugs cultivation, the so-called infernal trilogy, supported, almost exclusively, the urban economy of Nador.

Minimal investment rates, in terms of territorial and economic development, both by the Spanish rulers but mostly by the Moroccan State, resulted into high poverty rates, among the highest in the country, and explain the still important delay with regard to basic public infrastructures and services in the region and the relatively late appearance of the urban phenomenon compared to other regions of the country. Conversely, the large sums of money coming into the region of Nador from the so-called infernal trilogy "emigration, smuggling and drugs', throughout the second half of the twentieth century, along with the intertwined city development dynamics and the unstable land market situation, resulted in a tremendous and uncontrolled urban growth from the mid-1970s to the mid-1990s.

Lack of urban planning, informal housing and chaotic growth, on land devoid of public infrastructure facilities, characterized this accelerated and massive construction period, that went along with a fierce land speculation process, leading to the actual urban fabric typified by a total lack of cohesion and a spread of housing space in a fully saturated urban perimeter.

These districts, that shelter at present the majority of the population of the GN urban agglomeration were also characterized by the absence of a clear legal land property status of the land registered in the name of the original owner or of heirs. Still today the unevenly regulated land situation prevents the control of urbanisation, causing an exaggerated explosion of the urban fabric and the predominance of self-construction, situation that becomes more complicated with the deficit in urban planning documents, adding thus important legal uncertainties.

This urban growth has also had its effects mostly in the form of the uneven provision-access and use of public urban facilities in the agglomeration of GN, as well as within each urban area. This aggravated the socio-spatial inequalities and the social well-being in the area, showing the clear disparity and the spatial imbalance that exists between the center and the periphery, both within the same municipality and between municipalities. This distortion results particularly acute within the city of Nador, and between the city of Nador and the other municipalities of the agglomeration.

Hence the most significant paradox that the city of Nador exemplifies, i.e. the gap between an anarchic city under-equipped and apparently poor and the large flows of know-how and money that it receives and that may stimulate sumptuous consumptions in some cases (food habits to name one). This was precisely what highlighted the need to contextualize the socio-political and historical development of urban growth in Nador for the full understanding, of metabolic flows that will be studied in the next chapters.

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Chapter 3.- Assessment of Nutrient flows for the urban metabolism of food in Grand Nador, Morocco

Introduction

Nitrogen (N) and phosphorus (P) are essential nutrients to all life for the biosphere (Smil, 2000). Both constitute the key factors in controlling and limiting the productivity of managed and unmanaged terrestrial and aquatic ecosystems (Antikainen, 2005; Childers et al., 2011; Smil, 2000; Vitousek et al., 2002). Through the control of growth they enable species and populations to develop or vanish. In sum, in the context of food-security, both macronutrients are critical inputs for agricultural production and its growth and hence indispensable nutrients for the production of food for humans and animals (Antikainen, 2007; Brunner and Rechberger, 2004; Chowdhury et al., 2014; Cordell et al., 2009; Smil, 2000).

During the 20th century, and especially in the last decades, an increased used of N and P for food production has been mainly driven by world population growth, accelerated urbanization and changes in food diets, as well as by agricultural practices and waste recycling (Bouwman et al., 2009; Ma, 2014; Metson et al., 2012a; Neset et al., 2008; Qiao et al., 2011; Smil, 2000). The composition of diets of urban lifestyles is typically associated with animal rich products, which require higher N and P input for their production than other foodstuffs (Qiao et al., 2011; Neset et al., 2008).

The Green Revolution, in the early 1960s, favoring the application of chemical fertilizers in agriculture, along with improvements in the practice of agricultural production and, to a lesser extent, the extension of the agricultural areas, fostered fast increases in food production in order to provide for the expanding food demands of the rapid population growth (Cordell et al., 2009; Ma, 2014; Ma et al., 2010; Smil, 2000). The Green Revolution was actually possible to a great extent thanks to the Haber-Bosch process, an invention that made possible to produce large amounts of artificial nitrogenous fertilizers (Cordell et al., 2009; Smil, 2000). However, at the same time, changes of N and P uses have resulted in deteriorated qualities of soil, air and water, along with a reduction of natural ecosystem areas due to severe environmental impacts ranging from global to regional scales (Conley et al., 2009; Galloway et al., 2008; Ma, 2014).

Besides, urbanization has a significant impact on food consumption patterns (Ma, 2014; Qiao et al., 2011), becoming therefore a key driver in altering the biogeochemical cycles (Grimm et al., 2008; Liu et al., 2008; Qiao et al., 2011). While in the past food was consumed close to its place of production, and the resulting animal manure and human excreta were applied to the same land, assuring a recycled nutrient flow by an approximately close loop, nowadays, these two activities are moving further and further away from each other, contributing to change the biogeochemical cycling of both N and P elements (Qiao et al, 2011).

Urbanization promotes the shift from a society relying on nutrient recycling (the traditional closed rural cycle of nutrients) to a society totally dependent on external nutrient inputs (the open urban cycle). Consequently, urban agglomerations, especially those with high population densities, become N and P 'hotspots' which cause large amounts of nutrients loss in waterways via urban sewers or as sludge in landfills because of the openness of urban systems (Cohen, 2006; Cordell et al., 2009; Ma, 2014; Neset et al., 2008). As acknowledged by Kaye et al. (2006) urban ecosystems have been identified as sources of nutrient pollution to receiving waters in many areas worldwide. All this shapes one of today's main societal challenges, namely to respond to the increasing demand for food and agriculture's growing need of nutrients without exhausting P mineral resources, and reducing N and P negative environmental impacts.

The case of Nitrogen

Nitrogen (N) is an abundant element found in the atmosphere as nonreactive molecular N (N_2 comprises 78 percent of the atmosphere) (Smil, 1991; 2000). In nature N compounds are classified into nonreactive and reactive. The first is diatomic nitrogen (N_2); reactive N (Nr) comprises all biologically, photochemically, and radioactively active N compounds in the Earth atmosphere and biosphere (Galloway et al., 2003, 2004). Reactive nitrogen predominantly exists in soils as organic N, whereas in waters it is found in molecular form N_2, ammonium (NH_4^+), nitrites (NO_2^-), nitrates (NO_3^-), dissolved organic nitrogen and/or particulate organic nitrogen (Antikainen, 2007; Galloway et al., 2004).

Vegetation, in general, primarily assimilates N in the form of soluble N or as ammonium compounds. Therefore, either fixation[7] and/or conversion of N to a bioavailable form are essential for life. The natural mechanisms that increase bioavailable N for plants are N-fixing by bacteria organisms and organic N transformation by microbial process (Antikainen, 2007; Galloway et al., 2003; 2004; Smil, 2000, 2001). These naturally occurring processes were the only means of obtaining bioavailable N in the biosphere, prior to the production and commercialization at industrial scale, early in the 20th century, of the Haber-Bosch synthesis of ammonia, rapidly diffused worldwide in the 1960s and 1970s (Antikainen, 2007; Smil, 1999, 2002c). The Haber-Bosch process is chiefly used to produce N-fertilizer by industrial N fixation converting unreactive N_2 to NH_3 (Galloway, 1998; Galloway et al., 2004; Smil, 2001). At present, N cycling in the global food production system is essentially based on the Haber-Bosch synthesis (Antikainen, 2007).

Several studies acknowledge that human activities have significantly altered the natural N cycle in air, land and water and at local, regional, and global scales since the onset of industrialization (Bouwman et al., 2005; Fowler et al., 2013; Galloway et al., 1995, 2003, 2004; Millennium Ecosystem Assessment 2005; Smil, 1993; Vitousek et al., 1997, 2002). Precisely, as Bobbink et al. (2010) indicate, the major factor that drives the changes in the global N cycle is the increased creation rate of Nr. Two anthropogenic activities have greatly contributed to intensify the creation of reactive N on the planet: food (chiefly through the industrial production of N-fertilizers) and energy production, since during combustion of fossil fuels N is

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[7] According to Bouwman et al. (2005) nitrogen fixation is the transformation of the highly abundant but biologically unavailable atmospheric dinitrogen (N_2) to "reactive" reduced and oxidized N forms such as ammonia (NH_3), nitrate (NO_3^-), nitrous oxide (N_2O) and nitric oxide (NO).

emitted to the atmosphere as a waste product (NO) from either oxidation of atmospheric N_2 or organic N in the fuel (Bobbink et al., 2010; Galloway, 1998; Galloway et al., 1995, 2003, 2004; Vitousek et al., 1997), with a resulting widespread accumulation of N in many regions of the world. Galloway (1998) and Galloway and Cowling (2002) note that the effects of N are widespread and, given N biogeochemistry, both cascading and cumulative. Precisely, Rockström et al. (2009) estimate that humanity has already transgressed the planetary boundary of changes to the global nitrogen cycle.

The case of Phosphorus

Phosphorus (P) is the eleventh most abundant mineral in the earth's crust, and ranks thirteenth in seawater (UNEP, 2011). Unlike N, the atmospheric flows of P are small because P has no stable atmospheric gas phases (Liu et al., 2008). Moreover, the P cycle is not dominated by biota, as it is the case of the N cycle, even though microbes and plants play a significant role in the assimilation, decomposition and mineralization of P (Antikainen, 2007; Li et al., 2010).

Before industrialization, weathering from soil was the main source of P into the biological cycle. Bioavailable P is taken up by plants and bioaccumulated by animals while decomposition and mineralization of organic matter releases P back into soil solution closing the cycle (Antikainen, 2007). Erosion and water runoff transfer are important parts of the P cycle, as well as the eventual sink of particulate and soluble P in water sediments. Oceans form the largest reservoir of biospheric P (Smil, 2000).

Similarly to the cycle of N, the cycling of P has been significantly enlarged by humans (Liu et al., 2008; Smil, 2000). Two major contributors have been the use of P as a chemical fertilizer for the production of food, mainly driven by the increased consumption of meat- and dairy-based diets, and the expansion of the biofuel industry (Childers et al., 2011; Cordell and White, 2011; Cordell et al., 2009; Matsubae-Yokoyama et al., 2009; Neset et al., 2008). Phosphorus is the most immobile of the major nutrients, and P deficiency of agricultural soil is a general phenomenon, thus the application of phosphate fertilizers to reduce this deficit and to grow food (Antikainen, 2007; Neset et al., 2008). About 90 percent of worldwide demand for rock phosphate is for food production (including fertilizers, feed and food additives) (Childers et al., 2011; Matsubae-Yokoyama et al., 2009; Qiao et al., 2011; Smil, 2000). Yet, phosphate rock, from which P chemical fertilizer is produced, is a non-renewable and a non-substitutable resource (Metson, 2012a). Estimates note that at the present rate of consumption, current economically exploitable reserves will be depleted in around 100-300 years, leaving at most the lower quality and less accessible rocks (Childers et al., 2011; Cordell et al., 2009; Dawson and Hilton, 2011; Liu et al., 2008; Metson et al., 2012a; Smil, 2000; UNEP, 2011). On the other hand, as Cordell et al. (2009) explain, the growing worries about oil scarcity and climate change led to the recent sharp increase in biofuel production. The industry of biofuel not only competes with food production for grains and productive land, but also for phosphorus fertilizers (Cordell et al., 2009).

Globally, alteration of the Earth's natural N and P cycles by humans started with industrialization, yet it sharply expanded during the past 50 years. According to some authors

(Antikainen, 2007; Galloway et al., 2003), since 1960 flows of reactive N (biologically available) in terrestrial ecosystems have doubled, and Smil (2000) estimated that global P cycle has roughly tripled compared with its natural flows, therefore, becoming a major emerging challenge for the twenty-first century (Ma, 2014).

The major categories of human interferences in the N and P cycle are accelerated erosion and runoff from agricultural lands or urban areas, owing to the conversion of forests and grasslands; production and recycling of crop residues and manure; discharges of urban and industrial wastes, and production of inorganic fertilizers (Antikainen, 2007; Carpenter et al., 1998; Galloway et al., 2003; Li et al., 2010). These human interferences have altered the balanced nutrient cycles of natural systems causing a myriad of pollution and environmental problems resulting from nutrient accumulation and loss to the soil, waters and air. These problems include eutrophication of aquatic and terrestrial ecosystems (N, P), groundwater pollution (N), acidification (N), global warming (N), depletion of stratospheric ozone (N), formation of tropospheric ozone (N) and poor urban air quality (N) (Antikainen et al., 2005; 2007; Carpenter et al., 1998; Forkes, 2007; Galloway et al., 2003; Li et al., 2010; Vitousek et al., 1997, 2002). It should be noted that the pollution via excess reactive N represents an important challenge, since N has many complex effects as it cascades through many chemical forms as it is transformed to different N species (Galloway et al., 2003, 2004; Sutton et al., 2011). Eutrophication refers to an excess supply of nutrients, resulting in increased biological activity (Antikainen, 2007). Phosphorus-induced eutrophication is due above all to the trigger effect it exerts on the nutrient cycling of N (Smil, 2000).

Further description of the typical biogeochemical processes of the two studied nutrients, N and P, can be obtained from the available literature as well as consequences of anthropogenic alteration of these cycles (Boyer et al., 2002; Cordell et al., 2009; 2011; Fowler et al., 2013; Galloway, 1998; Galloway and Cowling, 2002; Galloway et al., 1995, 2003, 2004, 2008; Smil, 1991, 1997; Vitousek et al., 1997). Likewise, see Galloway and Cowling (2002) and Galloway et al.(2003) for further analysis on beneficial and detrimental effects of reactive nitrogen.

Nitrogen and phosphorus in Morocco

In Morocco, a rapid and intense process of growth has exposed coastal areas to many forms of environmental pressures such as continuing urbanization, the over-concentration of industrial activities, the loss of agricultural land and the intensification of agricultural practices, the destruction of dunes or the pollution of terrestrial and marine ecosystems (Nakhli, 2010).

If Moroccan cities have to alleviate the negative ecological and environmental impacts caused by the accumulation of nutrients and/or loss from the food system, interactions between societies (i.e., their living patterns in terms of resource consumption and waste discharges) and the biosphere need to reach a certain balance. Accordingly, the fundamental previous step for this objective is to obtain a better understanding of the flows and stocks of N and P in the urban system (that is, of their amounts and linkages through inputs and outputs of the different parts of the system) and the potential impacts and implications of urban lifestyles (Baccini, 1997; Decker et al., 2000; Girardet, 1996). A holistic picture of the nutrient flows helps to identify possible leaks in the system and to inform policy and technological control instruments in order to recover or increase nutrient use efficiencies through improved recycling of N and P (Antikainen et al., 2005, 2007; Ma, 2014). Actually, the recovery of these nutrients has an important potential for replacing industrial fertilizers (Forkes, 2007).

Objectives of the Grand Nador Case Study

In order to increase compatibility with the surrounding environment, to gain a clear understanding of the functioning and processes of the urban system, and to assess the impacts and implications of urban lifestyles (in terms of consumption and discharge patterns) it is essential that cities confront the social, environmental, and economic challenges of the nearer future and manage the urban environment in more compatible ways with their hinterlands.

The concept of urban metabolism (UM) has been used as a tool to enhance our understanding of the way in which environmental, social and economic factors interact to shape urban phenomena and processes. The prevailing interpretation of UM today is the biophysical quantitative and accounting perspective (Kennedy et al., 2011) measuring the exchange and transformation of energy and matter between a city and its environment (Moles et al., 2008). This interpretation draws mostly on approaches in the field of urban and industrial ecology which are seen as tools both for identifying environmental problems and designing more efficient urban planning policies (Baccini, 1997; Barles, 2009; Niza et al., 2009). Thus, UM can be a productive and useful way to conceptualize how urban areas function, and a valuable concept for understanding urban processes, structures and functions and the relations between society and nature in urban areas (Rapoport, 2011).

The main objective of the present case study is to increase our understanding of how the human production and consumption of food affects nutrient flows by means of identifying and quantifying the major N and P food-related flows of the Grand Nador urban region in Morocco. The aim is to elucidate whether and to what extend the nutrient food system studied is cyclic or linear. A deeper comprehension of the sources, flows and possible openness of the N and P cycles is necessary for assessing ways to reduce nutrient emissions to the environment and to mitigate problems caused by their loss and/or accumulation to soil, water and air. Finally, a discussion on how these studies can serve to support decision-making on environmental problems and solutions, and possible means by which to increase the efficiency in use and the degree of recovery for the cycling of N and P is developed. The UM approach is primarily used as the basis of an accounting framework with the final aim of better understanding flow dynamics in orientation towards long-term resource use to achieve more compatible development of urban areas with their hinterlands.

Specifically, the flows of nitrogen (N) and phosphorus (P) in the urban region of Grand Nador have been investigated in relation to food production, processing, consumption and waste disposal (waste management) subsystems.

The remainder of the chapter is organized into six additional sections. After this presentation of the context and the objectives of the case study, the third section lays out the methodology used for the accounting approach, including a brief description of the study area (see chapter two for a complete description of the study area) and data collection and sources. The fourth section develops the analysis of the system including definition and description of the system boundary, the description of the model and the estimation of nutrient (N and P) flows. The fifth section introduces the uncertainty analysis. The sixth section presents the results, examining the analysis and describing the status of nitrogen and phosphorus flows in the urban agglomeration of Grand Nador. The seventh section discusses the analytical results and provides suggestions for N and P consumption reduction as well as recovery and recycling of nutrients; it also discusses about data uncertainty, and suggests possible lines for future research. The conclusions are presented in the eight and final chapter.

To the best of our knowledge, the present study represents not only the first study on nutrient flows in Morocco but also in a North African country/region. Magdy's study (2014) on the UM assessment through Eurostat's MFA methodology to the Egyptian cities of Cairo and Giza was the only specific UM study found, though it helps to fill the application gap of UM analysis in the Middle East region. Worth mentioning is the African Urban Metabolism Network (AUM Network) (http://www.urbanmetabolism.org/projects/resources-and-urban-africa/), a collaboration between the Urban Metabolism Group at MIT and multiple local partners in Africa, whose aim is to create resource efficient cities through research partnerships and trans-disciplinary collaboration. This network, specifically dedicated on the development of UM studies in different African cities, not only shows the increasing significance of UM studies, but also the increasing interest on the continent.

Besides, this present study responds to one of the knowledge gaps in the available analysis of nutrient flows, as identified by Chowdhury et al. (2014), by analyzing a case study at a regional scale which is the least studied compared with country scale. Furthermore, according to Chowdhury et al. (2014), the regional scale not only has been the least studied, but also is the scale that more intimately considers the agricultural (both crop and livestock) production sector, which usually is more important in terms of N and P flows, and therefore needing more attention in nutrient analysis.

Methodology

Description of the study area

The urban region of Grand Nador (GN), situated in the North-East of Morocco, is part of the administrative province of Nador belonging to the Oriental region of this country. With an area of 1,491Km^2 (ASRO, 2011; PNC, 2010) and an estimated population of 451,779 in 2010 (RGPH, 2004; PPMM, 2007) (population density of 303 inhabitants/Km^2) the Grand Nador is formed by fourteen communes (six urban or municipalities and eight rural)(see Figs. 1 and 2).

Located on the Gareb Bou-Areg plain, in the subsiding basin "Gareb Bou-Areg", the GN selected region of study, with a typically semi-arid Mediterranean climate and an irregular annual rainfall pattern (a.a.p 290-346mm), is characterized by a morphologically heterogeneous area with a succession of mountains, basins and plains, bounded to its north by the so-called Nador Lagoon, locally known as Marchica Lagoon or Sebkha Bou Areg (see Fig.3) (El Yaouti et al., 2009; Khattabi et al., 2007; Re et al., 2013; Zerrouqi et al., 2011). This coastal lagoon of Nador, with a surface area of ca. 115 km^2, is recognized to be a site of biological and ecological interest, yet threatened by several anthropic pressures (González et al., 2007; Pastres et al., 2013; Zerrouqi et al., 2011).

Therefore, this region of GN has been selected as the case study because of its relatively recent intense process of urbanization and littoralization (Côte and Joannon, 1999; Liziard and Voiron-Canicio, 2012), in particular, experiencing an intensive industrialization, concentrating almost all of the regional economy, accompanied by excessive, rapid and disorderly urban growth, most of which is localized on the edges of the Marchica Lagoon (González et al., 2007; Nakhli, 2010) (See chapter two for a complete description of the study area).

Methodology

The analytical method used to develop the study is the so-called Substance Flow Analysis (SFA) procedure. SFA is included in the analytical framework of Material Flow Accounting and Analysis, which provides a methodological groundwork offering a greater scope for the generic application, harmonization and advancement of environmental accounting and systems analysis (Hammer et al., 2003; Loiseau et al., 2012; Niza et al., 2009). Actually, some authors classify SFA as a subcategory of material flow analysis (MFA). Rather than for a single substance, MFA investigates bulky materials, such as wood, flowing through a specific system (Antikainen, 2007).

Based on system perspectives, the core principle of SFA is the mass balance principle, in which the modelling of material and energy flows is governed by the laws of conservation of matter and energy (Barles, 2010; Daniels and Moore, 2001; Hammer et al., 2003). The law of mass conservation states that the mass of a closed system will remain constant, regardless of the processes acting inside the system (Van der Voet et al., 1995; Asmala and Saikku, 2010).

SFA quantifies specific substance inflows and outflows from processes and key stocks within a system to better understand and identify the nature and magnitude of nutrient wastage from the system, pollution loads on a given environment, as well as imbalances in the stocks and flows. Consequently, SFA helps in locating and quantifying losses and determining unsustainable use of resources, and thus assists in identifying potential recovery and reuse points and/or places to intervene within the system to increase its use efficiency, minimizing nutrient loss or reduce wastage and pollution (Antikainen et al., 2005; Brunner, 2010; Brunner and Rechberger, 2004; Cordell et al., 2009; Chowdhury et al., 2014).

SFA focuses on the relevant processes and flows within a system defined in space and time, and estimates the emissions from human activities to the environment (Burström, 1999). It is therefore an effective systematic tool for tracing and quantifying specific substance flows in the economy and environment (Van der Voet et al., 1995). Likewise, SFA, used as a priority setting tool, provides information about the relative importance of environmental pressure from flows and their causes in society (Danius and Burström, 2001). On the other hand, SFA can also be used as a monitoring tool to track trends and changes of flows, stocks, and environmental pressure over time, caused by the different flows. Besides, follow-up with SFA is also used as a tool to evaluate the effectiveness of pollution abatement measures, other actions ex-post, or the side-effects of other influencing measures on environmental problems (Antikainen, 2007; Danius and Burström, 2001). Therefore, the identification of potential ways of closing material cycles and diminishing material flows is an important goal in studying substance and material flows (Antikainen, 2007).

Studies that can be classified as SFA applications have been conducted since the 1920s, first in ecology, and later on in biogeochemical cycles, including human interference, and on flows in economic systems. More harmonized SFA efforts began in the 1990s (Van der Voet, 2002).

A number of SFA studies (or that could be classified as such) of nitrogen and phosphorus flows have been conducted through different systems at various geographical and temporal scales such as the global scale (Bouwman et al., 2005, 2009; Childers et al., 2011; Cordell et al., 2009; Dawson and Hilton, 2011; Fowler et al, 2013; Galloway and Cowling, 2002; Galloway et al., 2004, 2008; Liu et al., 2008; Smil, 2000, 2002c; Villalba et al., 2008), country or national level (Antikainen, 2007; Antikainen et al., 2005; Chen et al., 2008, 2010; Cooper and Carliell-Marquet, 2013; Cordell et al., 2013; Ma, 2014; Ma et al., 2012; Matsubae-Yokoyama et al., 2009; Risku-Norja and Mäenpää, 2007; Saikku et al., 2007; Senthilkumar et al., 2012; Sokka et al., 2004; Thaler et al., 2013), at regional scale (Boyer et al., 2002; Faerge et al., 2001; Kalmykova et al., 2012; Metson et al., 2012b; Montangero, 2006; Vladimirovna, 2013; Wu et al., 2012; Yuan et al., 2011) and at city scale (Erni, 2007; Forkes, 2007; Li et al., 2010; Ma et al., 2008; Neset, 2005; Neset et al., 2008; Qiao et al., 2011; Yuan et al., 2011), even some studies have been conducted at smaller geographical scales, such as household level (Baker et al., 2007), or specific production sector, like the rainbow trout aquaculture in Finland (Asmala and Saikku, 2010) (see Appendix VI for detailed information on case studies).

As said before, to the best of our knowledge no SFA studies on Moroccan societal systems exist. Therefore, the present study provides a first example of an SFA application on N and P food flows and the relative significance of these different flows in the Grand Nador urban agglomeration of Morocco.

However, the method applied has necessarily been adapted and modified to the scale of analysis, since a uniform and standardised methodology does not exist yet at the regional or local scales (Hammer et al., 2003; Loiseau et al., 2012; Niza et al., 2009).

The approach presented here gives a static picture of the recent past (for the year 2010) on the N and P food-related flows in Grand Nador and is unable to reveal any future changes. Predictive modelling, especially dynamic modelling, requires abundant initial data which was not available, nor accessible. Hence, the model is a simple inflow/outflow model consisting of the major nutrient food flows within the subsystems studied of food production, processing, consumption and waste management, the later comprising municipal solid waste and wastewater.

It should also be noted that the present study examines the flows of total N and P. The impact of such emissions as NO_x, N_2O and NH_3 will depend on the actual chemical compositions of the substances and on the receiving environments. These aspects were not fully considered in detail here.

Data collection and sources

Data collection included the provision of statistical data, mainly from the official statistics of the Moroccan *Haut-Commissariat au Plan* and from international institutions (e.g. Faostat), academic literature, external studies, institutional and business reports and grey literature, and environmental monitoring data when existing and accessible. Data was also derived from expert estimates and knowledge by interviews with the major actors involved, as well as from unpublished reports provided by the experts working at the institutions interviewed. All these data and sources provided the basis for the calculations of the nutrient food-related flows.

However, in developing countries, as it is the case of Morocco, data at some administrative level was scarce and means of data collection and/or access limited. Therefore a data cross-check was important. In order to assess and validate the quality of local data, more than one source was consulted and data was compared with the values in the literature, wherever this was possible. Interviews with local experts, together with personal visits to the facilities/sites allowed qualitative assessments of the data. Likewise, information gaps were supplemented by a combined evaluation from different sources.

However, for all results obtained, attention must be paid to the fact that some of the raw data is correlated with a certain level of uncertainty (see section five on uncertainty analysis for further details).

We must finally add that the multiplicity of actors from different sectors involved in the management of the region, all with their own, sometimes even confronted, interests required extra efforts when collecting data.

System Analysis. Model description and estimation of nutrient flows

System boundary definition and description

The definition and establishment of the spatial and temporal system boundaries largely determine the analysis of the system, and significantly affect conclusions drawn from SFA results (Antikainen, 2007; Brunner and Rechberger, 2004; Chowdhury et al., 2014). Therefore, it must be taken into account that depending on the system boundaries the results of the analysis may change.

The regional system boundaries were defined according to the politico-administrative division because data is systematically collected at these scales. Thus, the spatial boundaries of the studied system correspond with the administrative borders that result from the aggregation of the fourteen communes (six urban, eight rural) comprising the defined urban region of Gran Nador (see Figs. 1 and 2). Yet, we attempted to make these divisions coincide with the hydrological boundaries of the subbasin Gareb-Bou-Areg, because water and mostly its final path into the Nador Lagoon was fundamental for the study of N and P food-related flows, with satisfactory results.

The temporal boundary was established for a period of one year, corresponding to 2010. The year of 2010 was chosen since it is the latest available year for which quite extensively data existed and could be located. Furthermore, it is also the year in which the new wastewater treatment plant (WWTP) of Grand Nador, one of the most modern WWTPs in Morocco, began to operate.

In sum, the established system of study not only focused on the larger urban population and the major volume of socio-economic activities of the Oriental region, but also attempted to match this boundary with the sub-watersheds of the rivers that direct their waters to the Lagoon of Nador.

Model description

To assess food-nutrients substance flows within the urban region of GN, based on the SFA method (Baccini and Brunner, 1991; Brunner and Rechberger, 2004), a model system was conceptualized as a flow diagram of boxes and arrows. The boxes designate processes[8] and the arrows represent flows of relevant goods (food, waste and wastewater) and substances (N and P) (see Fig.12 corresponding to the schematic representation of the analysed system).

Within the proposed system (see Fig.12), the following processes and flows were identified (see also Appendix I):

15 **Boxes**	B_n ; n = number of box/process
9 **Inflows**	I_j ; j= number of destination box
8 **Outflows**	O_s ; s= number of source box
19 **Internal flows**	R_{s-j} ; s= box of origin; j= box of destination

The system was divided into four main processes, as presented in Fig.12., which part of them were in turn divided into sub-processes:

- The **agricultural** production process, mainly represented by the peri-urban food production sector and comprising crop rising and livestock breeding as sub-processes.
- The **agro-food** industrial process, including the processing of agricultural products and the fish transformation sector.
- The **domestic consumption** process, characterized by the rural and urban domestic household consumption sub-processes.
- The **waste management** process, divided into the sewage and wastewater and the organic solid waste collection and treatment sub-processes.

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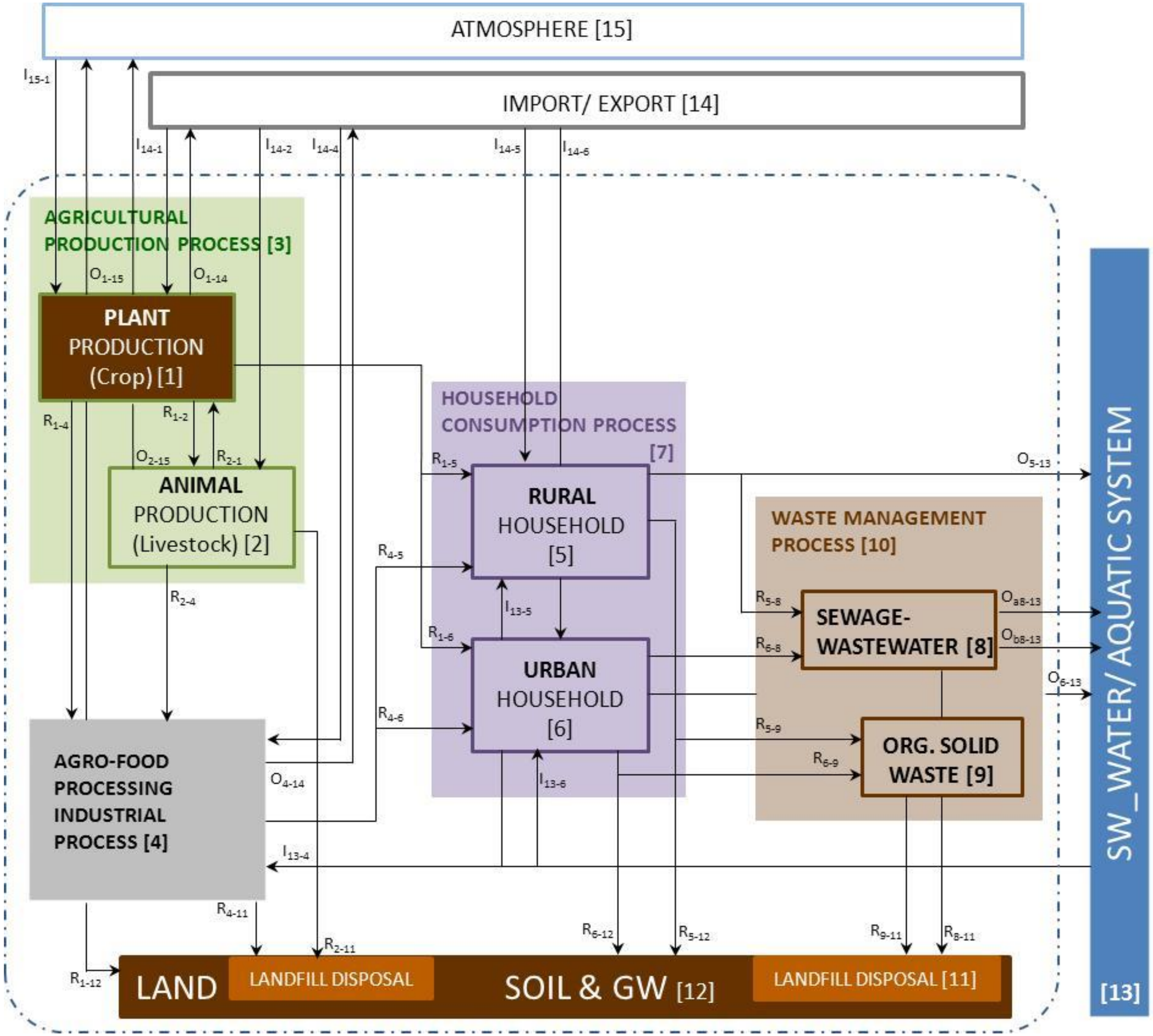
[8] Goods are materials or material mixtures with functions valued by human beings such as food, waste, and wastewater. Indicator substances are chemical elements and their compounds such as nitrogen and phosphorus. Processes, such as agriculture or household consumption, describe the transformation, transport or storage of goods and substances (Brunner and Rechberger, 2004; Montangero, 2006).

The food system is known to be among the most important for human-induced N and P flows (see Ayres, 1994; Vitousek et al., 1997; Smil, 2002c; Millennium Ecosystem Assessment, 2005). Along the food cycle chain, the agricultural system has demonstrated to be one of the largest contributors, having a large impact on nutrient flows. Moreover, we subdivided this system into crop and livestock sub-processes because of the peculiarities and interlinks of these two sub-processes. Although the object of study was the urban agglomeration, the latter requires the supply of agricultural products to provide for food needs. Besides, it is in the surroundings of this important urban area that a significant share of all the irrigated agriculture of the Oriental region develops. Therefore, we considered essential to include in the study the agricultural sector that lies inside the boundaries of our system. On the other hand, the agro-food industry is the second most important branch within the industrial sector of Nador's province. Furthermore, urban and rural populations were distinguished according to their different dietary patterns and distinct waste disposal systems.

System analysis (i.e., selection of system border, processes, goods and substances) is the conceptual model forming the basis of both the mathematical model and the determination of the variables (Montangero, 2006). The MFA/SFA system is regarded as fully described when all variables (i.e. stock change rates of goods or substances in each process and all good or substance flows in the system) are known. The mathematical model will allow to study the potential impact (e.g. by household consumption patterns, wastewater and solid waste reuse strategies, types of crops and livestock categories, etc.) on nutrient discharge into the environment and nutrient recovery for food and fodder production and less use of fertilizers (Montangero, 2006).

Therefore, the key problems in food-nutrient metabolism and management of the GN system were identified according to the quantitative analysis of N and P cycling through the activity "to nourish", i.e. through the processes of food production, processing, consumption and waste handling.



I_{15-1}: Atmospheric Deposition
I_{14-1}: Imports of fertilizers
I_{14-2}: Imports of fodder and feedstuff
I_{14-4}: Imports of food to agro-food p.Ind.
I_{14-5}: Imports of food pdcts. to Rural HH.
I_{14-6}: Imports of food pdcts. to Urban HH.
I_{13-4}: Fish local catches to agro-food p.Ind.
I_{13-5}: Fish local catches/pdct. to Rural HH.
I_{13-6}: Fish local catches/pdct. to Urban HH.
R_{1-2}: Fodder crops as animal feed
R_{1-4}: Locally produced plant/crop pdcts. to agro-food p.Ind.
R_{1-5}: Locally produced plant/crop pdcts. to Rural HH consumpt.
R_{1-6}: Locally produced plant/crop pdcts. to Urban HH consumpt.
R_{1-12}: Leaching/runoff from agric. land
R_{2-1}: Manure to agricultural land
R_{2-4}: Animal pdcts. to agro-food p.Ind.
R_{2-11}: Manure (poultry) to landfill
R_{4-5}: Agro-food pdcts. to Rural HH Cons.
R_{4-6}: Agro-food pdcts to Urban HH Cons.
R_{4-11}: OSW from agro-food p.Ind. (Landfill)
R_{5-8}: WW/S from Rural HH to sewerage
R_{5-9}: OSW from Rural HH collected
R_{5-12}: Non-collected OSW and WW/S from Rural HH to soil & GW
R_{6-8}: WW/S from Urban HH to sewerage
R_{6-9}: OSW from Urban HH collected
R_{6-12}: Non-collected OSW and WW/S from Urban HH to soil & GW
R_{8-11}: Sludge from WWTP to Landfill
R_{9-11}: Collected OSW to Landfill
O_{1-15}: Air Emissions from fertilizer
O_{2-15}: Air Emissions from manure
O_{1-14}: Export of locally produced plant/crop pdcts.
O_{4-14}: Export of agro-food industrial pdcts.
O_{5-13}: Non-collected OSW and WW/S from Rural HH to surface waters.
O_{6-13}: Non-collected OSW and WW/S from Urban HH to surface waters.
O_{a8-13}: Collected WW/S and treated by the WWTP.
O_{b8-13}: Collected WW/S but untreated

Figure 12.: Flow diagram representation of the system analysed. Source: Author's elaboration.

Estimation of nutrient flows. Developing the substance flow model

In this following section we define for each process and/or sub-process the correspondent balance and model equations illustrating how these equations were developed. A balance equation is formulated for each process and/or sub-process within the system border. On the left side of the equation we place the stock change rate of the N and P of the process or sub-process under description, which equals the difference between input and output flows of these substances on the right side of the equation (Montangero, 2006).

After all balance equations are defined, model equations are formulated. In the mathematical model, each flow or stock change rate is a variable expressed as a function of parameters; thus, model equations express how different parameters determine the variables in the system (Montangero, 2006).

A stochastic model was developed based on the proposed system analysis (see Fig.5) describing goods (food, waste, wastewater) and substance (i.e., nitrogen and phosphorus) flows in the system. Good mass flows (food and waste) are expressed in tonnes year^{-1} and (wastewater) cubic meter year^{-1}, N and P flows in Kg year^{-1}. All parameters (symbol, description, unit, quantity, and reference) are presented in Appendix IV. Process numbers refer to the flow diagram system analysis (see Fig.12).

AGRICULTURAL production process [3] = ∑ (Plant production sub-process [1]; Animal Production sub-process [2])

Agriculture, the backbone of Morocco's economy, has benefited as a priority investment sector by the Government since the Independence of the country in 1956 to secure food supply for a rapid growing population and to ensure labor for peasants. As a result of this policy, large dams were built along with other infrastructures that made possible the increase of irrigated land in the area of study (Berkat and Tazi, 2006; Sraïri, 2008). Hence, despite limited rainfall (about 300mm/year) (Hamoumi, 2012) and generally shallow soils a significant intensive agriculture exists in these irrigated perimeters. Moreover, with the extension of crops at the expense of grazing land, the development of irrigation and the rapid demographic growth, production systems that associate crops and livestock are rapidly expanding (Berkat and Tazi, 2006).

In order to promote the enormous potential of Moroccan agriculture in 2008 the Green Morocco Plan («Plan Maroc Verd») was implemented. The main objectives of this national action plan are to increase the contribution of agriculture to gross domestic product (GDP), job creation, increased profits from the export of agricultural products, and strengthening the struggle against poverty in rural areas (Runge et al., 2011). To this end, changes in farmer's organization, and diverse measures in livestock and crop production are planned. However, the increased exploitation of natural resources due to the development of the Moroccan agricultural sector has negative effects on soil productivity, erosion and increasing soil salinization that represents a serious problem in irrigated perimeters (Runge et al., 2011).

Is in the fertile soils of the plains Gareb Bou-Areg, near the coast of the Nador province, where intensive irrigated agriculture is practiced. Tree crops (citrus, wine, olives), vegetables, fodder crops, but also large areas of sugar beet are the main products raised in this area (ASRO, 2011, 2009; Runge et al., 2011). Conversely, cereal crops predominate in rainfed areas and since crop yield is extremely low, cereal residues are already mostly used as bedding and fodder for animals (Runge et al., 2011). Livestock production primarily based on cattle, sheep, goat rearing and poultry industry is an also equally important activity for farmers in this area (Monographie RO, 2012). A good level of organization within the agricultural sector has developed, particularly in the areas of dairy, red meat, sugar, and citrus cultivation, allowing farmers working on mixed production system -livestock and crop- to work in a relatively closed system. Thanks to this, positive effects are achieved for soil fertility, fight against erosion and climate protection (Runge et al., 2011).

Nutrient inputs to the agricultural process considered included atmospheric deposition, synthetic fertilization and feedstuff/fodder imports. Nutrient outflows examined consisted of air emissions from synthetic and organic fertilization, harvest, animal products, manure to landfill and nutrient losses to the soil and groundwater.

The agricultural production process was divided into crop raising and livestock breeding sub-processes.

PLANT (CROP) production sub-process [1]:

The agricultural production land represents about 38 percent (totaling 56,707 ha) of the study area (SA, from hereafter) of which 48 percent (27,317 ha) correspond to intensive irrigated agriculture (97.5% yield) whereas 52 percent (29,390 ha) is rainfed agriculture (2.5% yield; cereal cultivation is especially practiced) (ORMVAM. ASRO, 2011) (see Figs.13 and 14). The term agricultural production land refers to arable land used for permanent crops and horticultural land, and it does not include rangeland (or pastoral areas) nor fallow (ASRO, 2011; Monographie RO, 2012).

The total agricultural production land of the SA is under the administration of the Moulouya Regional Office of Agricultural Development (ORMVAM – l'Office Régional de Mise en Valeur Agricole de la Moulouya). The ORMVAM action zone is precisely defined around large irrigated areas and the attached peripheral rainfed areas existing in the Moulouya hydrographic watershed (ATLASsynthese, 2008).

According to the ORMVAM statistics, in 2010, the major crop categories harvested in irrigated perimeters were industrial crops (sugar beet), fodder (alfalfa), fruit trees (citrus, wine grapes and olives) and cereal crops (wheat), whereas in rainfed systems were cereal crops (barley and wheat) and fruit trees (olives).

Nutrient (N and P) inputs to crop sub-process considered included atmospheric N deposition ($I_{15\text{-}1}$), synthetic or artificial fertilization ($I_{14\text{-}1}$) and organic fertilization mainly animal manure ($R_{2\text{-}1}$). Nutrient (N and P) outputs included harvested crops either for human processing and/or consumption (formed by the sum of exported crop products ($O_{1\text{-}14}$), crops for industrial processing ($R_{1\text{-}4}$), crops for rural household consumption ($R_{1\text{-}5}$) and crops for urban household consumption ($R_{1\text{-}6}$)), or for animal feeding (fodder crops ($R_{1\text{-}2}$)), leaching/runoff from agricultural land (to soil and groundwater) ($R_{1\text{-}12}$), and N losses to the atmosphere ($O_{1\text{-}15}$) (mainly from fertilizers and manure).

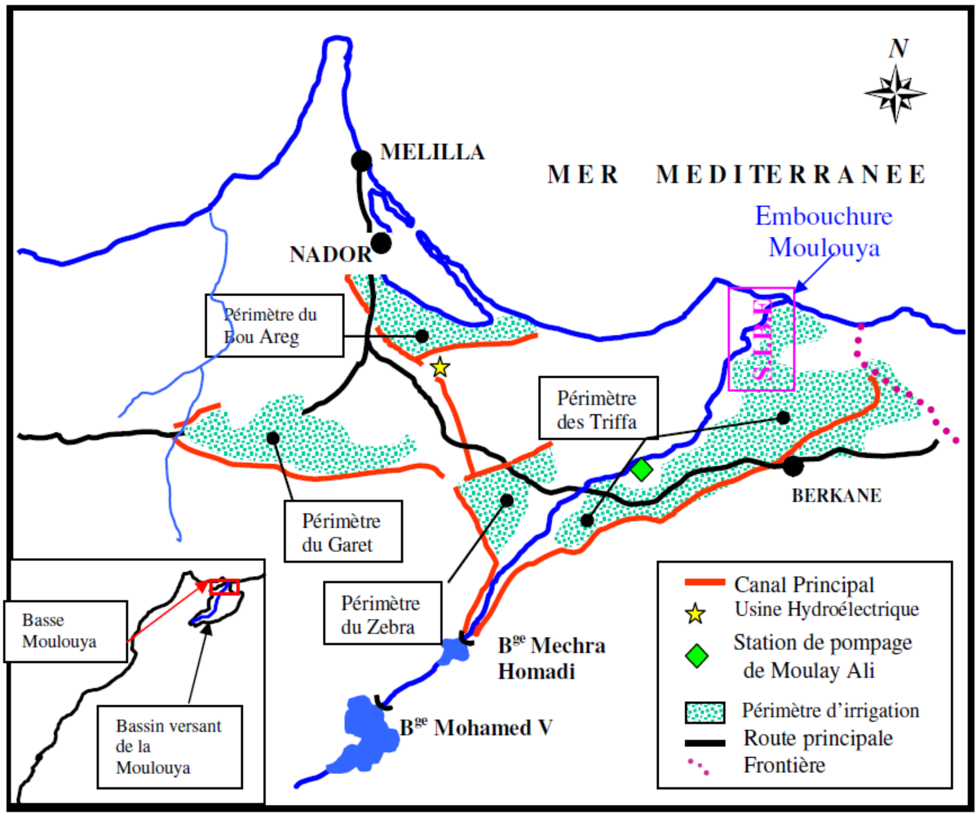


Figure 13.: Irrigated perimeters of Bou-Areg and Gareb under the administration of the Moulouya Regional Office of Agricultural Development – ORMVAM, and the principal irrigation channel. Source: Snoussi, 2007, p.3.

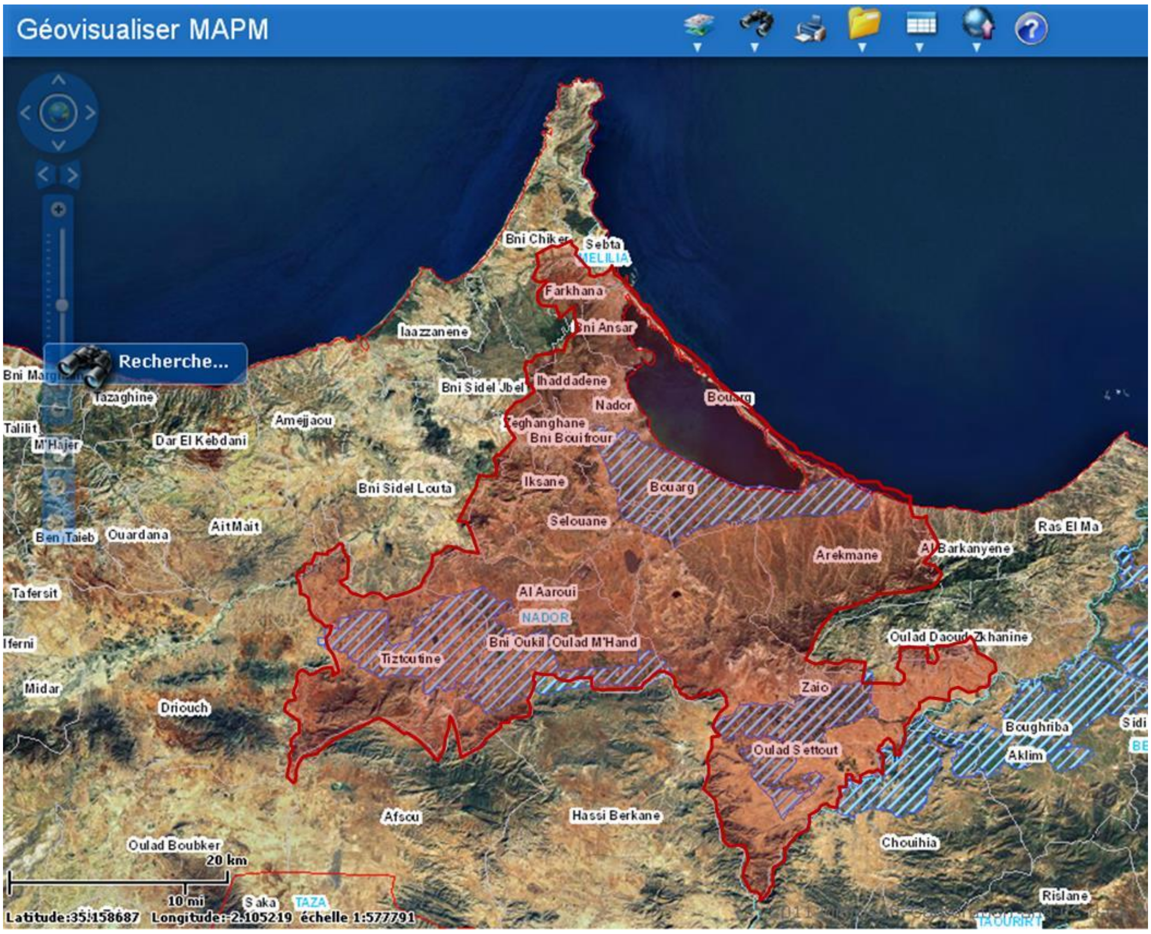


Figure 14.: Irrigated perimeters under the administration of the Moulouya Regional Office of Agricultural Development – ORMVAM- and the Grand Nador area of study. Source: Ministère de l'Agriculture et de la Pêche Maritime. Statistiques Agricoles. GEOPortail (http://geoportail.agriculture.gov.ma/geoportal/catalog/main/home.page). http://www.agriculture.gov.ma/pages/statistiques-agricoles.

Since the focus was mainly on driven anthropogenic flows, we excluded from the study the natural biological process of nitrogen fixation (BNF) as it is a natural or terrestrial flow, yet accelerated by human activities, for instance, through cultivation-induced BNF (Galloway, 1998; Galloway et al., 2003, 2004). On the other hand, crop residues as noticed by Runge et al. (2011) are barely non-existent, and they are left in the field for the conservation of soil organic matter (i.e., protection against erosion, maintenance of soil fertility). This is assumed according to Bouwman et al. (2005) to be an internal cycle with no effects on the annual nutrient balance. Therefore, crop residues as part of the organic fertilization were ignored. Besides, due to a lack of data, the study does not consider, nor calculate, the soil nutrient stock. Finally, it should also be noted that because of a lack of precise knowledge about the nutrient cycling associated with processes such as denitrification, retention in ecosystems, uptake by biota, soil and streambed storage, and losses to groundwater, the detailed internal flows for agriculture were not fully investigated in the present analysis.

Therefore, the balance equations for the indicator substances nitrogen (N) and phosphorus (P) and the crop production sub-processes can be formulated as follows:

$dM^{(1)}_{N}/dt = I_{N,\,15\text{-}1}+I_{N,\,14\text{-}1}+R_{N,2\text{-}1}-O_{N,\,1\text{-}15}-O_{N,1\text{-}14}-R_{N,\,1\text{-}2}-R_{N,1\text{-}4}-R_{N,\,1\text{-}5}-R_{N,\,1\text{-}6}-R_{N,\,1\text{-}12}$

$dM^{(1)}_{P}/dt = I_{P,\,14\text{-}1}+R_{P,\,2\text{-}1}-O_{P,1\text{-}14}-R_{P,\,1\text{-}2}-R_{P,1\text{-}4}-R_{P,\,1\text{-}5}-R_{P,\,1\text{-}6}$

Atmospheric deposition ($I_{N,15\text{-}1}$):

Elevated atmospheric N deposition (AND) affects both ecosystem composition and key ecosystem services by influencing processes such as plant growth, decomposition, and nitrate leaching, which in turn regulate the production of clean water and several greenhouse gases (e.g., Butterbach-Bahl et al., 2011).

Notwithstanding its significance, the quantification of total N deposition rates is still an ongoing challenge. Major data gaps such as measurement of dry deposition (particularly challenging to measure) and organic-N forms of N deposition (infrequently measured), together with absence of monitoring in some regions limit assessments of N deposition impacts (Cornell, 2011; Ochoa-Hueso et al., 2011). Furthermore, the natural variability in atmospheric N deposition is very high and sampling and monitoring density is generally much lower than ideal, so policy has had to be developed in ways that accommodate a high degree of uncertainty (Cornell, 2011). This becomes a more pressing problem as more of the world's ecosystems become nitrogen enriched as a result of human activities (and thus potentially begin to approach critical thresholds) (Cornell, 2011; Rockström et al., 2009). On the other hand, the emissions and deposition of inorganic N species are known to have anthropogenic sources. Actually, and for agricultural systems, it has been found that N deposition serves as a significant N input to crop production (Ochoa-Hueso et al., 2011).

With regard to most Mediterranean regions, several authors (Fenn et al., 2009, 2010; EMEP, 2010, in Ochoa-Hueso et al., 2011) acknowledge that N deposition estimates have large uncertainties. Primarily, because of the underestimation of dry N deposition, that is proven to be the dominant form of atmospheric N deposition, up to 90 percent (depending on the regional climate, vegetation type and orography, but usually between 30 and 70 percent) in Mediterranean ecosystems, but also due to the general lack of appropriate monitoring stations across the Mediterranean basin (Ochoa-Hueso et al., 2011).

Therefore, acknowledging the above mention assessment restrictions, AND was expressed on the basis of the specific N atmospheric deposition estimate by the Biodiversity Indicators Partnership (BIP) and the agricultural production land of Grand Nador. Thus, it was calculated by multiplying the total hectares dedicated to the agricultural production (S_{area}) per an estimate of the annual average deposition ($a_{N,\,atm\_dep}$) in kg N ha^{-1} year^{-1}:

$(I_{N,15\text{-}1}) = (S_{area}) * (a_{N,\,atm\_dep})$

Atmospheric phosphorus deposition on the agricultural production land was assumed to be negligible because of the low reactivity of P, and since the P content of the atmosphere remains low. The same has been assumed likewise by other studies/authors (e.g. by Li et al., 2010).

Fertilization (I_{14-1}) and (R_{2-1})

Agriculture critically depends on N and P nutrients. Since most soils are not sufficiently fertile, partly because accelerated population and economic growth has put more and more pressure on productive soils, these require regular addition of macronutrients such as nitrogen (N) and phosphorus (P), either organic such as manure or sludge, or manufactured as artificial fertilizer (Dawson and Hilton, 2011). It has been demonstrated by several authors that artificial fertilization strongly contributes in accelerating the cycles of N and P (Galloway, 1998; Galloway et al., 2004; Smil, 2001).

Synthetic fertilization (I_{14-1}) was calculated on the basis of the cultivated area per crop and type of irrigation, i.e. the fraction of a cultivated area, per crop and type of irrigation, that was effectively fertilized, and the annual average supply of fertilizer unit per hectare and crop type. That is, N and P flows in chemical fertilizers were assessed based on the sown area per crop and per irrigation method (i.e., irrigated perimeter or rainfed agriculture) (s_{crop_wm}) in hectares (ha), the proportion of the sown area, under a certain crop and irrigation method, that is receiving fertilization (i.e., percentage area per crop and per watering method fertilized) ($r_{fert\_crop\_wm}$) in percentage, and the mineral fertilizer application rate per crop, referring to the average national amount of fertilizer applied to one hectare of a crop (a_{mfert_crop}) (in Kg ha^{-1} $year^{-1}$). Therefore, the total use of fertilizers for the given study area and year was obtained in kg of N and P by adding up the quantities of nutrient (N and P) used per individual crop and per type of irrigation.

$I_{N,14-1} = \Sigma_{c,wm} (s_{crop\_wm}) * (r_{fert\_crop\_wm}) * (a_{N,mfert\_crop})$

$I_{P,14-1} = \Sigma_{c,wm} (s_{crop\_wm}) * (r_{fert\_crop\_wm}) * (a_{P,mfert\_crop})$

Since there was no fertilizer industry in the region it was assumed that it originated from outside the region and thus it was imported.

Sludge produced by wastewater treatment plants is another source of organic fertilization when recycled back to agricultural land. Yet, in some countries, this is still a source of quality concerns due to perceived or real risks of heavy metals and other contaminants, as is the case of Moroccan legislation which does not allow the use of sludge as safe organic fertilizer. However, since sludge is deposited outdoors the plant in open space to dry where anyone can have access, farmers may take the sludge, an informal practice that happens sometimes. In this case, the WWTP does not assume any responsibilities (interview, direct communication with M.M.Oulbacha de l'Agence de Service de l'ONEE- Branche Eau à Nador). Accordingly, being an informal and unrecognized practice, and lacking data, we assumed no recovery of sludge.

Detailed explanation and calculations of manure flow ($R_{2\text{-}1}$) can be found in the following section on manure.

Emissions from artificial fertilization ($O_{N,\,1\text{-}15}$) and ($R_{N,\,1\text{-}12}$)

N losses to the atmosphere and soil that result from the application of synthetic fertilizers to the agricultural production land consist of ammonia (NH_3) and direct and indirect nitrous oxide (N_2O) emissions ($O_{N,1\text{-}15}$), and N-leaching/runoff processes ($R_{N,1\text{-}12}$). Specifically, N_2O is produced by microbial processes of nitrification and denitrification taking place on the addition site (direct emissions), and after volatilisation/redeposition and leaching/runoff processes (indirect emissions) (IPCC, 2006).

Emission data was calculated at tier 1 following IPCC guidelines, 2006, Vol. 4, Ch. 11. Specifically, N_2O emissions were estimated through model equation:

$$N_2O\text{-}N_{F\_Direct\&Indirect} = (I_{N,14\text{-}1} * EF_1) + (I_{N,14\text{-}1} * Frac_{GASF} * EF_4) + (I_{N,14\text{-}1} * Frac_{LEACH\text{-}(H)} * EF_5)$$

Where direct emissions ($I_{N,14\text{-}1} * EF_1$) were the result of multiplying the total annual amount of synthetic N fertilizer application (in Kg N yr^{-1}) per a default IPCC emission factor value (EF_1 ; in kg N_2O-N (Kg N yr^{-1}), taken from Tab.11.1).

Indirect emissions were the sum of volatilisation and leaching/runoff processes. Emissions of N_2O following volatilization ($I_{N,14\text{-}1} * Frac_{GASF} * EF_4$) were estimated by applying a default value fraction ($Frac_{GASF}$; in kg N volatilised (kg of N applied)$^{-1}$) (i.e., fraction of synthetic fertilizer N that volatilises as NH_3 and NO_x) to the annual amount of synthetic N fertilizer input (IN,14-1 ; in Kg N yr-1) as well as an emission factor of N volatilisation and redeposition (EF_4 ; in kg N–N_2O (kg NH_3–N + NOx–N volatilised)$^{-1}$) taken from tab.11.3). On the other hand, N_2O emissions from N leaching/runoff processes ($I_{N,14\text{-}1} * Frac_{LEACH\text{-}(H)} * EF_5$) were calculated by multiplying the annual amount of synthetic fertilizer N applied to soils per a default value fraction of all N added to soils, in regions where leaching/runoff occurs, that is lost through leaching and runoff ($Frac_{LEACH\text{-}(H)}$; in kg N (kg of N additions)$^{-1}$) and then multiplied by the default emission factor for N_2O emissions from N leaching and runoff (EF_5; in kg N_2O–N (kg N leached and runoff)$^{-1}$; taken from tab.11.3).

In order to estimate total N losses to the atmosphere, it was hypothesized that when synthetic fertilizers were spread to soil, 10 percent of their nitrogen content volatilizes as NH_3 (according to IPCC, 2006). Therefore, total emissions from application of synthetic fertilization were estimated by:

$$O_{N,1\text{-}15} = (N_2O\text{-}N_{F\_Direct\&Indirect}) + (I_{N,14\text{-}1} * Frac_{GASF})$$

Since the phosphorus content of the atmosphere remains low, phosphorus fluxes from the soil and water into the atmosphere were considered negligible (Li et al., 2010).

Following the same IPCC 2006 guidelines, Vol.4, Ch.11, N losses to soil/groundwater from agricultural soil through N-leaching/runoff was computed ($R_{N,1\text{-}12}$). However, and according to the guidelines, in order to estimate the N-leaching/runoff from the agricultural production land, it was only taken into account the annual average amount of N-fertilizer used in irrigation perimeters:

$R_{N,1\text{-}12} = (\Sigma_{c,\ irr}\ ((s_{crop\_irr})*(r_{fert\_crop\_irr})*(a_{N,mfert\_crop}))) * (Frac_{LEACH\text{-}(H)})$

Moreover, lacking basic data about P soil leaching process (that is, any mean annual/average P-leaching/runoff value from agricultural land), we were not able to quantify this flow.

Although these results might have large degree of uncertainties, we considered that an estimate was important to be computed, since the region is characterized by torrential rains that wash down soil material containing nutrients (Bowman et al., 2005).

Crop production or harvest ($O_{1\text{-}14}$) and ($R_{1\text{-}2}$; $R_{1\text{-}4}$; $R_{1\text{-}5}$; $R_{1\text{-}6}$)

The flows of nutrients in plant products (harvest) were divided into three parts: fodder for livestock ($R_{1\text{-}2}$), agro-processing industrial use ($R_{1\text{-}4}$) and human consumption. Human consumption was in turn subdivided into rural ($R_{1\text{-}5}$) and urban ($R_{1\text{-}6}$) household consumption, and export of crop products ($O_{1\text{-}14}$). All these flows were calculated by means of addition and subtraction between two main information sources. These two sources were the local production of agricultural products (harvest) and the consumption of vegetal foods by the studied population of GN.

Data on vegetal food consumption was primarily derived by the FAOSTAT online database (FAO, 2010) and from the official statistics of the population census (RGPH, 2004; PPMM, 2007) (see the following section on the consumption process for a more detailed explanation).

Data on primary production (harvest/yield) of the SA in 2010 was obtained from the statistics reported at the “Annuaire Statistique de la Région de l’Oriental-2009-2011” (ASRO, 2009, 2011). This data was presented on the basis of the cultivated area of the most important crops differentiating between irrigated and rainfed agriculture. At this point, we also differentiated between plant production for human consumption, for agro-industrial use and for livestock feeding.

In order to be comparable, both sources of information were classified following FAO’s categorization. It was assumed that locally produced agricultural products were first consumed by local populations, bred livestock and local industry. Based on this assumption, a relation was computed by subtracting the total vegetal food supply to the population of the SA from the local agricultural production (i.e., local production minus local consumption). When the subtraction result was positive a surplus of production existed, and it was assumed to be completely exported, except for the case of industrial beet crops, that were assumed to be 100 percent supplied to the agro-processing factory of SUCRAFOR located in Zaïo. When the subtraction gave a negative result this implied that vegetal food products needed to be imported to cover local population’s food needs. Thus, no stock amount occurred.

Nitrogen and phosphorus content in the respective agricultural local products and food products consumed by the SA population were calculated based on the N and P concentrations of food nutrition tables (SFK, 2000; Sika et al., 1995; USDA Food Composition Database online, release 27, 2011; West African FCT, 2012). However, estimations on N and P nutrient content in cereal, owing to its paramount importance in the Moroccan diet, and thus crucial for the nutrient balance, were estimated more precisely by using data on the composition of selected Moroccan cereals and legumes from Sika et al. (1995).

ANIMAL (LIVESTOCK) production sub-process [2]

The sudden demographic changes of the 20th century together with the massive urbanization forced Morocco to quickly increase its livestock in order to ensure food security (Sraïri, 2011). Besides, Morocco's pronounced water stress (with less than 800 m^3 per capita per year) and erratic rainfall, directs new strategies to increase agricultural production (including livestock) necessarily through optimal uses of water, especially in irrigated areas (Sraïri, 2011).

In Morocco, ruminant livestock feed resources are mainly based on inputs from natural pastures (or rangeland), forage crops and crops by-products (straw, stubble, crop residues), cereal grains and agro-industrial by-products. Yet, their relative proportion in covering livestock feed needs varies depending on the production system adopted, coupled with the agro-ecological zone in which livestock is raised, and the weather conditions in any given year (Berkat and Tazi, 2006; Boulanouar and Matthess-Guerrero, 1997; RdM, 2011 - Sit Agric MA).

Therefore, feed resources (in amount, quality and availability) remain the main criteria in determining livestock production systems in Morocco (Berkat and Tazi, 2006). Accordingly, the main feed systems are:

The *"agricultural-irrigated" feed system* (intensive), found in small, medium and large irrigated perimeters, is characterized by intensive farming with significant productivity (milk and meat output). Feeding regime is highly based on on-farm forage crops and crop residues practice whereas rangelands are less significant (Berkat and Tazi, 2006; Guessous, 1991; Le Gal et al., 2007; RdM elevage, 2005; Sraïri et al., 2003, 2009a, 2009b). Cattle production system on dual-purpose (milk and meat) prevails (Chafai, 2004; Runge et al., 2011; Sraïri, 2011), and although not dairy specialized, milk output is prioritized, and secondarily calves from dairy herds and cows are sold for fattening/slaughtering. Sheep production is becoming more and more significant, mainly in peri-urban areas, whereas breeding goats are hardly existent (RdM elevage, 2005).

Accordingly, we assumed that total volume of milk produced (in the SA in 2010) originated from dairy cows in irrigated farming areas (Ait El Mekki, 2008; Guessous, 1989; Sraïri, 2011). Sheep and goat milk production is very low and basically for domestic consumption (Guessous, 1989), thus it was not considered in the calculations.

The *"agro-pastoral" feed system* (semi-intensive) is found both in irrigated perimeters (and/or in the surrounding areas) and in rainfed cereal agricultural regions. Feeding regime is varied and diverse, yet on-farm fodder crops may attain up to 60 percent of the animal requirements (Berkat and Tazi, 2006; Guessous, 1991; RdM elevage, 2005; Sraïri, 2011). In addition, cereal grains and by-products (straw and stubble), fallow, rangelands, concentrated feed and agro-industrial by products contribute significantly (Berkat and Tazi, 2006; Chafai, 2004; RdM elevage, 2005). It is the prevailing sheep farming system (Guessous, 1989). Yet, cattle production system on dual-purpose (milk and meat) is abundant (Chafai, 2004; Sraïri, 2011), in this case, however, cattle are mainly raised for meat production and low milk yields are domestically consumed (Guessous, 1991; Sraïri, 2011). Sheep are primarily raised in rainfed areas, and when raised in irrigated areas, fodder crops are seldom fed to sheep and are almost all distributed to dairy cows only (Sraïri, 2011). Thus, feed resources for sheep are dominated by range production and cereal by-products such as straw and stubble (Guessous, 1989). In rainfed areas (and also in the periphery of irrigated perimeters) though, smallholders farm units under this system are more exposed to climate variations (rainfall levels), and particularly to droughts (Guessous, 1991; Sraïri, 2011). It is not surprising, therefore, to increasingly find crop production, sheep and range highly integrated with the recycling of by-products and the utilization of fresh or conserved forage at the regional and national levels (Guessous, 1989; Sraïri, 2011).

The *"pastoral" feed system* (extensive) corresponds to a feeding regimen where rangeland grazing dominates, supporting the herds throughout the year and providing more than half of the animals food needs. Secondarily, fallow, stubble and other crop residues contribution remains substantial, though in variable amounts because of variations in annual rainfall and drought impact on cereal production (Berkat and Tazi, 2006; Guessous, 1989; RdM elevage, 2005; Sraïri et al., 2003). Performances in extensive livestock farming system are highly dependent on feed availability, thus on climate variability (Sraïri, 2011). The practice of extensive farming is characteristic of small ruminant (Sraïri et al., 2003). Actually, it is the prevailing production system of goats, which are kept almost entirely in rangeland and forest (RdM elevage, 2005). Yet, sheep rearing is also found (Guessous, 1989). However, general trends indicate that rangeland is decreasing in contribution due to excess livestock and resultant overgrazing (Berkat and Tazi, 2006; Guessous, 1989; Sraïri, 2011).

The Moroccan poultry production system primarily consists of a modern intensive industrial production sector that has always been a private activity, implemented by private operators since the early 1960s, and never intervened by the Moroccan government (Barkok, 2007; Sraïri, 2011). At the national level, the industrial poultry farming supplies the country 86 percent of consumption for white meat and 71 percent for eggs, whereas the traditional poultry breeding (backyard) represents 14 percent of total consumption in white meat and 29 percent in eggs (Barkok, 2007). Traditional farming type still plays an important role in the subsistence economy of rural poor (Barkok, 2007). Poultry industrially raised is fed by a complete composite, i.e. feed concentrates, manufactured in specialized factories for poultry feeds and adapted to the type and stage of production (Barkok, 2007). According to Barkok, nearly all poultry farming units in Morocco belong to sector 2 of the FAO classification, meaning that chickens are raised in confinement strictly preventing contact with other poultry or wildlife. In 2010, Nador had produced broilers for meat in intensive farming units, but it did not have any farm unit concentrated on eggs for consumption (Barkok, 2007).

In Gran Nador, because of limited rainfall and generally shallow soils, a large area is used as grazing for sheep and goats. However, a number of irrigated areas raise dairy cattle, sheep and to a lesser extend goats (also found in the surroundings of irrigated perimeters). Cultivation is actively encroaching on grazing lands, coupled with an increasing grazing pressure; it has induced into a downward spiral of pasture degradation (Berkat and Tazi, 2006).

Data on livestock production was obtained from the statistics reported in the “Annuaire Statistique de la Région de l’Oriental-2009-2011” (ASRO, 2009, 2011), which are presented on the basis of the most important animals produced/slaughtered, differentiated on irrigated and rainfed. According to these statistics, in 2010, the main livestock categories raised in the SA, thus considered in this model were: cattle, sheep, goats (3.65, 81.2 and 15.15 percent respectively of the total number of ruminants, in heads) and poultry.

Nutrient (N and P) inputs were contained in feed, in specific: fodder locally produced from crop production sub-process (R_{1-2}), imports of feedstuff and fodder crops (I_{14-2}), whereas N and P outputs were the animals (meat and milk) (R_{2-4}), manure (R_{2-1}; R_{2-11}) and N losses during manure storage/management or direct deposition (O_{2-15}).

Stocks and flows of N and P in livestock production sub-process were estimated on the basis of the annual (in 2010) average number of slaughtered animals and amount of animal products produced (basically milk and meat) (ASRO, 2011), since no other information was available on the statistics. Likewise, N and P concentrations of the considered animals were accounted.

Therefore, the balance equations for the indicator substances nitrogen (N) and phosphorus (P) in the animal production sub-processes were expressed as follows:

$$dM^{(2)}_N/dt = I_{N,\,14-2}+R_{N,\,1-2}-O_{N,\,2-15}-R_{N,2-4}-R_{N,2-1}-R_{N,2-11}$$

$$dM^{(2)}_P/dt = I_{P,\,14-2}+R_{P,\,1-2}-R_{P,2-4}-R_{P,2-1}-R_{P,2-11}$$

Feed intake from livestock (I_{14-2}) and (R_{1-2})

The flows of nutrients (N and P) in feed resources consisted of locally cultivated forage crops (R_{1-2}) and imports of feedstuff and fodder crops (I_{14-2}).

Based on the literature on livestock farming systems in Morocco, and in particular to our SA, coupled with the statistics on animal production in the SA (ASRO, 2009, 2011), feed intake resources were assessed. N and P intake of cattle, sheep and goats were estimated on the basis of the annual (2010) average number of slaughtered animals, the recommended feeding allowances or feed intake requirements (Chafai, 2004) and according to the livestock-feeding production systems (Berkat and Tazi, 2006; Chafai, 2004; Guessous, 1991; RdM elevage, 2005; Sraïri, 2011).

In 2010, 99 percent of the cultivated forage crops in the study area were alfalfa (ASRO, 2009; 2011). In order to simplify, it was assumed that locally produced fodder was first used to feed the bred livestock. However, in accordance with the main livestock production systems presented, a large quantity of ruminants was also fed, partly, on grazing conditions in pastures. Therefore, to estimate ruminants feed intake, it was assumed that ruminants reared in irrigated perimeters and/or surroundings were 100 percent fed on alfalfa, whereas ruminants raised in rainfed, were fed on 60 percent alfalfa and 40 percent through grazing pastures. Since information on forages from pastures (natural grasslands, rangelands and non-agricultural lands), that provides about 40 to 90 percent of the feed consumed by the ruminants depending on the feed production system, is limited because of the wide variations in the botanical composition of these forages (Jarrige, 1989), we applied as a reference forage the assumption according to Chafai (2004) that one feed unit (FU) equals one kilogram of standard barley 84.9 percent dry matter (DM), and hence its correspondent N and P content (Feedipedia, 2014).

Likewise, N and P intake of broilers were calculated according to the daily nutrient requirements needed to produce an animal suitable for slaughter (NRP, 1994). According to the production system, it was assumed that commercial feed for poultry was entirely imported ($I_{14\text{-}2}$) from outside the SA.

The duration of the production cycle was assumed to be of at least 12 months approximately for sheep and goats (Chafai, 2004; Guessous, 1991; RdM elevage, 2005), and of 42 days for broilers (Barkok, 2007), cattle lasted more than 12 months, so a feed intake of one year was selected.

Thus, N and P feed intake from the main livestock categories considered followed the model equations of:

$$\mathbf{F.Intake}_{\mathbf{N\_Ruminants}}=\sum \left(n_{\mathrm{livestock\_irr}} * a_{\mathrm{feed\_livestock\_irr}} * DM_{\mathrm{Alfalfa\_H}} * C_{\mathrm{N,feed\_Alfalfa\_H}}\right) + \sum \left(n_{\mathrm{livestock\_rfd}} * a_{\mathrm{feed\_livestock\_rfd}} *(0{,}6*DM_{\mathrm{Alfalfa\_H}}*C_{\mathrm{N,\ feed\_Alfalfa\_H}}+0{,}4*DM_{\mathrm{Barley\_H}}*C_{\mathrm{N,\ feed\_Barley\_H}})\right)$$

$$\mathbf{F.Intake}_{\mathbf{P\_Ruminants}}=\sum \left(n_{\mathrm{livestock\_irr}} * a_{\mathrm{feed\_livestock\_irr}} * DM_{\mathrm{Alfalfa\_H}} * C_{\mathrm{P,feed\_Alfalfa\_H}}\right) + \sum \left(n_{\mathrm{livestock\_rfd}} * a_{\mathrm{feed\_livestock\_rfd}} *(0{,}6*DM_{\mathrm{Alfalfa\_H}}*C_{\mathrm{P,\ feed\_Alfalfa\_H}}+0{,}4*DM_{\mathrm{Barley\_H}}*C_{\mathrm{P,\ feed\_Barley\_H}})\right)$$

$$\mathbf{F.Intake}_{\mathbf{N\_poultry}} = (n_{\mathrm{poultry}} * a_{\mathrm{N.\ req.\_broiler}} * n_{\mathrm{broiler\ feeding\ days}})$$

$$\mathbf{F.Intake}_{\mathbf{P\_poultry}} = (n_{\mathrm{poultry}} * a_{\mathrm{P.\ req\_broiler}} * n_{\mathrm{broiler\ feeding\ days}})$$

Therefore,

$$R_{\mathrm{N,\ 1\text{-}2}} = (\mathrm{Alfalfa}\_{}_{\mathrm{Locally\ harvested}} * DM_{\mathrm{Alfalfa\_F}} * C_{\mathrm{N,\ feed\_Alfalfa\_F}})$$

$$R_{\mathrm{P,\ 1\text{-}2}} = (\mathrm{Alfalfa}\_{}_{\mathrm{Locally\ harvested}} * DM_{\mathrm{Alfalfa\_F}} * C_{\mathrm{P,\ feed\_Alfalfa\_F}})$$

$I_{N,\ 14\text{-}2}$ = F.Intake $_{N\_poultry}$ + $[(\sum(n_{livestock\_irr}*a_{feed\_livestock\_irr}*DM_{Alfalfa\_H}*C_{N,\ feed\_Alfalfa\_H}) + \sum(n_{livestock\_rfd}* a_{feed\_livestock\_rfd}*0{,}6*DM_{Alfalfa\_H}*C_{N,\ feed\_Alfalfa\_H})) - R_{N,\ 1\text{-}2})]$

$I_{P,\ 14\text{-}2}$ = F.Intake $_{P\_poultry}$ + $[(\sum(n_{livestock\_irr}*a_{feed\_livestock\_irr}*DM_{Alfalfa\_H}*C_{P,\ feed\_Alfalfa\_H}) + \sum(n_{livestock\_rfd}* a_{feed\_livestock\_rfd}*0{,}6*DM_{Alfalfa\_H}*C_{P,\ feed\_Alfalfa\_H})) - (R_{P,\ 1\text{-}2})]$

Where $n_{livestock}$ and $n_{poultry}$ are the number of animals ("livestock" corresponds to ruminants, which are differentiated per irrigated or rainfed), in heads, slaughtered in 2010 according to regional statistics (ASRO, 2009, 2011), $a_{feed\_livestock}$ is the feed requirement per animal in kg yr^{-1} (also differentiated per irrigated or rainfed), $DM_{Alfalfa\_H}$ and DM_{Barley_H} are the percentage of dry matter content in alfalfa hay and barley hay correspondingly, $C_{N,feed\_Alfalfa\_H}$ and $C_{P,feed\_Alfalfa\_H}$ are nitrogen and phosphorus content, respectively, in kg, of alfalfa hay 89.4 percent DM, $C_{N,feed\_Barley\_H}$ and $C_{P,feed\_Barley\_H}$ nitrogen and phosphorus content, respectively, in kg, of barley hay 84.9 percent DM, $a_{N.req.\_broiler}$ and $a_{P.req.\_broiler}$ are the daily N and P requirement needed to produce a broiler suitable for slaughter, $n_{broiler\ feeding\ days}$ duration of the broiler production cycle. Likewise, the alfalfa locally harvested, assumed fresh, is multiplied by its content of dry matter $DM_{Alfalfa\_F}$ and its corresponding nitrogen and phosphorus content, $C_{N,\ feed\_Alfalfa\_F}$ and $C_{P,\ feed\_Alfalfa\_F}$ in Kg of alfalfa fresh 19.9 percent DM.

Animal products ($R_{2\text{-}4}$)

N and P in animal products (meat and milk) were assessed on the basis of the number of animals (cattle, sheep, goats and poultry) slaughtered in 2010, according to regional statistics (ASRO, 2009, 2011), live weight of animal before slaughtering or at the end of the fattening period, and N and P content of animal body. For cattle, milk was also considered. Thus, animal products were computed following equations:

$R_{N,\ 2\text{-}4} = \sum (n_{livestock} * w_{\ livestock} * C_{N,body\_livestock}/100) + (n_{milk} * C_{N,\ milk}/100)$

$R_{P,\ 2\text{-}4} = \sum (n_{livestock} * w_{\ livestock} * C_{P,body\_livestock}/100.000) + (n_{milk} * C_{P,\ milk}/100.000)$

Where $n_{livestock}$ correspond to the number of slaughtered animals in heads, $w_{\ livestock}$ is the average live weight of animals before being slaughtered, in kg $head^{-1}$, $C_{N,body\_livestock}$ nitrogen content of animal body in g $(100g\ product)^{-1}$, $C_{P,body\_livestock}$ phosphorus content of animal body in mg $(100g\ product)^{-1}$, n_{milk} kg of milk produced in 2010, $C_{N,\ milk}$ nitrogen content of milk in g $(100g\ product)^{-1}$, $C_{P,\ milk}$ phosphorus content of milk in mg $(100g\ product)^{-1}$.

Part of the N and P flows in animals products will be transformed to waste in slaughterhouses, whereas the rest will be sold as meat for human consumption (see section on agro-food processing process for further details).

Manure ($R_{2\text{-}1}$) and ($R_{2\text{-}11}$)

Total amounts of N and P in manure were calculated by subtracting the amount of nutrients in animal body from the nutrient intake of animal (Antikainen et al., 2005). According to IPCC Guidelines 2006, Vol.4 AFOLU, Ch.10 (p.10.58): “the annual amount of N excreted by each livestock species/category depends on the total annual N intake and total annual N retention of the animal, hence, N excretion rates can be derived from N intake and N retention data”.

The flows of N and P in manure (including dung and urine) were divided into two parts: manure excreted by ruminants (cattle, sheep and goats) and manure from poultry. The division was done to respond to the different types of animal production and corresponding manure management systems. In the case of ruminants, no information was found on the different manure management systems applied per ruminant category, yet as the majority of ruminants were raised outdoors by agro-pastoral feeding-production system, we assumed that all manure excreted by ruminants was spread over or directly deposited on agricultural land and used as organic fertilizer (Runge et al., 2011). In the case of poultry, as it is almost entirely industrially produced, we assumed that manure was managed through a system of “poultry manure with litter” according to IPCC guidelines 2006 on manure management system (MMS) classification (see tab 10.18 in pag.10.49, ch.10), and after storage/treatment was transported and disposed of to the landfill.

Therefore, data was computed following equations:

$$R_{N,2\text{-}1} = \text{F.Intake}_{\text{N\_Ruminants}} - \sum [(n_{\text{livestock}} * w_{\text{livestock}} * C_{\text{N,body\_livestock}}/100)]$$

$$R_{P,2\text{-}1} = \text{F.Intake}_{\text{P\_Ruminants}} - \sum [(n_{\text{livestock}} * w_{\text{livestock}} * C_{\text{P,body\_livestock}}/100.000)]$$

$$R_{N,2\text{-}11} = (\sum [(n_{\text{poultry}} * a_{\text{N. req\_broiler}} * n_{\text{broiler feeding days}}) - (n_{\text{poultry}} * w_{\text{poultry}} * C_{\text{N,body\_poultry}}/100)]) * (1 - \text{Frac}_{\text{LossMS}})$$

$$R_{P,2\text{-}11} = (\sum [(n_{\text{poultry}} * a_{\text{P. req\_broiler}} * n_{\text{broiler feeding days}}) - (n_{\text{poultry}} * w_{\text{poultry}} * C_{\text{P,body\_poultry}}/100.000)])$$

Where $R_{2\text{-}1}$ refers to manure flows of ruminants and $R_{2\text{-}11}$ to those of poultry. With regard to the latter, we must account that a significant fraction of the total nitrogen excreted by animals in managed systems in general, and specifically by poultry in “with litter” MMS, is lost prior to final application or disposal. The majority of total nitrogen losses from MMS are due to volatilisation losses, primarily ammonia losses that occur rapidly following the excretion of the manure and are highly volatile and easily diffused into the surrounding air (IPCC, 2006).

Therefore, in estimating the amount of poultry manure nitrogen that was transported and disposed of into the landfill ($R_{N,2\text{-}11}$), it was necessary to reduce the total amount of nitrogen excreted by poultry in “with litter” MMS by the losses of N through volatilisation. Hence the application of the fraction that is lost through volatilization, $\text{Frac}_{\text{LossMS}}$ (in percentage). The rate $\text{Frac}_{\text{LossMS}}$ was computed by dividing N losses by ammonia and nitrous oxide direct and indirect emissions to the total manure N excreted by poultry (for further explanation on this see next section on manure N losses).

N losses from manure ($O_{2\text{-}15}$)

N losses from manure into the atmosphere consist of ammonia (NH_3) and nitrous oxide (N_2O) emissions. Particularly, N_2O is produced by microbial processes of nitrification and denitrification taking place on the deposition site (direct emissions), and after volatilisation/re-deposition and leaching processes (indirect emissions) (IPCC, 2006).

Direct and indirect N_2O emissions from manure nitrogen (N) left on pastures by ruminants were calculated at tier 1 following the IPCC guidelines, 2006: Vol.4, Ch. 11. Explicitly using equations 11.1, eq.11.9 and eq.11.10, and default emission factors associated taken from Tab.11.1 and Tab.11.3, respectively. Therefore, following equation:

$$\mathbf{N_2O\text{-}N_{R\_Direct\&\ Indirect}} = \sum(m_{livestock}*EF_{3,PRP}) + \sum(m_{livestock}*Frac_{GasM}*EF_4) + \sum(m_{livestock}*Frac_{LEACH\text{-}(H)}*EF_5)$$

Where, the annual amount of total N manure excreted by ruminants and left on pastures ($m_{livestock}$, in kg N yr^{-1}) was multiplied by a default IPCC emission factor value ($EF_{3,PRP}$, in kg N_2O-N (Kg N yr^{-1}), taken from Tab.11.1) to compute direct emissions. Indirect emissions were estimated likewise, first by calculating the fraction of manure N deposited by animals that volatilised ($Frac_{GASM}$, representing kg N volatilised (kg of N applied or deposited)$^{-1}$) and that lost through leaching and runoff processes ($Frac_{LEACH\text{-}(H)}$, representing kg N (kg of N additions)$^{-1}$) and then multiplied by the indirect N_2O emission factors associated with these losses (EF_4 and EF_5, in kg N_2O-N (kg NH_3-N + NOx–N volatilised)$^{-1}$ and in kg N_2O–N (kg N leached and runoff)$^{-1}$, respectively.

Therefore, N losses from ruminant manure consisted of ammonia volatilisation and nitrous oxide direct and indirect emissions, that is:

$$Nloss_{\_m,ruminants} = (\sum (m_{livestock} * Frac_{GasM})) + (N_2O\text{-}N_{R\_Direct\ \&\ Indirect})$$

Regarding manure excreted by poultry, since it is industrially produced, we assumed that it was managed under a management system of “poultry manure with litter” in accordance with IPCC manure management system (MMS) classification (in IPCC, 2006: Vol.4, Ch.10, Tab.10.18). Consequently, direct and indirect N_2O emissions were calculated based on this specific MMS. Here again, N_2O emissions were estimated at tier 1 as per IPCC guidelines, 2006: Vol.4, Ch. 10 and 11, precisely using equations 10.25 and Eq.10.27, and default emission factors associated taken from Tab.10.21 and Tab.11.3, respectively. Hence the following equation:

$$\mathbf{N_2O\text{-}N_{P\_Direct\&\ Indirect}} = (m_{poultry} * EF_3) + (m_{poultry} * Frac_{GasMS} *EF_4)$$

Where, annual amount of poultry manure ($m_{poultry}$, in kg N yr^{-1}) was multiplied by an IPCC emission factor (EF_3, in kg N_2O-N (Kg N excreted^{-1}), taken from Tab.10.21) associated with the “poultry manure with litter” MMS. Indirect N_2O emissions were computed likewise, first estimating the fraction of poultry managed manure nitrogen that volatilises ($Frac_{GasMS}$, rate of volatilisation, in percentage), and then multiplied by the indirect N_2O emission factor associated with volatilisation loss (EF_4, in kg N_2O-N (kg NH_3-N + NO_X–N volatilised)$^{-1}$. Indirect N_2O emissions due to leaching from “poultry manure with litter” MMS were not computed because of lack of data. N losses from poultry manure managed under "poultry manure with litter" system consisted of ammonia and nitrous oxide direct and indirect emissions, that is:

$Nloss_{\_m,poultry} = (m_{poultry} * Frac_{GasMS}) + (N_2O\text{-}N_{P\_Direct\ \&\ Indirect})$

Therefore, $O_{N,2\text{-}15}$ flow corresponding to N losses from ruminant manure and poultry manure managed under "poultry manure with litter" system followed the equation:

$O_{N,2\text{-}15} = Nloss_{\_m,ruminants} + Nloss_{\_m,poultry}$

AGRO-Industrial/ AGRO-FOOD processing process [4]

During the years 2002-05, the food industry of Morocco ranked between the first and the second position in terms of its contribution to the industrial gross domestic product -GDP, which reinforces the agricultural vocation of the country. Specially, the food industry plays a leading role in promoting activities of industrial transformation (Ait El Mekki, 2008).

The strength of the economy of Nador province focus on its role as a business and financial center, the service sector marked by the cross-border trade, exports outside national borders, and sea fishing. Actually, thanks to Nador, the banking sector is the third financial center of Morocco (Runge et al., 2011). The industrial sector is dominated by the food industry, followed by the cement and metal and mechanical industries. Though still relatively low, the increasing role of the transformative fishing industry in Nador's economy is becoming significant (Runge et al., 2011).

Information about the operation of the different units that formed the agro-food processing process was hardly existent, or at least much was not available, nor accessible. Lacking basic data about the process made quantification quite difficult. However, because of the increasing importance of the fisheries sector in Nador, we considered that at least some estimation needed to be done. Therefore, this process includes the fisheries sector, the slaughterhouse, and a brief explanation of the SUCRAFOR factory. The processing of olives was excluded from the study since basic data was lacking. In any of these three units studied was possible to estimate the wastewater generated in their production process because of lack of basic data, hence wastewaters from agro-food industry were not computed.

Nutrient (N and P) inputs to the agro-food processing process included agricultural ($R_{1\text{-}4}$) and animal products ($R_{2\text{-}4}$), fish catches ($I_{13\text{-}4}$) and imports ($I_{14\text{-}4}$). Nutrient (N and P) outputs comprised processed meat products for local consumption (rural ($R_{4\text{-}5}$) and urban ($R_{4\text{-}6}$) household consumption), export of products ($O_{4\text{-}14}$) and waste ($R_{4\text{-}11}$).

Therefore, the balance equations for the indicator substances nitrogen (N) and phosphorus (P) were formulated as follows:

$dM^{(4)}{}_N/dt = I_{N,\ 13\text{-}4}+I_{N,\ 14\text{-}4}+R_{N,\ 1\text{-}4}+R_{N,\ 2\text{-}4}-O_{N,\ 4\text{-}14}-R_{N,\ 4\text{-}5}-R_{N,\ 4\text{-}6}-R_{N,4\text{-}11}$

$dM^{(4)}{}_P/dt = I_{P,\,13\text{-}4}+I_{P,\,14\text{-}4}+R_{P,\,1\text{-}4}+R_{P,\,2\text{-}4}-O_{P,\,4\text{-}14}-R_{P,\,4\text{-}5}-R_{P,\,4\text{-}6}-R_{P,4\text{-}11}$

Fisheries sector ($I_{14\text{-}4\_fish}$) , ($I_{13\text{-}4}$) ; ($R_{4\text{-}11\_fish}$) and ($O_{4\text{-}14\_fish}$)

The Beni Ansar port, also known as the Nador port, is the main port of the Nador province, and the one selected in our SA. Coastal fishing has experienced in recent years an unprecedented development due to increased catches by the Beni Ansar port, the modernization of the fleet and an emerging fishing processing industry (Runge et al., 2011).

According to the “Annuaire Statistique de la Région de l’Oriental-2011” (ASRO, 2011) in 2010, at the port of Beni Ansar, major catches were of pelagic fish and whitefish. Despite much of the total catches are sold directly for local consumption (43 percent) or for export (57 percent), a processing industry, placed in Nador and surroundings, is expanding. Fish processing consists of canning (salting), freezing and decortication of fish (Runge et al., 2011). Actually, the fish that supplies the processing industry either comes from other regions of Morocco or from Europe (Runge et al., 2011).

Accordingly, nutrient (N and P) inputs from fishing to the fisheries processing industry are supplied by imports ($I_{14\text{-}4}$) instead from local fishing ($I_{13\text{-}4}=0$). Fishing imports ($I_{14\text{-}4\_fish}$) were estimated on the basis of the real quantities of production by the main fishing factories operating at Nador and surroundings (see Tab.2), assuming, according to Runge et al. (2011) an operating capacity of 60 percent (r_{op_cpty}) from the company’s production capacity ($a_{pc\_company}$, in kg year^{-1}). Since no further data was available, to estimate N and P concentrations, we assumed that the global amount of processed fish was 50 percent pelagic and 50 percent demersal. Therefore, N and P concentrations of pelagic and demersal fish were applied correspondingly ($C_{N\_pelagic}$ and $C_{N\_Demersal}$ in gN (100g product)$^{-1}$, and $C_{P\_pelagic}$ and $C_{P\_Demersal}$ in mgP (100g product)$^{-1}$, respectively).

$I_{N,14\text{-}4\_fish} = \sum (a_{pc\_company} * r_{op\_cpty} * 0{,}5 *((C_{N\_pelagic}/100) + (C_{N\_Demersal}/100)))$

$I_{P,14\text{-}4\_fish} = \sum (a_{pc\_company} * r_{op\_cpty} * 0{,}5 *((C_{P\_pelagic}/100.000) + (C_{P\_Demersal}/100.000)))$

According to Runge et al. (2011) studies conducted by the Higher Institute of Marine Fisheries in Agadir showed that about 30 percent of the processed quantities of fish by the fishing processing industry become waste ($R_{4\text{-}11\_fish}$). Waste levels vary greatly between different types of fishing and processing (from 5-7 percent for octopus to 60 percent for shrimp). Therefore, waste produced by the fishing processing industry was computed by applying the approximate average ratio of waste production of 30 percent (r_{waste_fish}) to the real quantities of production. N and P concentrations were estimated alike. Finally, we assumed that all the solid amount of waste produced was transported and disposed of in the landfill.

$R_{N,4\text{-}11\_fish} = \sum (a_{pc\_company} * r_{op\_ctpy} * r_{waste\_fish} * 0{,}5 *((C_{N\_pelagic}/100) + (C_{N\_Demersal}/100)))$

$R_{P,4\text{-}11\_fish} = \sum (a_{pc\_company} * r_{op\_ctpy} * r_{waste\_fish} * 0{,}5 *((C_{P\_pelagic}/100.000) + (C_{P\_Demersal}/100.000)))$

The following table shows per company its main processing activity and its corresponding production capacity. Almost all processing units are placed in Nador (ONP, 2010; ONSSA, 2010; Runge et al., 2011).

Table 3.: List of companies forming the fishing processing industry of Nador, specifying its main activity and production capacity.

Firm/enterprise	City	Main activity	Total Capacity (kg/year)
AHIMEX	Nador	Freezing and packaging of fresh fishery products	4,400,000
CONGELMAR	Nador	Freezing and packaging of fresh fishery products	660,000
COPRINCO	Nador	Freezing and packaging of fresh fishery products	2,640,000
HUILMAR	Nador	Shrimp peeling	4,620,000
IMBADEX	Nador	Packaging of fresh fishery products	3,300,000
MARISCO SERVISUR	Nador	Packaging of fresh fishery products	1,540,000
MER FRUIT	Nador	Freezing and packaging of fresh fishery products	4,400,000
PESCAM	Nador	Packaging of fresh fishery products	2,200,000
PETIT MER	Nador	Freezing and packaging of fresh fishery products	1,760,000
RIFO FISH	Nador	Freezing and packaging of fresh fishery products	440,000
RESTINGA MAR	Nador	Freezing and packaging of fresh fishery products	3,520,000
SAMAK ANWAL	Nador	Freezing and packaging of fresh fishery products	880,000
MIOB MARE	Nador	Packaging of live eels	880,000
SONOP	Nador	Freezing and packaging of fresh fishery products	1,320,000
Total		**Total production capacity**	**32,560,000**
Total estimated production		**Total actual production quantity = 60% production capacity**	**19,536,000**
Production Waste		**= 30% of total processed quantities or actual produced amounts**	**5,860,800**

Source: Author's from «Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches»; Runge et al., 2011; and http://onssa.gov.ma/fr/images/pdf/DeneresAlimentaires/Controle-etablissements/Proudit_Peche_MA_fr.pdf

Finally, it was assumed that all produced products from the fisheries processing industry were exported ($O_{4\text{-}14}$), again N and P concentrations were estimated the same way.

$O_{N,4\text{-}14\_fish} = I_{N,14\text{-}4\_fish} - R_{N,4\text{-}11\_fish}$

$O_{P,4\text{-}14\_fish} = I_{P,14\text{-}4\_fish} - R_{P,4\text{-}11\_fish}$

Slaughterhouse ($R_{4\text{-}5}$); ($R_{4\text{-}6}$); ($O_{4\text{-}14\_meat}$) and ($R_{4\text{-}11\_meat}$)

Nutrient (N and P) inputs to slaughterhouses were supplied by livestock production sub-process outputs. Nutrient (N and P) outputs from slaughterhouses consisted of meat consumed by rural ($R_{4\text{-}5}$) and urban ($R_{4\text{-}6}$) households, meat export ($O_{4\text{-}14}$) and wastes ($R_{4\text{-}11}$).

Data on meat production (n_{meat_animal}, in kg year^{-1}), ready for consumption, so as the slaughterhouses output, was derived from the statistics of the "Annuaire Statistique de la

Région de l’Oriental-2011” (ASRO, 2011) in 2010. To estimate nutrient content, meat production was then multiplied by its associated N and P concentrations ($C_{N,meat\_animal}$ in g N (100g product)$^{-1}$ and $C_{P,meat\_animal}$ in mg P (100g product)$^{-1}$, respectively).

The flows of nutrients in meat production were divided into three parts: meat consumed by rural (R_{4-5}) and urban (R_{4-6}) households, and meat exports (O_{4-14_meat}). All these flows were calculated by means of addition and subtraction between data on meat production and data on meat consumption by the studied population of GN, primarily derived from the FAOSTAT online database (FAO, 2010) and the official statistics of the population census (see the section on consumption process for a more detailed explanation).

Slaughterhouses solid wastes ($R_{N,\ 4-11\_meat}$) were calculated by the difference between both data, i.e. animal and meat production:

$$R_{N,4-11\_meat} = \sum (n_{livestock} * w_{livestock} * C_{N,body\_livestock}/100) - (n_{meat\_animal} * C_{N,meat\_animal}/100)$$

$$R_{P,4-11\_meat} = \sum (n_{livestock} * w_{livestock} * C_{P,body\_livestock}/100.000) - (n_{meat\_animal} * C_{P,meat\_animal}/100.000)$$

Moroccan slaughterhouses wastes mainly consist of blood, offal parts, rumen and intestines contents and part of the skin. Bones and fat waste quantities are quite low because beef cattle, mutton and goat meat are sold with bones and largely non-dismembered. The bulk of solid material is collected and sent to the landfill, whereas liquid wastes are largely eliminated in the pipes (Runge et al., 2011). Lacking basic data about the process, we were not able to quantify liquid wastes.

SUCRAFOR (R_{1-4})

SUCRAFOR, located at the municipality of Zaïo, and with over 30 years of existence, is a sugar factory specialized in the manufacture of granulated sugar from sugar beet industrial crops. According to Runge et al. (2011), it processes about 360,000 tonnes of sugar beet per year, corresponding to an annual output of 50,000 tons of sugar. Of these 360,000 tonnes, about 80 percent of sugar beet industrial crops were supplied, in 2010, by the local agricultural production of GN (corresponding to flow R_{1-4}).

During the manufacturing process, several types of wastes are produced. However, according to Runge et al. (2011) most of them are already reused, for the greater part for animal fodder.

- 5,500 tonnes of beet leaves that are used as fodder for cattle.
- 18,500 tonnes of pressed dry pulp for the production of pellets that are used as fodder for cattle.
- 15,400 tonnes of molasses that are used for the production of yeast and alcohol.
- Liquid wastes are stored into ponds next to the factory.
- Recovered solid sludge is used as fuel in brick factories.

According to EEIRO (2013) the final waste quantities, for which neither reuse nor recover is possible, are estimated around 2,300 tonnes year^{-1}. This waste consists of liquid materials and solid sludge that is stored in lands belonging to the same factory unit. However, lacking basic data about the process, we were not able to quantify it.

To end this process section, it must be noted that total export products ($O_{4\text{-}14}$) from the agro-food processing industry or process were finally composed by fish and meat export products, and that it happen the same for the waste disposed of to the landfill ($R_{4\text{-}11}$). Therefore, following equations:

$$O_{4\text{-}14} = O_{4\text{-}14\_fish} + O_{4\text{-}14\_meat}$$

$$R_{4\text{-}11} = R_{4\text{-}11\_fish} + R_{4\text{-}11\_meat}$$

Consumption Process [7] = ∑ (Rural household –HH [5]; Urban household –HH [6])

As in many other areas of the Mediterranean basin, the food consumption pattern of Morocco is based on a large consumption of cereals (mainly wheat), fruits and vegetables (PNRdM, 2011). Yet, the Moroccan diet is progressively being diversified, especially regarding urban households and wealthier classes. According to the RdM/HCP (2005) while cereal consumption was higher in rural areas, the consumption of fruit, vegetables and meat was larger in urban areas. More specifically, the consumption of fish and eggs was two times higher in urban than rural areas; while for milk and dairy products, urban households consumed three times more than rural households (RdM/HCP, 2005). Socio-economic inequalities between urban and rural population could partly explain these differences in diet composition (PNRdM, 2011).

This process includes household activities related to food and nutrient flows in the food consumed by the population of Grand Nador. Therefore, nutrient (N and P) inputs considered were those that enter the household through food ($I_{13\text{-}5}$; $I_{14\text{-}5}$; $R_{1\text{-}5}$ and $R_{4\text{-}5}$ for rural HH; $I_{13\text{-}6}$; $I_{14\text{-}6}$; $R_{1\text{-}6}$ and $R_{4\text{-}6}$ for urban HH). With regard to process outputs, food is either consumed or discarded as food waste (inedible part of food and food preparation leftovers, and uneaten food from households) and some of it is flushed out during dish washing (greywater). Consumed nutrients leave the human body through excreta (see Fig.16). A few percentage of the N consumed leaves the body through perspiration (Montangero, 2006). Therefore, N and P leave the household in the form of excreta (with or without flush water) and greywater ($R_{5\text{-}8}$; $O_{5\text{-}13}$ rural; $R_{6\text{-}8}$; $R_{6\text{-}13}$ urban), kitchen waste ($R_{5\text{-}9}$; $R_{5\text{-}12}$ rural; $R_{6\text{-}9}$; $R_{6\text{-}12}$ urban) (see Fig.12), and gasses (Montangero, 2006). Because of insufficient basic data to compute, food consumption and waste from commercial establishments, such as restaurants or the food markets were not taken into account.

We differentiated between urban and rural populations, though most of the population lives in cities, because not only the composition of urban and rural diets, but also family budget regarding food expenses was different. Also, in Grand Nador, household connections to sewage system, as well as collection of municipal solid waste, differs for urban and rural municipalities, which leads to differences in the final destination and disposal of nutrients (see Fig.16).

The following equations describe N and P flows in the rural and urban household consumption sub-processes, constituting the consumption system process. The flows described here are illustrated graphically in the system analysis (see Fig.12). Therefore, the balance equations for N and P in the rural household consumption sub-process were expressed as:

$dM^{(5)}_N/dt = I_{N,\,13\text{-}5}+I_{N,\,14\text{-}5}+R_{N,\,1\text{-}5}+R_{N,\,4\text{-}5}-O_{N,\,5\text{-}13}-R_{N,5\text{-}8}-R_{N,\,5\text{-}9}-R_{N,\,5\text{-}12}$

$dM^{(5)}_P/dt = I_{P,\,13\text{-}5}+I_{P,\,14\text{-}5}+R_{P,\,1\text{-}5}+R_{P,\,4\text{-}5}-O_{P,\,5\text{-}13}-R_{P,5\text{-}8}-R_{P,\,5\text{-}9}-R_{P,\,5\text{-}12}$

Likewise, the balance equations for N and P in the urban household consumption sub-process were expressed as:

$dM^{(6)}_N/dt = I_{N,\,13\text{-}6}+I_{N,\,14\text{-}6}+R_{N,\,1\text{-}6}+R_{N,\,4\text{-}6}-O_{N,\,6\text{-}13}-R_{N,6\text{-}8}-R_{N,\,6\text{-}9}-R_{N,\,6\text{-}12}$

$dM^{(6)}_P/dt = I_{P,\,13\text{-}6}+I_{P,\,14\text{-}6}+R_{P,\,1\text{-}6}+R_{P,\,4\text{-}6}-O_{P,\,6\text{-}13}-R_{P,6\text{-}8}-R_{P,\,6\text{-}9}-R_{P,\,6\text{-}12}$

Data on food consumption was barely existent and the scant information found was insufficient and outdated (“Enquête Nationale sur la consommation et les dépenses des ménages 2000-2001; RdM/HCP, 2005 in Benjelloun et al., 2011). Hence, following Faerge et al. (2001) and Metson et al. (2012a), data on average per capita food supply in Morocco from the FAOSTAT online database (FAO, 2010) was used as a proxy for food consumption at national level, and by assuming that supply was equal to consumption. Metson et al. (2012a) recognizes that standardized data for food consumption are not consistently available and that food supply has been successfully used as a proxy for dietary consumption by the FAO and other public agencies. This data on national food consumption per capita was then multiplied by the estimated population of Gran Nador in 2010 according to its place of residence (RGPH, 2004; HCP-projections 2005-2030, 2007; Monographie RO, 2012). Finally, data on food consumption was adjusted by level of annual average per capita food expenditure. That is, the total food consumed by urban/rural populations was adjusted to a ratio on urban/rural difference in the food budget coefficient (ENRNVM, 2011).

This latter adjustment on the urban/rural food budget coefficient was applied to include the above mentioned socio-economic differences between rural and urban systems. Yet, since remittances most likely play a significant role as alternative sources of income, particularly in the case of Nador, it was the annual average food expenditure per capita, instead of the GDP per capita, the selected and applied indicator as a measure of the population living standards.

In this regard, and according to the survey results of the “Enquête National sur les revenues et les niveaux de vie des Ménages 2006/2007” (ENRNVM, 2011), food expenses (excluding tobacco) ranked first in household budgets with a share of 40.6 percent in 2007. Yet, the share of the budget dedicated to food expenses varied with the place of residence, from 49.3 percent in rural areas to 36.8 percent in urban areas, showing that the share on food expenditure was higher at households of lower levels of living standards (ENRNVM, 2011) (the food budget coefficient). Therefore, differences in the global quantities of food purchased/consumed by urban and rural population were considered by applying a ratio on urban/rural differences in food budget expenditure (i.e.,“Écart sur dépenses d’alimentation urbain/rural) (ENRNVM, 2011).

To sum up, the total supply of food to Grand Nador ($a_{\_Rur.HH\ food}$ and $a_{\_Urb.HH\ food}$) was computed from data on annual average food supply per capita at national level ($n_{consump\_food}$ in kg (cap year)$^{-1}$), adjusted by the number of rural and urban inhabitants of Grand Nador (n_{pop_rural} and n_{pop_urban}, for rural and urban populations respectively, in inhabitants) and by the ratio on the food budget coefficient per the rural and urban population ($r_{food\ exp}$). Thus, the following equations:

$$a_{\_Rur.HH\ food} = \Sigma\ (n_{consump\_food} * n_{pop\_rural} * r_{food\ exp\_rural})$$

$$a_{\_Urb.HH\ food} = \Sigma\ (n_{consump\_food} * n_{pop\_urban} * r_{food\ exp\_urban})$$

An adjustment to consider differences in urban and rural diet composition was not applied since quantitative basic data required was insufficient and outdated, thus, not available. Hence, we assumed an equal diet composition for urban and rural populations. However, results from the “Enquête nationale sur la consommation et les dépenses des ménages 2000/2001 du Royaume du Maroc-HCP” (in the PNRdM, 2011) showed that urban inhabitants consumed about 11 percent more proteins than rural populations, as well as more animal proteins. Sraït (2011) adds that wide variations in animal products consumption among individuals linked to the level of households’ income, which agrees with Faerge et al. (2001) argument that, in general, the relative consumption of non-cereal products such as meat, fish, and vegetables increases with income, causing this substitution of cereals by meat a corresponding increase in the N and P inflow.

Nitrogen and phosphorus content in the food items consumed by the Grand Nador population were both derived from using information on food nutrition tables (SFK, 2000; Sika et al., 1995; USDA Food Composition Database online, release 27, 2011; West African FCT, 2012) (in g 100g pdct^{-1} and mg 100g pdct^{-1}, respectively). However, estimations of N and P nutrient content in cereal, owing to its paramount importance in the Moroccan diet, and thus crucial for the nutrient balance, were estimated more precisely by using data on the composition of selected Moroccan cereals and legumes from Sika et al (1995). Therefore, the following equations were developed:

$$a_{N\_Rur.HH\ food} = \Sigma\ (n_{consump\_food} * n_{pop\_rural} * r_{food\ exp\_rural} * C_{N\_food\ item} / 100)$$

$$a_{P\_Rur.HH\ food} = \Sigma\ (n_{consump\_food} * n_{pop\_rural} * r_{food\ exp\_rural} * C_{P\_food\ item} / 100.000)$$

$$a_{N\_Urb.HH\ food} = \Sigma\ (n_{consump\_food} * n_{pop\_urban} * r_{food\ exp\_urban} * C_{N\_food\ item} / 100)$$

$$a_{P\_Urb.HH\ food} = \Sigma\ (n_{consump\_food} * n_{pop\_urban} * r_{food\ exp\_urban} * C_{P\_food\ item} / 100.000)$$

Where $C_{N\_food\ item}$ and $C_{P\_food\ item}$ were the N and P content in the different food items considered, in g 100g pdct^{-1} and mg 100g pdct^{-1} respectively.

Food nutrient inflows to rural ($I_{13\text{-}5}$; $I_{14\text{-}5}$; $R_{1\text{-}5}$ and $R_{4\text{-}5}$) and urban ($I_{13\text{-}6}$; $I_{14\text{-}6}$; $R_{1\text{-}6}$ and $R_{4\text{-}6}$) households were computed as the difference between data on urban/rural population consumption and data from local production systems of agriculture, industry and fishing catch. In computing these calculations per difference, imports of various food products consumed by the local population but not locally produced were also estimated.

With regard to process outflows ($R_{5\text{-}8}$; $O_{5\text{-}13}$; $R_{5\text{-}9}$; $R_{5\text{-}12}$ rural and $R_{6\text{-}8}$; $O_{6\text{-}13}$; $R_{6\text{-}9}$; $R_{6\text{-}12}$ urban), they are explained in detail in the following section on the waste management process (see Fig.16).

Waste management process [10] = ∑ (Sewage/Wastewater sub-process [8]; Organic Solid Waste -OSW- [9])

According to Runge et al. (2011), Morocco produces about 7.5 million tons of waste per year, of which 5.9 million tons are generated in households, and about 1.6 million tons are industrial waste (Runge et al, 2011; Sweepnet, 2010). In regard to the latter amount, some 256,000 tons yr^{-1} of hazardous waste and 6,300 tons of medical waste are produced per year. Increasing urbanization and the changing consumption patterns of the population create important challenges for waste management.

The *communal* charter concerning Law Nº 78/00 -promulgated by the Dahir of 3 October 2002- relative to the organization of the *communes* and municipalities entrusts these administrative units the competence of providing local public services including that of collection, treatment, transport and disposal of domestic waste and similar refuse (EEIRO, 2013; Metaich, 2013). Yet, the difficulties faced by local authorities in performing this task led almost all major cities of Morocco to delegate the management of waste to private companies, in the context of joint ventures and licensing agreements (EEIRO, 2013; Runge et al., 2011).

In November 2006, the Law Nº 28-00 relative to waste management and disposal was adopted. Promulgated by Dahir Nº 1-06-153 (22 November 2006) it establishes the specific legal framework for solid waste dealing with the problem of domestic, industrial, medical and hazardous solid waste (EEIRO, 2013; Metaich, 2013). Its main objective is to avoid negative environmental impacts by reducing the amount of waste through the collection, recovery and disposal of refuse (Runge et al., 2011). The law discusses several aspects related to Solid Waste Management (SWM) including SWM services and sector organization, waste valorization, local, national and regional planning, public information and control systems (Sweepnet, 2010). In addition, the enactment of Act Nº 28-00 prohibited uncontrolled landfills (Metaich, 2013).

In 2008, the National Program on Household Waste Management (-PNDM- in its French acronym, *Programme National de Gestion des Déchets Ménagers*) targeting quantitative objectives on waste collection for the following years, was put into effect. This program also regulates the establishment of sanitary landfills, the remediation and closure of 300 existing non controlled landfills, and the reduction and recovery of waste (Runge et al., 2011) On the other hand, Law № 10-95 on the water provides a regulation, in general terms, on waste deposits (EEIRO, 2013).

Under this legal framework and the Household Waste Management National Program, together with the fact that according to Law № 78/00 each municipality/commune is responsible of managing and treating their own waste, Nador has supported the creation of an association, composed of 11 communes/municipalities (Nador, Beni Ansar, Selouane, Zegangane, Al Aroui, Ihaddadene, Arekmane, Bni Bouifrour, Bouarg, Oulad Settout and Zaïo) to jointly build and operate a sanitary or controlled landfill (Metaich, 2013). Thus, by Order of the Interior Ministry (ministry of home affairs) № 149 of 13 December 2005, the *groupement des communes pour l'environnement* was created. After, executive powers were instituted by the Minister of Interior № 172 of May 5, 2008 for the collection and disposal of household garbage (EEIRO, 2013).

Since March 2009, the Veolia Group has been responsible for the collection and disposal of waste in Grand Nador. In 2010, waste collected was completely disposed of in the uncontrolled landfill of Nador. This non-sanitary landfill, located 25km outside Nador at the rural commune of Oulad Settout, has existed for 20 years and covers an area of about 40 hectares, which is easily flooded because of the impermeable subsoil (CAP Nador, 2008; Metaich, 2013). According to Runge et al. (2011), between 300-400 tons of waste were disposed of at this site every day, being the organic fraction of the waste around 75 percent of the total. This has led in the past to increased pollution (landfill gas emissions and contamination of soil and ground water) around the landfill (see Fig.15).

Adjacent to the uncontrolled disposal site, a sanitary landfill is under construction. Planned to be commissioned in 2014, the greatest achievement of the new sanitary landfill, equipped with a waterproof cover and a gas collection and burning system, is the recovery and treatment of the leachate, preventing damages to the water table (Metaich, 2013; Runge et al., 2011). In the former landfill and during the rainy season (from November to February) torrential downpours flooded the area and flushed downstream the garbage ending in the lagoon and the sea. The new landfill, not only protects the Lagoon from receiving wastes, but also foresees the recovery and treatment of the leachate (Metaich, 2013). Moreover, the old uncontrolled landfill is going to be rehabilitated and become part of the new. In the long term, a separate collection (wet-dry) should be built in Grand Nador as well as a recycling center at the landfill site (Metaich, 2013; Runge et al., 2011).

Figure 15.: Location of three depolluting initiatives/programs developed in the region of Grand Nador and supported by the Royal initiative and compelled by national legal frameworks: The WWTP of Nador, the sanitary landfill and the new inlet of the Nador Lagoon. Source: Metaich, H. (2013). Presentation sur la gestion des déchets solides à la province de Nador, et le Groupement de Communes pour l'environnement, par Hassan Metaich (Chef de la Division Technique). (Personal communication with Hassan Metaich, October 2013).

As regards recycling, the amount of recoverable non-organic waste in 2010 was low, about 10 percent of the waste collected at national level. The most recycled waste is that with significant economic value such as metals, glass, paper and cardboard. However, this activity suffers from a complete absence of recognition at the institutional, legal and regulatory levels, and recycling remains dominated by the informal sector (Bouchareb, 2010; Metaich, 2013; Sweeptnet, 2010).

In 2010, recycling in the SA was rather limited. Different valuable materials were sorted out and sold both, in the city of Nador or at the landfill site, but always under informal settings. In the city, mostly metal, plastic and cardboard are collected and sold to wholesalers. On the landfill site, were about 80 collectors work organized in different "clans", the waste collected and sorted is sold to middlemen dealers that transport materials to Casablanca which is considered the national waste recycling center (Runge et al., 2011; Metaich, 2013). However, being an informal activity no basic data existed and thus we were not able to quantify these flows. Still, there are persisting waste management problems related to the insufficient and inadequate means for the collection and transport of waste, the scattering of plastic bags, and the dumping of untreated domestic, industrial and medical waste. Technical, financial and human constraints undermine the proper management of waste. Furthermore, an integrated waste management system supported by the required financial, human and technical means is still lacking. Altogether, this is becoming a major environmental issue (EEIRO, 2013).

With regard to the collection and treatment of wastewater and/or sewage, in 2005, Morocco only treated 10 percent of its municipal effluent, despite the fact that 70 percent of the urban population was connected to the sewerage network.

Faced with mounting pollution problems, in 2005 the Moroccan government approved within the National Wastewater Strategy, the *Programme National d'Assainissement Liquide et d'Epuration des Eaux Usées (PNA)*, whose long term objective is to achieve 80 percent rate of collected effluent treatment and 80 percent of urban connection rate to sewerage network by 2020 (http://www.environnement.gov.ma/index.php/fr/eau?id=207). Five years later, the situation improved and 20 percent of treated municipal effluent and 73 percent of population connected to the sewerage network was achieved at national level.

At the regional level of Grand Nador, and framed within the PNA program of the National Wastewater Strategy, the most prominent action was the commissioning in 2010 of the new WWTP of Gran Nador (see Fig.15) that receives the wastewaters from the main urban centers (Nador, Taouima, Selouane, Zeghanghan, Ihaddaden, Jaadar and Bni Ansar). The National Office of Potable Water (ONEP) is managing this new WWTP with tertiary system and of activated sludge treatment technology. It receives and treats the raw wastewater of the urban centers of Grand Nador (EEIRO, 2013).

This process of waste management analyses nutrient (N and P) flows in food waste. That is, nutrients in food, that once eaten or disposed of as food waste, result in nutrients either as solid waste or/and wastewater and sewage. These household outputs, when collected and treated, form the nutrient (N and P) inputs to the waste management system. This process consists of two sub-processes; the sewage-wastewater sub-process and the solid waste sub-process (see Figs. 12 and 16 corresponding to the schematic representation of the analysed system, and the flow diagram of the specific waste management process).

According to Antikainen et al. (2005) and Forkes (2007) a significant fraction of the nutrients originally present in the consumed food finally end up in sewage wastes (i.e., the post-consumption form of food wastes) because their excessive intake also leads to their higher excretion. For example, up to 90 percent of the total protein consumed in a year is excreted by the body as urea and other nitrogenous products (Baker et al., 2001; Forkes, 2007). Jönsson et al. (2004) affirm that close to 100 percent of phosphorus eaten in food is excreted. Likewise, household organic solid waste contains mostly nonedible parts of food, e.g. fish parings and fruit and vegetable peelings, as well as non-consumed food. Taking into account these factors, N and P amounts in household wastewater and organic solid waste were calculated.

It must be noted that although we understand the term of municipal solid waste (MSW) as it refers to all the miscellaneous waste, such as kitchen waste, yard trimmings, waste paper and packaging that is treated in the municipal waste management system, we consider here only the organic fraction of the MSW, i.e., that fraction coming from the preparation and consumption of food.

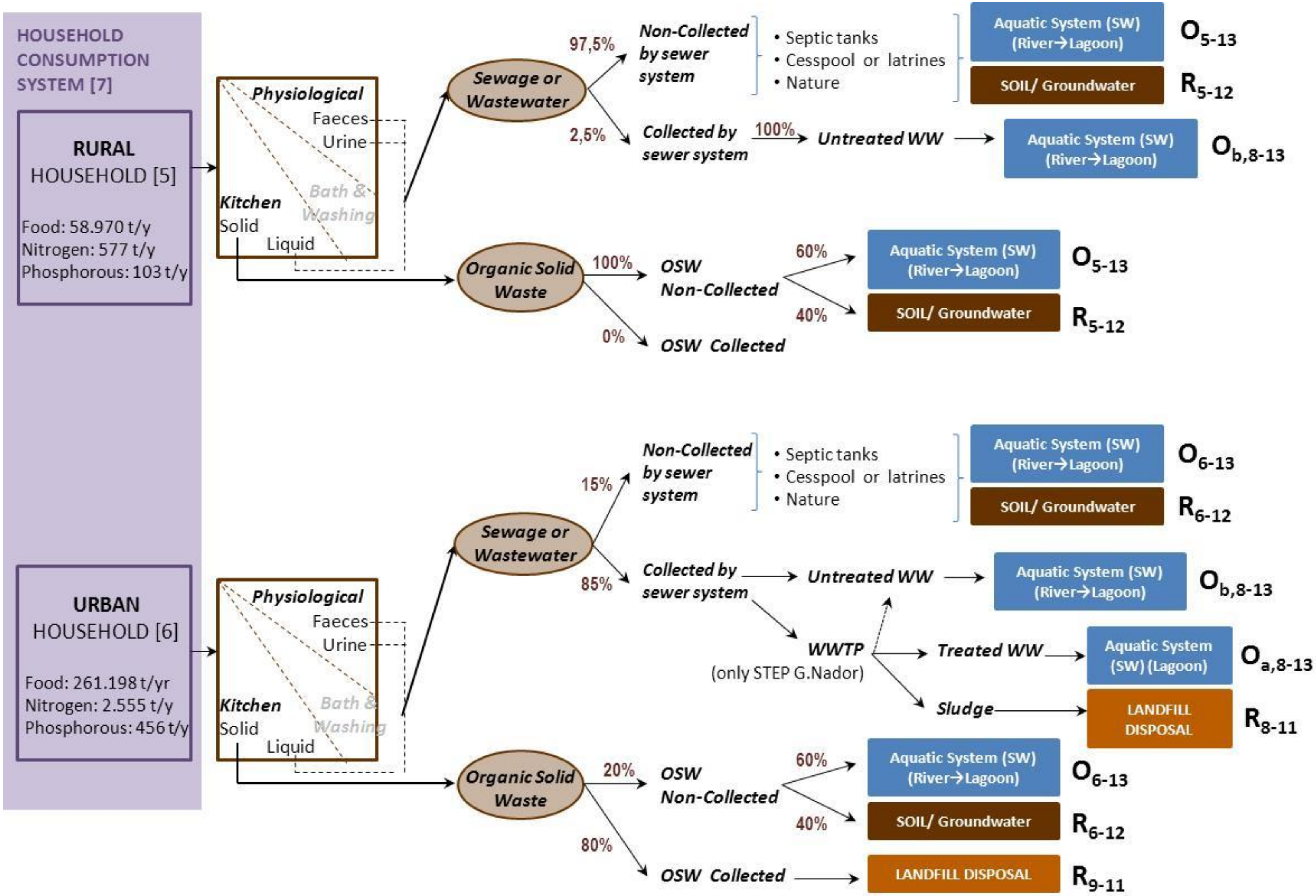


Figure 16.: Flow diagram representation of the Consumption and Waste management processes analysed. Source: Author's elaboration.

According to Faerge et al. (2001) waste food is generally of lower nutritional quality than in food. Thus, nutrient content in food was reduced in approximately 25 percent ($r_{N\&P\_minus}$, in percentage) to estimate nutrient content in food waste. After applying this reduction, and in order to determine the total amount of N and P that result in solid waste and in wastewater from food consumed/discarded, partitioning coefficients were applied:

$$a_{N\_Rur\_WW} = (\Sigma\ ((n_{consump\_food} * n_{pop\_rural} * r_{food\ exp\_rural} * C_{N\_food\ item} /100) * (1-r_{N\&P\_minus})))*(K_{N\_feces} + K_{N\_urine} + K_{N\_kitchen\ W})$$

$$a_{P\_Rur\_WW} = (\Sigma\ ((n_{consump\_food} * n_{pop\_rural} * r_{food\ exp\_rural} * C_{P\_food\ item} /100.000) * (1-r_{N\&P\_minus})))*(K_{P\_feces} + K_{P\_urine} + K_{P\_kitchen\ W})$$

$$a_{N\_Rur\_OSW} = (\Sigma((n_{consump\_food} * n_{pop\_rural} * r_{food\ exp\_rural} * C_{N\_food\ item} /100) * (1-r_{N\&P\_minus})))*(K_{N\_kitchen\_OSW})$$

$$a_{P\_Rur\_OSW} = (\Sigma((n_{consump\_food}*n_{pop\_rural}*r_{food\ exp\_rural}* C_{P\_food\ item}/100.000) * (1-r_{N\&P\_minus})))*(K_{P\_kitchen\_OSW})$$

$$a_{N\_Urb\_WW} = (\Sigma\ ((n_{consump\_food} * n_{pop\_urban} * r_{food\ exp\_urban} * C_{N\_food\ item} /100) * (1-r_{N\&P\_minus})))*(K_{N\_feces} + K_{N\_urine} + K_{N\_kitchen\ W})$$

$$a_{P\_Urb\_WW} = (\Sigma\ ((n_{consump\_food} * n_{pop\_urban} * r_{food\ exp\_urban} * C_{P\_food\ item} /100.000) * (1-r_{N\&P\_minus})))*(K_{P\_feces} + K_{P\_urine} + K_{P\_kitchen\ W})$$

$$a_{N\_Urb\_OSW} =(\Sigma((n_{consump\_food}*n_{pop\_urban} * r_{food\ exp\_urban} * C_{N\_food\ item} /100) * (1-r_{N\&P\_minus})))*(K_{N\_kitchen\_OSW})$$

$$a_{P\_Urb\_OSW} =(\Sigma((n_{consump\_food}*n_{pop\_urban}*r_{food\ exp\_urban}*C_{P\_food\ item} /100.000)*(1-r_{N\&P\_minus})))*(K_{P\_kitchen\_OSW})$$

Where $a_{N\_Rur\_WW}$, $a_{P\_Rur\_WW}$, $a_{N\_Urb\_WW}$, $a_{P\_Urb\_WW}$ refer to nutrients in wastewater/sewage from food consumed by rural and urban populations, respectively (in kg N year^{-1} and kg P year^{-1}), and, $a_{N\_Rur\_OSW}$, $a_{P\_Rur\_OSW}$, $a_{N\_Urb\_OSW}$, $a_{P\_Urb\_OSW}$ apply for nutrients in organic solid waste from food consumed by the rural and urban population of Gran Nador (in kg N year^{-1} and kg P year^{-1}). Besides, K_{N_feces}, K_{N_urine}, $K_{N\_kitchen\ W}$ and $K_{N\_kitchen\_OSW}$, as well as K_{P_feces}, K_{P_urine}, $K_{P\_kitchen\ W}$ and $K_{P\_kitchen\_OSW}$, relate to partitioning coefficients of nutrient (N and P) flows to wastewater and solid waste, namely the nutrient fraction of consumed food that is excreted either in the form of urine (K_{N_urine}; K_{P_urine}) or feces (K_{N_feces}; K_{P_feces}) by human body, the fraction of food that is flushed out during food cleaning and dish washing ($K_{N\_kitchen\ W}$; $K_{P\_kitchen\ W}$) and the fraction of food that ends as food refuse and leftovers ($K_{N\_kitchen\_OSW}$; $K_{P\_kitchen\_OSW}$), all fraction values are in percentage. The rest of the variables were already introduced in previous sections (see Appendix IV for parameters description).

SEWAGE-WASTEWATER sub-process [8]:

Nutrient (N and P) inputs considered included those from consumed food that leave the human body with excreta (including feces and urine), as well as, food refuse that is flushed out during food cleaning and dish washing ($R_{5\text{-}8}$ from rural, and $R_{6\text{-}8}$ from urban households) and that were collected through a sanitation system. Nutrient (N and P) outputs were comprised by sewage/wastewater collected and treated by the wastewater treatment plant of Nador (WWTP) ($O_{a,8\text{-}13}$), sewage/wastewater collected but not treated ($O_{b,8\text{-}13}$), and the sludge that results from the treatment process of the WWTP ($R_{8\text{-}11}$).

As already mentioned elsewhere, sludge was not recycled back to the agricultural production land, since no Moroccan law exists regulating the use of sludge as a safe organic fertilizer, and although informal and unrecognized practices do exist, we assumed no recovery of sludge and that it was all disposed of to the landfill ($R_{8\text{-}11}$).

Therefore, the balance equations for the indicator substances nitrogen (N) and phosphorus (P) in the sewage/wastewater sub-process were expressed as:

$dM^{(8)}{}_N/dt = R_{N,\,5\text{-}8}+R_{N,\,6\text{-}8}-O_{Na,\,8\text{-}13}-O_{Nb,\,8\text{-}13}-R_{N,\,8\text{-}11}$

$dM^{(8)}{}_P/dt = R_{P,\,5\text{-}8}+R_{P,\,6\text{-}8}-O_{Pa,\,8\text{-}13}-O_{Pb,\,8\text{-}13}-R_{P,\,8\text{-}11}$

In order to estimate $R_{5\text{-}8}$ and $R_{6\text{-}8}$ flows the variables a_{Urb_WW} and a_{Rur_WW} were multiplied by the corresponding urban and rural ratio of inhabitants connected to sewerage ($r_{\_Urb\_sewerage}$ and $r_{\_Rur\_sewerage}$, both in percentage):

$R_{N,\,5\text{-}8} = a_{N\_Rur\_WW} * r_{\_Rur\_sewerage}$

$R_{P,\,5\text{-}8} = a_{P\_Rur\_WW} * r_{\_Rur\_sewerage}$

$R_{N,\,6\text{-}8} = a_{N\_Urb\_WW} * r_{\_Urb\_sewerage}$

$R_{P,\,6\text{-}8} = a_{P\_Urb\_WW} * r_{\_Urb\_sewerage}$

With regard to outputs, the flows of N and P from the sewerage were divided into three parts: sewage that though collected did not undergo treatment ($O_{b,8\text{-}13}$), sewage collected and treated by the wastewater treatment plant of Nador (WWTP) ($O_{a,8\text{-}13}$), and the sludge that results from wastewater treatment ($R_{N,8\text{-}11}$).

Although other WWTP within the area of study exist, we could not find basic information on treatment typology, capacity, N and P removal efficiency, or data on water quality, among other needed data, hence, we only considered the recently commissioned WWTP of Grand Nador.

The wastewater generated by the urban population of Grand Nador was estimated, only urban wastewater was computed, since the large majority of inhabitants connected to the sewerage were residing in urban areas. The urban wastewater ($WW_{\_UrbPop}$; in m^3 $year^{-1}$) generated was then multiplied by the ratio of urban inhabitants connected to sewerage ($r_{\_Urb\_sewerage}$), resulting in the wastewater collected that enters the WWTP. N and P content in urban wastewater collected were estimated by water quality concentrations of N and P (C_{N_WWin} and C_{P_WWin}, respectively, both in mg l^{-1}) at the entrance of the WWTP. Therefore, following equations:

$$WW_{\_UrbPop} = (a_{WW\_Urb\&connect} * n_{UrbPop\_drinkNet}) + (a_{WW\_Urb\&Non\text{-}connect} * n_{UrbPop\_Non\text{-}drinkNet}) * (360/1000)$$

$$WW_{N\_UrbPop\_sewerage} = ((a_{WW\_Urb\&connect} * n_{UrbPop\_drinkNet}) + (a_{WW\_Urb\&Non\text{-}connect} * n_{UrbPop\_Non\text{-}drinkNet})) * (360/1000) * (r_{\_Urb\_sewerage}) * (C_{N\_WWin}) /1000$$

$$WW_{P\_UrbPop\_sewerage} = ((a_{WW\_Urb\&connect} * n_{UrbPop\_drinkNet}) + (a_{WW\_Urb\&Non\text{-}connect} * n_{UrbPop\_Non\text{-}drinkNet})) * (360/1000) * (r_{\_Urb\_sewerage}) * (C_{P\_WWin}) /1000$$

Where $a_{WW\_Urb\&connect}$, refer to the average production of daily wastewater by urban population connected to the drinking supply water network (in liters inhab^{-1} year^{-1}) and $a_{WW\_Urb\&Non\text{-}connect}$ to that produced by urban population non-connected to the drinking water network (in liters inhab^{-1} year^{-1}); $n_{UrbPop\_drinkNet}$ are the urban population connected to the drinking water network (in inhabitants) and $n_{UrbPop\_Non\text{-}drinkNet}$ are the urban population non-connected to the drinking water network (in inhabitants).

On the other hand, it was assumed that the operational capacity of the WWTP was 63 percent ($r_{\_OpCap}$) of its capacity ($WWTP_{\_cap}$, in m^3 day^{-1}), according to the average of treated and discharged flow of about 13,000m^3/d. It is known that treated wastewater from the WWTP is discharged directly into the lagoon of Nador (EEIRO, 2013).

The volume of treated wastewater by the WWTP ($WW_{\_WWTP;}$ in m^3 year^{-1}) proved to be lower than that received by the urban sanitation system ($WW_{UrbPop\_sewerage}$). Therefore, the difference between these two volumes provide us with an estimation of the wastewater that though collected by the WWTP, did not undergo treatment ($O_{b,8\text{-}13}$ WW untreated, partly). N and P content estimated in both volumes of wastewater, that of wastewater collected and received by the WWTP ($WW_{UrbPop\_sewerage}$), and that which effectively undergone treatment ($WW_{\_WWTP}$), were estimated by water quality concentrations of N and P at the exit of the WWTP (C_{N_WWout} and C_{P_WWout} ; respectively, both in mg l^{-1}).

$$WW_{\_WWTP} = (r_{\_OpCap} * WWTP_{\_cap})$$

$$O_{N\_a,\,8\text{-}13} = (r_{\_OpCap} * WWTP_{\_cap}) * (C_{N\_WWout}) /1000$$

$$O_{P\_a,\,8\text{-}13} = (r_{\_OpCap} * WWTP_{\_cap}) * (C_{P\_WWout}) /1000$$

The nutrient content in the sludge product ($R_{8\text{-}11}$) that results from the treatment process of the WWTP was computed from the difference in nutrient content in wastewater that undergone treatment. It was assumed that sludge was disposed of in the landfill. Therefore, following equations:

$R_{N,\,8\text{-}11}$ = (($r_{\_OpCap}$ * WWTP$_{\_cap}$) * (C_{N_WWin}) /1000) - (($r_{\_OpCap}$ * WWTP$_{\_cap}$) * (C_{N_WWout}) /1000)

$R_{P,\,8\text{-}11}$ = (($r_{\_OpCap}$ * WWTP$_{\_cap}$) * (C_{P_WWin}) /1000) - (($r_{\_OpCap}$ * WWTP$_{\_cap}$) * (C_{P_WWout}) /1000)

With regard to nutrient flows in sewage/wastewater collected but not treated ($O_{b,8\text{-}13}$) it was computed from the difference in nutrient content in wastewater collected by the sewer system ($R_{6\text{-}8}$ urban and $R_{5\text{-}8}$ rural) and the wastewater treated by the WWTP. It was assumed that wastewater collected from rural inhabitants connected to the sanitation system was not treated. Hence, following equation:

$O_{b,\,8\text{-}13} = R_{5\text{-}8} + R_{6\text{-}8} - O_{a,8\text{-}13}$

A small percentage of urban inhabitants and nearly all inhabitants in rural areas were not connected to the sewerage. In this case, other evacuation methods of wastewater were used. We consider, according to statistics (ENRNVM, 2011), that were discharged in septic tanks (r_{ST}, in percentage), cesspools or latrines ($r_{CessLat}$, in percentage) or directly into the environment (r_{Nat}, in percentage). The use of these releasing mechanisms were different for urban than for rural communities. Simultaneously, and for each evacuation mechanisms, an estimated coefficient of nutrients eventually deposited in soil and/or groundwater ($K_{ST\_Soil\&GW}$, $K_{CessLat\_Soil\&GW}$, $K_{Nat\_Soil\&GW}$) and surface waters (K_{ST_SurfW}, $K_{CessLat\_SurfW}$, K_{Nat_SurfW}) were also applied. Therefore, nutrient flow $O_{5\text{-}13}$ and $R_{5\text{-}12}$ for rural areas, and $O_{6\text{-}13}$ and $R_{6\text{-}12}$ for urban ones, coming from wastewater, were expressed as follows (see Fig.16):

$R_{N,5\text{-}12\_Rur\_WW} = \Sigma\ ((a_{N,\,Rur\_WW})*((r_{ST\_Rur}*K_{ST\_Soil\&GW})+(r_{CessLat\_Rur}*K_{CessLat\_Soil\&GW}) + (r_{Nat\_Rur}*K_{Nat\_Soil\&GW})))$

$R_{P,5\text{-}12\_Rur\_WW} = \Sigma\ ((a_{P,\,Rur\_WW})*((r_{ST\_Rur}*K_{ST\_Soil\&GW})+(r_{CessLat\_Rur}*K_{CessLat\_Soil\&GW}) + (r_{Nat\_Rur}*K_{Nat\_Soil\&GW})))$

$O_{N,5\text{-}13\_Rur\_WW} = \Sigma\ ((a_{N,\,Rur\_WW}) * ((r_{ST\_Rur}*K_{ST\_SurfW}) + (r_{CessLat\_Rur}*K_{CessLat\_SurfW}) + (r_{Nat\_Rur}*K_{Nat\_SurfW})))$

$O_{P,5\text{-}13\_Rur\_WW} = \Sigma\ ((a_{P,\,Rur\_WW}) * ((r_{ST\_Rur}*K_{ST\_SurfW}) + (r_{CessLat\_Rur}*K_{CessLat\_SurfW}) + (r_{Nat\_Rur}*K_{Nat\_SurfW})))$

$R_{N,6\text{-}12\_Urb\_WW} = \Sigma\ ((a_{N,\,Urb\_WW})*((r_{ST\_Urb}*K_{ST\_Soil\&GW})+(r_{CessLat\_Urb}*K_{CessLat\_Soil\&GW}) + (r_{Nat\_Urb}*K_{Nat\_Soil\&GW})))$

$R_{P,6\text{-}12\_Urb\_WW} = \Sigma\ ((a_{P,\,Urb\_WW})*((r_{ST\_Urb}*K_{ST\_Soil\&GW})+(r_{CessLat\_Urb}*K_{CessLat\_Soil\&GW}) + (r_{Nat\_Urb}*K_{Nat\_Soil\&GW})))$

$O_{N,6\text{-}13\_Urb\_WW} = \Sigma\ ((a_{N,\,Urb\_WW})*((r_{ST\_Urb}*K_{ST\_SurfW})+(r_{CessLat\_Urb}*K_{CessLat\_\,SurfW}) + (r_{Nat\_Urb}*K_{Nat\_\,SurfW})))$

$O_{P,6\text{-}13\_Urb\_WW} = \Sigma\ ((a_{P,\,Urb\_WW})*((r_{ST\_Urb}*K_{ST\_\,SurfW})+(r_{CessLat\_Urb}*K_{CessLat\_\,SurfW}) + (r_{Nat\_Urb}*K_{Nat\_\,SurfW})))$

ORGANIC MUNICIPAL SOLID WASTE sub-process [9]:

The domestic and industrial sectors are the greatest producers of waste in the Nador province. Waste production is increasing at the speed of the province socio-economic development and population growth. The management of solid waste has become a serious problem, since a large fraction of uncollected waste is discarded into the streams or on their sides waiting for torrential rainfalls that would carry them away into the Marchica Lagoon and the Mediterranean Sea (CAP Nador, 2008).

As already mentioned, at least in 2010, recycling in the SA was rather limited. No sorting of valuable materials was done at household level, nor at the region level by the solid waste management system. Though waste recycling activity existed, it was always under an informal sector (Runge et al., 2011; Metaich, 2013). Therefore, we only accounted for organic solid waste (OSW). According to Runge et al. (2011) and Metaich (2013) the OSW was directly transported and discharged into landfills with collection trucks. At urban municipalities garbage collection is quite effective with an average collection rate of 80 percent. It is primarily in rural areas where an organized collection of waste does not really exist, hence resulting in the creation of many small uncontrolled dump sites (Runge et al., 2011).

Nutrient (N and P) inputs considered include those from food refuse from inedible parts and food leftovers, i.e. organic solid waste that was collected by the waste management system ($R_{5\text{-}9}$ from rural and $R_{6\text{-}9}$ from urban households). Nutrient (N and P) outputs were comprised by organic solid waste collected and disposed of in the uncontrolled landfill of Nador ($R_{9\text{-}11}$).

The balance equations for N and P in the organic solid waste (OSW) sub-process were formulated as follows,

$dM^{(9)}{}_{N}/dt = R_{N,\,5\text{-}9}+R_{N,\,6\text{-}9}-R_{N,9\text{-}11}$

$dM^{(9)}{}_{P}/dt = R_{P,\,5\text{-}9}+R_{P,\,6\text{-}9}-R_{P,9\text{-}11}$

As already mentioned, in rural areas an organized collection system of waste did not really exist, thus, we assumed that OSW generated by rural populations was not collected ($R_{N,5\text{-}9}$= 0). However, in order to estimate the final fate of nutrients (i.e, either in soil/GW- $R_{5\text{-}12}$ - or the aquatic system - $O_{5\text{-}13}$) in non-collected OSW (mainly from rural areas), we assumed and applied the same coefficients as those used and applied in non-collected sewage/wastewater and discharged directly into nature. Therefore, following equations:

$R_{N,\,5\text{-}12\_Rur\_OSW} = (a_{N,\,Rur\_OSW})*(K_{Nat\_Soil\&GW})$

$R_{P,\,5\text{-}12\_Rur\_OSW} = (a_{P,\,Rur\_OSW})*(K_{Nat\_Soil\&GW})$

$O_{N,\,5\text{-}13\_Rur\_OSW} = (a_{N,\,Rur\_OSW})*(K_{Nat\_\,SurfW})$

$O_{P,\,5\text{-}13\_Rur\_OSW} = (a_{P,\,Rur\_OSW})*(K_{Nat\_\,SurfW})$

As mentioned, according to Runge et al. (2011) at urban municipalities garbage collection was quite effective with an average collection rate of 80 percent ($r_{\_Urb\_OSW\_collect}$). Therefore, nutrient (N and P) flows of $R_{6\text{-}9}$ were estimated according to:

$R_{N,\,6\text{-}9} = (a_{N\_Urb\_OSW})*(r_{\_Urb\_OSW\_collect})$

$R_{P,\,6\text{-}9} = (a_{P\_Urb\_OSW})*(r_{\_Urb\_OSW\_collect})$

Since, according to Runge et al. (2011) and Metaich (2013) the organic municipal solid waste was directly transported and discharge into the landfill of Nador, $R_{6\text{-}9}$ was equal to $R_{9\text{-}11}$.

With reference to the amount of organic municipal solid waste that was not collected, and in order to estimate the final fate of these nutrients (i.e., at soil/GW $R_{6\text{-}12}$ and to the aquatic system $O_{6\text{-}13}$), the same was applied as in the case of non-collected OSW for rural areas, thus:

$$R_{N,\,6\text{-}12\_Urb\_OSW} = ((a_{N,\,Urb\_OSW})*(1-r_{\_Urb\_OSW\_collect})*(K_{Nat\_Soil\&GW}))$$

$$R_{P,\,6\text{-}12\_Urb\_OSW} = ((a_{P,\,Urb\_OSW})*(1-r_{\_Urb\_OSW\_collect})*(K_{Nat\_Soil\&GW}))$$

$$O_{N,\,6\text{-}13\_Urb\_OSW} = ((a_{N,\,Urb\_OSW})*(1-r_{\_Urb\_OSW\_collect})*(K_{Nat\_\,SurfW}))$$

$$O_{P,\,6\text{-}13\_Urb\_OSW} = ((a_{P,\,Urb\_OSW})*(1-r_{\_Urb\_OSW\_collect})*(K_{Nat\_\,SurfW}))$$

Finally, nutrient (N and P) flows regarding either non-collected organic solid waste or wastewater/sewage that ended up in soil/groundwater or surface waters, and were generated by both rural and urban populations from food waste (i.e., $R_{5\text{-}12}$ and $O_{5\text{-}13}$; and $R_{6\text{-}12}$ and $O_{6\text{-}13}$; respectively) were finally expressed as:

$$R_{N,\,5\text{-}12} = (R_{N,\,5\text{-}12\_Rur\_OSW} + R_{N,\,5\text{-}12\_Rur\_WW})$$

$$R_{P,\,5\text{-}12} = (R_{P,\,5\text{-}12\_Rur\_OSW} + R_{P,\,5\text{-}12\_Rur\_WW})$$

$$O_{N,\,5\text{-}13} = (O_{N,\,5\text{-}13\_Rur\_OSW} + O_{N,\,5\text{-}13\_Rur\_WW})$$

$$O_{P,\,5\text{-}13} = (O_{P,\,5\text{-}13\_Rur\_OSW} + O_{P,\,5\text{-}13\_Rur\_WW})$$

$$R_{N,\,6\text{-}12} = (R_{N,\,6\text{-}12\_Urb\_OSW} + R_{N,\,6\text{-}12\_Urb\_WW})$$

$$R_{P,\,6\text{-}12} = (R_{P,\,6\text{-}12\_Urb\_OSW} + R_{P,\,6\text{-}12\_Urb\_WW})$$

$$O_{N,\,6\text{-}13} = (O_{N,\,6\text{-}13\_Urb\_OSW} + O_{N,\,6\text{-}13\_Urb\_WW})$$

$$O_{P,\,6\text{-}13} = (O_{P,\,6\text{-}13\_Urb\_OSW} + O_{P,\,6\text{-}13\_Urb\_WW})$$

Uncertainty analysis

The importance of assessing uncertainty aspects in material/substance flow studies to evaluate the reliability of material flow results has been increasingly raised by several authors (Brunner and Rechberger, 2004; Danius and Burström, 2001; Hedbrandt and Sörme, 2001; Laner et al., 2014; Montangero, 2006; Montangero et al., 2007; Wu et al., 2014).

As a result of data limitations, material flow studies mostly rely on data from different nature of sources and of varying quality as input for modelling. Namely, data used may be based on single measurements only, rescaled, extracted from another region, process, year or systems and transformed to apply to the investigated system, or even quantified using expert judgment, interviews or assumed using educated guesses and plausible reasoning (Brunner and Rechberger, 2004; Danius and Burström, 2001; Hedbrant & Sörme, 2001; Laner et al., 2014). Furthermore, as Danius and Burström (2002) stress, a basic obstacle is that the uncertainties of input data are very often unknown. Actually, secondary data and rescaled statistics with non-reported information on error distribution is a common practice (Danius and Burström, 2002). Therefore, since the majority of input data contain an inherent uncertainty, arising from different sources, results are inherently uncertain as well (Danius and Burström, 2002), hence the need to deal with data uncertainties when performing and interpreting M/SFA studies (Wu et al., 2014).

Danius and Burström (2002) and Laner et al. (2014) both review and evaluate the practice of uncertainty analysis, namely how data uncertainties are treated on the existent literature, and the major approaches and methods used for dealing with uncertainty in M/SFA studies. The authors acknowledge that uncertainties in M/SFA studies are not always considered in a systematic way, and that studies that either rarely include estimates of uncertainties in data, or consider uncertainty through a qualitative approach predominate. Therefore, Laner et al. (2014) suggest to appropriately consider uncertainty by systematically applying approaches that range from simple confidence ratings to sophisticated statistical analyses. Yet, because of the difficulty to estimate data uncertainty in M/SFA studies, data cross-checking is not only regarded as a suitable approach to facilitate the specification of uncertainty ranges (Laner et al., 2014), but also as a useful technique to compare the results with that of similar studies or with other sources of data to investigate if the results are reasonable (Brunner et al., 1994; Hekkert et al., 2000; Lassen and Hansen, 2000, in Danius, 2002).

To investigate data uncertainty in our study, we used a method developed by Hedbrant and Sörme (2001) (HS) based on uncertainty intervals. The HS model aims at determining the (unknown) uncertainty for all input data and for calculation of the uncertainty for the results or the output data (Antikainen, 2005; Danius, 2002; Danius and Burström, 2002; Hedbrant and Sörme, 2001; Laner et al., 2014; Wu et al., 2014).

The HS method is appropriate to be used in substance flow analyses, in which the use of societal data, that occasionally exist as only one sample (Antikainen et al., 2005; Hedbrant and Sörme, 2001), usually rules out the analysis of uncertainty by traditional statistical methods, i.e. too few data makes the decision of the statistical distribution impossible, and requires caution at the interpretation of result (Hedbrant and Sörme, 2001). Thus, the HS method is applicative when data is limited and the calculation formula is simple (Wu et al., 2014).

In the HS method, first, the level of uncertainty is determined for every single input data on the basis of its source (e.g., recognized authorities vs. informal estimate) and specificity (e.g., data related to the specific region vs. data on a general level) or the context from which the data were compiled (Brunner and Rechberger, 2004). To each predefined uncertainty level an uncertainty factor is allocated to compute the respective uncertainty interval. The intervals, defined as asymmetric, are obtained by dividing (lower limit) and multiplying (upper limit) the input data with the corresponding uncertainty factor. The probability that the interval comprise the actual value is 95 percent. By using asymmetrical intervals, lower limits keep positive (Danius and Burström, 2001; 2002; Hedbrant and Sörme, 2001; Laner et al., 2014).

Secondly, the uncertainty of the results is calculated, by combining the uncertainty connected to input data with specific equations to compute the uncertainty intervals for the result (see Hedbrant and Sörme, 2001, for the specific equations).

Although, as Laner et al. (2014) argue, subjective elements (e.g., the allocation of data sources to particular uncertainty levels or the selection of the uncertainty factor) remain with the analyst, the approach of Hedbrant and Sörme (2001) enables a transparent categorization of uncertainty ranges for data from different sources.

In our study, parameter values were determined by reviewing official national/regional and local statistical data, grey literature, scientific publications -case study and general literature-based values, e.g. nutrient content in food-, and databases. Besides, it has often been the case that the only available data were single values from measurements, interviews, or historical sources. Therefore, most of the estimations, supporting the present exercise, clearly contain some uncertainties associated with the calculated data. Although data for balancing each single process were collected independently for each individual process, in trying to significantly improve the accuracy of the total calculations, several factors, including variation in nutrient concentrations, and possible inaccuracies of statistics (estimates on, for instance, human consumption and waste production are based on official statistics) could affect results. A more accurate analysis on nutrient food-related flows studied would have been achieved with more detailed data instead of a desktop investigation and the adoption of assumptions and estimations, yet access to in-situ specific data was difficult to reach, sometimes not available and most of the time non-accessible. Furthermore, data at municipal level was not always collected and systematized. Thus, due to limited data, the N and P flow descriptions were most probably not entirely correct or complete. Nevertheless, several reference sources and comparisons were used in an attempt to minimize the uncertainties. In other cases, as it happens with the FAOSTAT online food supply database, we assumed the reliability of this database, though it is clear that eventual biases in FAOSTAT would be directly reflected in our calculations. Therefore, we considered appropriate to develop an assessment of data uncertainty.

As mentioned, we applied the HS method to investigate data uncertainty in our study. The HS method has also been used in other SFA studies as in Antikainen et al. (2005), Asmala and Saikku (2010), Danius and Burström (2001), Erni (2007), Montangero (2006), and Neset et al. (2005).

We followed and proceed according to the approach of Hedbrant and Sörme (2001). However, uncertainty intervals were slightly modified compared to the five used by Hedbrandt and Sörme (2001), to suit data concerning our study. Nine different uncertainty intervals were established for our data, and the uncertainty levels were re-classified in accordance for the purposes of our study (see table 4). The uncertainty factors were determined on the basis of data input source, specificity and context from which the data were acquired, as well as, whenever found, literature information about the uncertainty of the data collected. The uncertainty range for the flows was calculated by dividing and multiplying the average flow with the uncertainty factor as explained by Hedbrant and Sörme (2001).

It should be noted that the quantification of N flows tends to be more uncertain than the quantification of P flows, because of Nitrogen's tendency to escape to air and its high mobility. That is, reactive N is easily transformed among reduced and oxidized forms in many systems, thus being easily distributed by hydrologic and atmospheric transport processes (biogeochemcal circulation pathways of N). Therefore, complicating nitrogen flows estimations.

Table 4.: Definition of uncertainty level/intervals adapted to the present study.

Level	Source of information	Example
1 (interval */ 1)	Official statistics on national level Information from facilities	Population WWTP treatment capacity
2 (interval */ 1,05)	Official statistics on national/regional and local level Information from facilities/authorities	Population; N and P content in feed; N and P content in products (meat, milk, fish) Fisheries production capacity
3 (interval */ 1,1)	Official statistics on national/regional and local level Information from international institutions Information from facilities/authorities Computed data Values from literature	Area of agricultural production land; amount of animal, crop, produced milk; ratio of sanitation used systems Fertilization Fisheries production capacity Manure N and P contents in products (e.g. vegetables, cereals, etc.)
4 (interval */ 1,2)	Information from facilities/authorities Values from literature	Amount of N and P in treated wastewaters Average feed requirement per livestock; animal average weight
5 (interval */ 1,33)	Modelled data Values from literature	Amount of N and P in wastewaters Nutrient deposition coefficients
6 (interval */ 2)	Values from literature	Atmospheric N deposition; N_2O emission factors
7 (interval */ 3)	Values from literature	N_2O emission factors
8 (interval */ 5)	Values from literature	N_2O emission factors
9 (interval */ 7)	Values from literature	N_2O emission factors

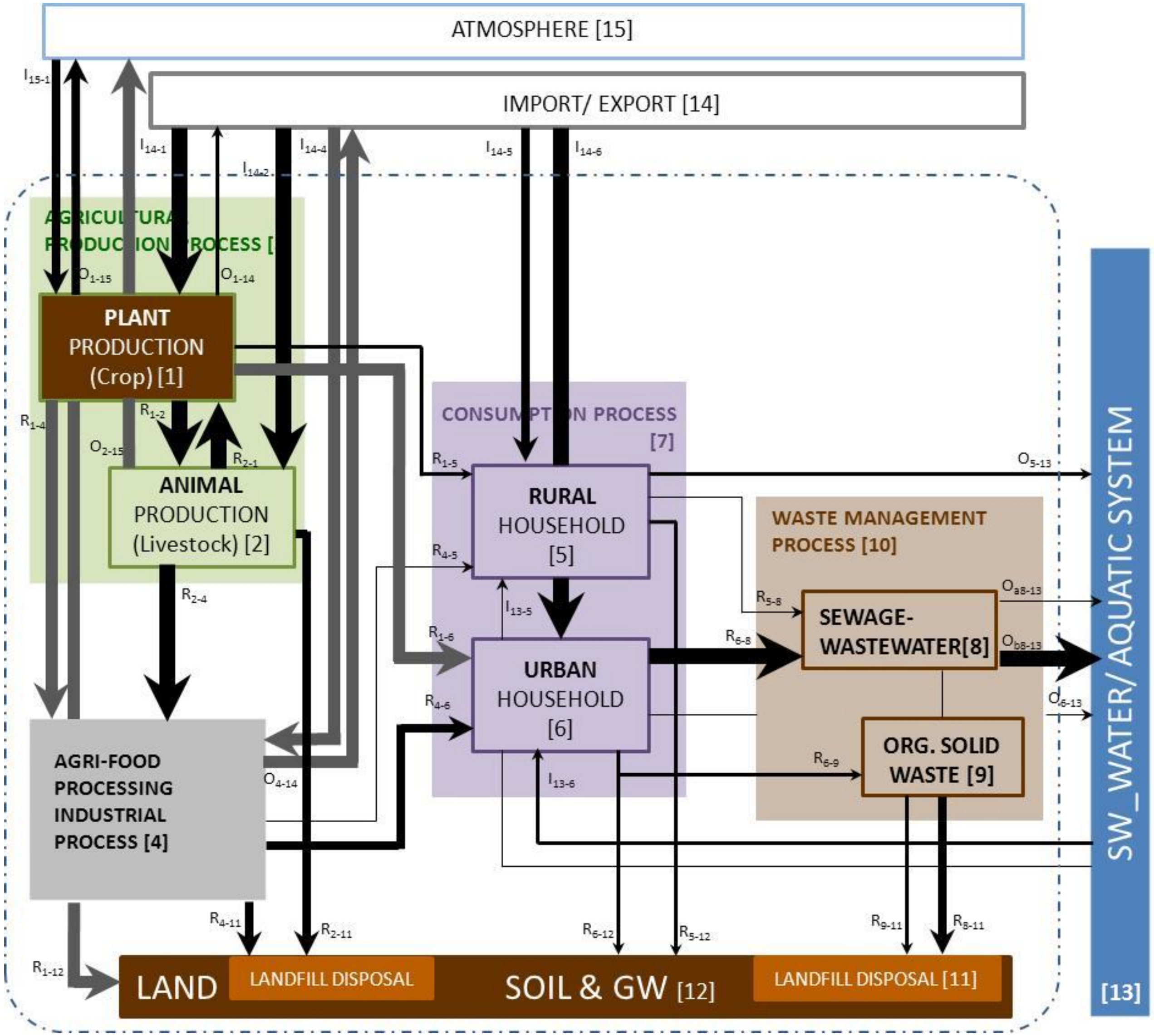
Source: Author's elaboration (based on Antikainen et al. (2005), Danius (2002), Hedbrant and Sörme (2001) and Montangero (2006)).

Results

Figures 17, 18 and 19 show the analytical results of the food-related flows of nitrogen and phosphorus of the urban agglomeration of Grand Nador in 2010.

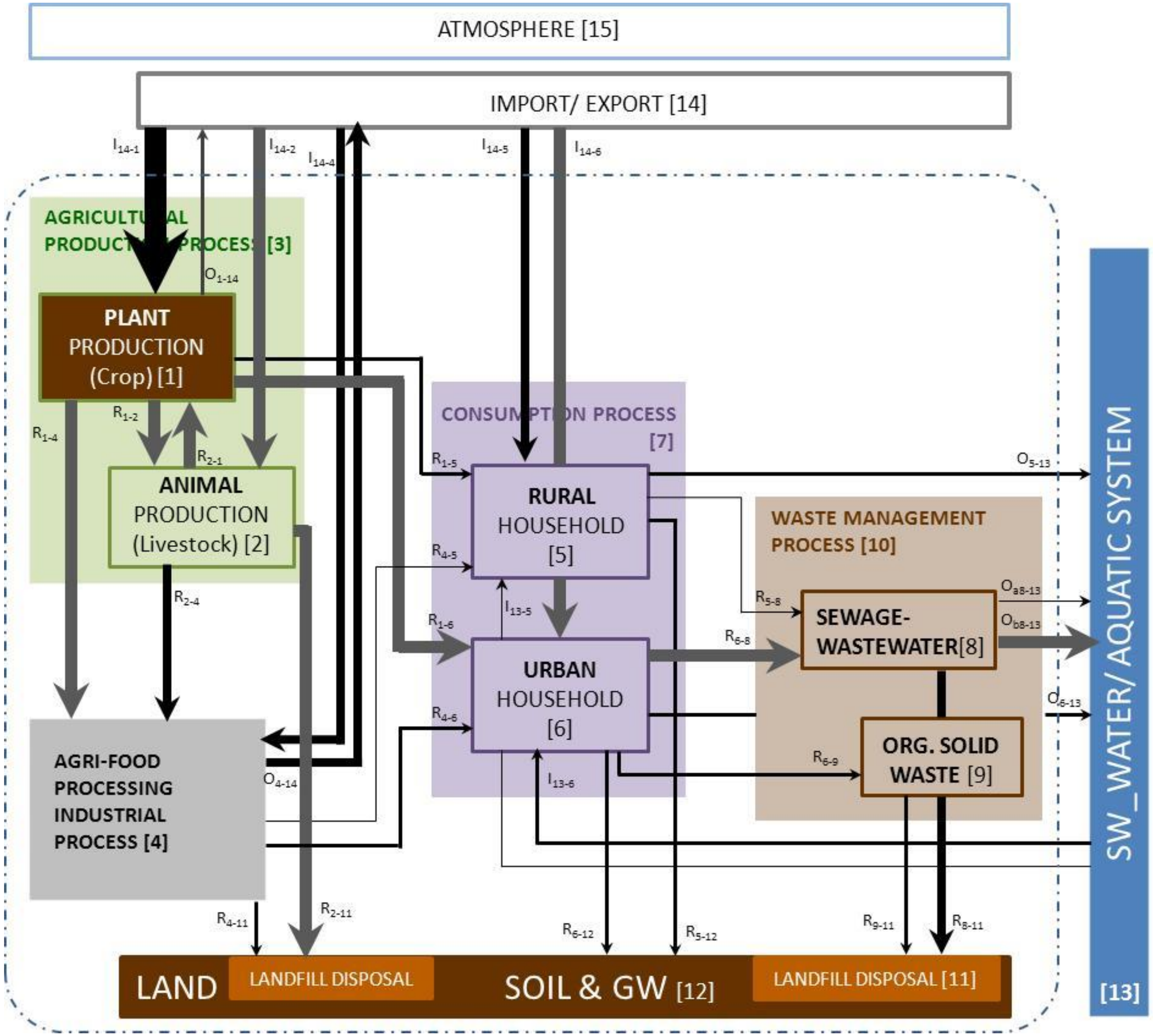
The total N and P imports of the GN urban area were 6,565t and 2,418t respectively. Up to 2,785t N and 1,666t P (42.4 percent and 69 percent of the total N and P imports, correspondingly) were imported in the form of fertilizers. The N and P content of imported feedstuff accounted for 19 and 14.4 percent respectively, and food products to domestic urban household consumption also amounted for a relative large proportion with about 22 and 11 percent respectively of the total imported N and P. Unlike imports, the total N and P exports were only about 860t and 62t correspondingly, being the agro-food industrial products the major export contributor (760t N, 88.4 percent ; 50t P, 80.6 percent), followed by locally produced crop products.

In 2010, the system discharged 1,354t N and 207t P into local surface water (primarily to the Caballo and Selouane rivers that drain into the Nador lagoon) from domestic waste processes. About 1,085t N and 419t P from industrial agro-food and household organic solid waste, poultry manure and sludge were disposed of to the landfill. Additionally, 1,008t N and 53t P from agricultural N leaching/runoff and household rural and urban non-collected OSW and WW/sewage were transferred to the soil and groundwater. Finally, total nitrogen emissions to air were estimated to be 917t N, of which 315t accounted from fertilizers and 602t N from manure.



$I_{N,14-1}$:	2.785 t.
$R_{N,1-2}$:	1.774 t.
$R_{N,2-1}$:	1.685 t.
$I_{N,14-6}$:	1.438 t.
$R_{N,6-8}$:	1.424 t.
$I_{N,14-2}$:	1.247 t.
$R_{N,2-4}$:	1.115 t.
$O_{N,b8-13}$:	1.102 t.
$I_{N,14-4}$:	770 t.
$O_{N,4-14}$:	760 t.
$R_{N,1-4}$:	741 t.
$R_{N,1-12}$:	716 t.
$R_{N,1-6}$:	685 t.
$O_{N,2-15}$:	602 t.
$I_{N,15-1}$:	397 t.
$R_{N,4-6}$:	395 t.
$R_{N,2-11}$:	346 t.
$I_{N,14-5}$:	324 t.
$O_{N,1-15}$:	315 t.
$R_{N,8-11}$:	284 t.
$R_{N,4-11}$:	278 t.
$R_{N,9-11}$:	175 t.
$R_{N,6-9}$:	175 t.
$R_{N,5-12}$:	164 t.
$R_{N,1-5}$:	155 t.
$O_{N,5-13}$:	133 t.
$R_{N,6-12}$:	129 t.
$I_{N,13-6}$:	122 t.
$O_{N,1-14}$:	101 t.
$R_{N,4-5}$:	89 t.
$O_{N,6-13}$:	71 t.
$O_{N,a8-13}$:	47 t.
$I_{N,13-5}$:	27 t.
$R_{N,5-8}$:	9 t.

Figure 17.: NITROGEN flow diagram of the Urban food metabolism of Grand Nador in 2010. Source: Author’s elaboration.



$I_{P,14-1}$:	1.666 t.
$I_{P,14-2}$:	347 t.
$R_{P,2-11}$:	284 t.
$I_{P,14-6}$:	266 t.
$R_{P,6-8}$:	258 t.
$R_{P,2-1}$:	194t.
$O_{P,b8-13}$:	165 t.
$R_{P,1-6}$:	141 t.
$R_{P,1-2}$:	135 t.
$R_{P,1-4}$:	129 t.
$R_{P,8-11}$:	90 t.
$I_{P,14-4}$:	78 t.
$R_{P,2-4}$:	76 t.
$I_{P,14-5}$:	60 t.
$O_{P,4-14}$:	50 t.
$R_{P,4-6}$:	34 t.
$R_{P,1-5}$:	32 t.
$R_{P,6-9}$:	30 t.
$R_{P,9-11}$:	30 t.
$R_{P,5-12}$:	29 t.
$O_{P,5-13}$:	24 t.
$R_{P,6-12}$:	23 t.
$R_{P,4-11}$:	15 t.
$O_{P,6-13}$:	13 t.
$O_{P,1-14}$:	11 t.
$I_{P,13-6}$:	10 t.
$R_{P,4-5}$:	8 t.
$O_{P,a8-13}$:	5 t.
$I_{P,13-5}$:	2 t.
$R_{P,5-8}$:	2 t.

Figure 18.: PHOSPHORUS flow diagram of the Urban food metabolism of Grand Nador in 2010. Source: Author's elaboration.

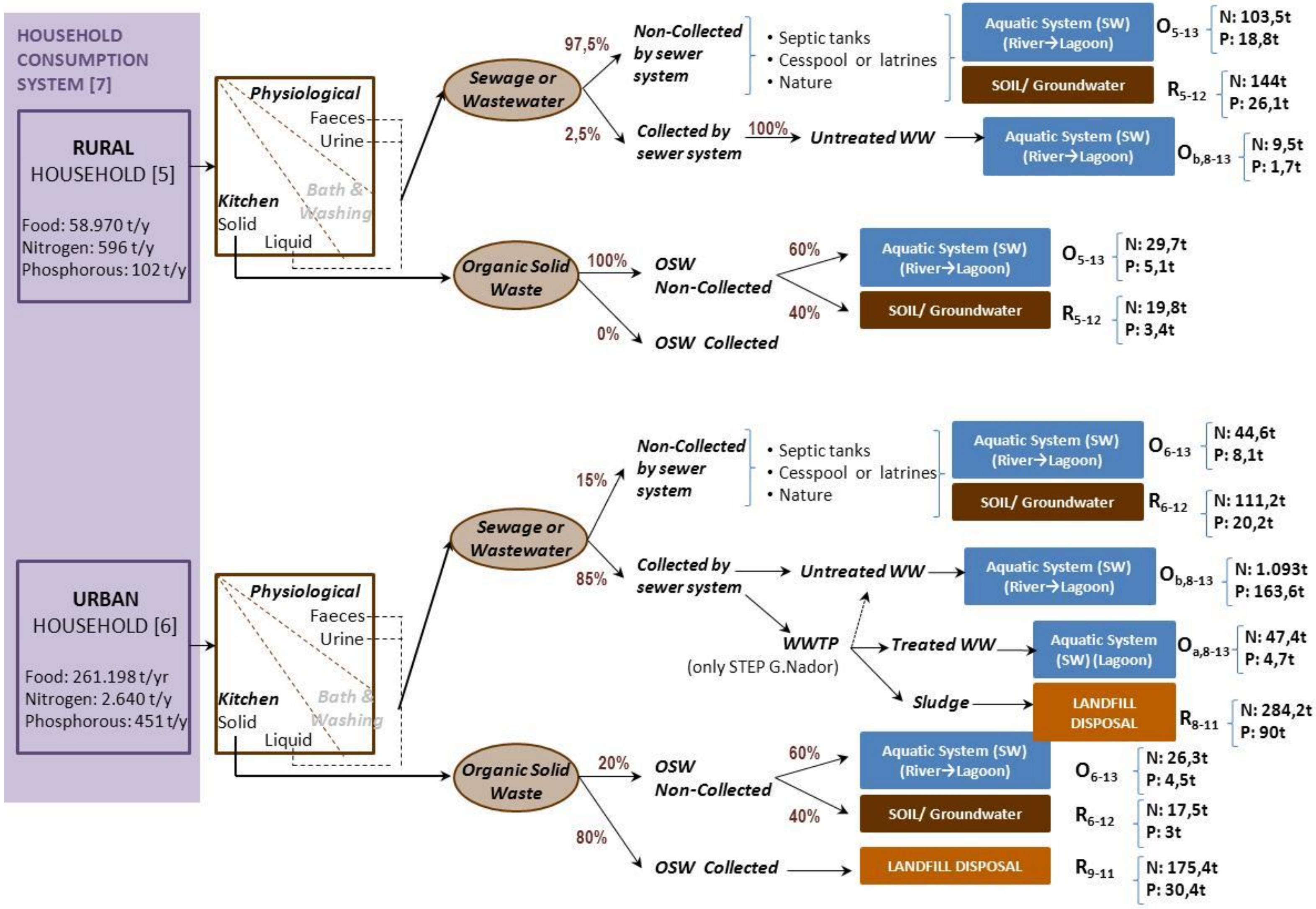
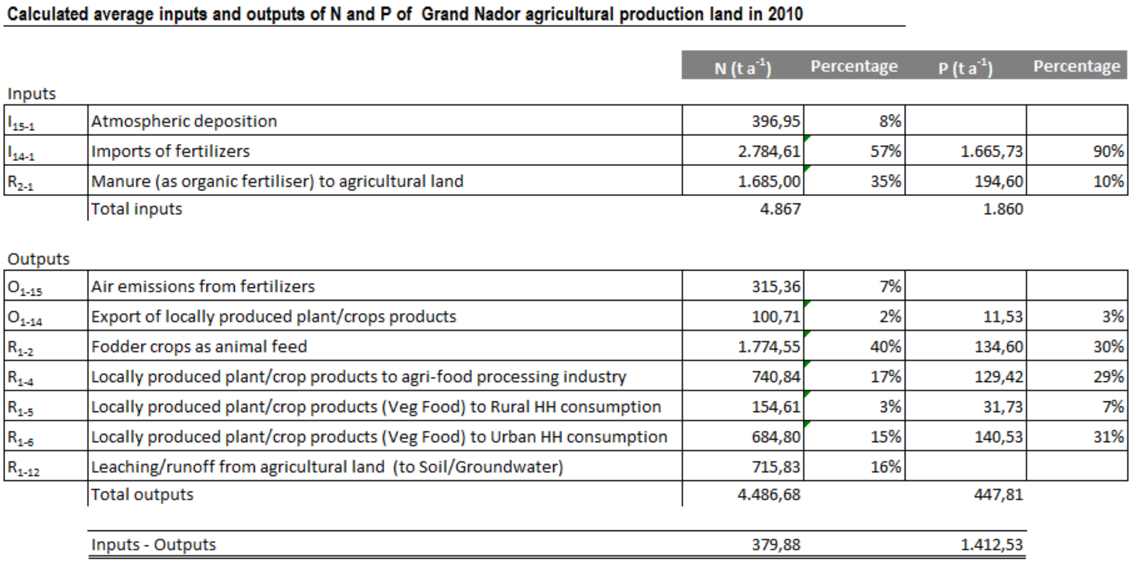


Figure 19.: Nitrogen and Phosphorus Waste Management Sub-process flow diagram of the Urban food metabolism of Grand Nador in 2010. Source: Author's elaboration.

Figs. 17 and 18 show the N and P food-related flows for each sub-process in 2010. According to our calculations, total inputs to the crop production sub-process were estimated to be 4,867t N and 1,860t P, whereas total outputs were approximately 4,487t N and 448t P (see table 5). Fertilizers made up the largest component, 57 percent of N and 90 percent of P inputs to the agricultural production land, followed by manure with 35 percent and 10 percent of N and P inputs respectively. Atmospheric deposition represented 8 percent of N inputs, P deposition was assumed to be negligible because of the low reactivity of P, and since the P content of the atmosphere remains low (Li et al., 2010). Harvest, comprised of $O_{1\text{-}14}$, $R_{1\text{-}2}$, $R_{1\text{-}4}$, $R_{1\text{-}5}$ and $R_{1\text{-}6}$ flows, caused the major nutrient outflow from the agricultural production land (3,455t N and 448t P), of which fodder crops used directly as animal feed ($R_{1\text{-}2}$) represented the largest share containing about 51 percent and 30 percent of the total N and P in the harvest, respectively. Other smaller outputs derived from leaching/runoff and air emissions from fertilizers, representing 16 and 7 percent of total N outputs from the agricultural production land (see table 5).

The local production of crops was intended to supply the agro-industrial factory of SUCRAFOR (39.6 percent of total yield corresponding to 287,594t of industrial beet crops were assumed to be 100 percent supplied to the factory providing for 80 percent of its production capacity), to feed livestock breeding (37.3 percent, equivalent to 270,550t of alfalfa fodder crops), and to human consumption (23.1 percent; 167,422 t), of which 57,761t were exported. Therefore, locally produced crops intended for domestic consumption only met around 40 percent of urban and rural food needs (corresponding to 109,661t), implying that imports of crop product amounted to 163,883t.

Table 5.: Calculated average inputs and outputs of N and P of Grand Nador agricultural production land in 2010.



Calculated average inputs and outputs of N and P of Grand Nador agricultural production land in 2010

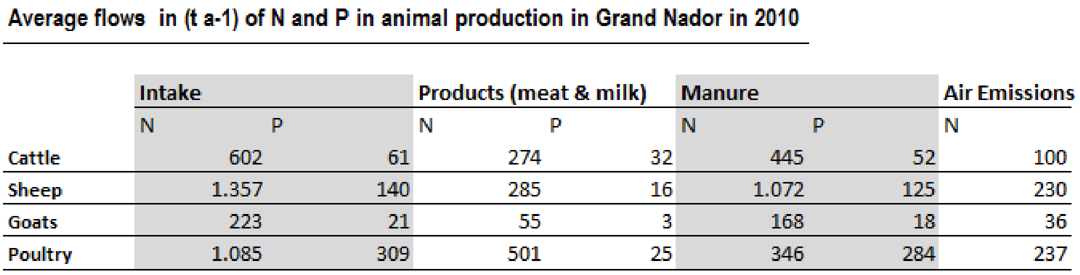
		N (t a^{-1})	Percentage	P (t a^{-1})	Percentage
Inputs					
$I_{15\text{-}1}$	Atmospheric deposition	396,95	8%		
$I_{14\text{-}1}$	Imports of fertilizers	2.784,61	57%	1.665,73	90%
$R_{2\text{-}1}$	Manure (as organic fertiliser) to agricultural land	1.685,00	35%	194,60	10%
	Total inputs	4.867		1.860	
Outputs					
$O_{1\text{-}15}$	Air emissions from fertilizers	315,36	7%		
$O_{1\text{-}14}$	Export of locally produced plant/crops products	100,71	2%	11,53	3%
$R_{1\text{-}2}$	Fodder crops as animal feed	1.774,55	40%	134,60	30%
$R_{1\text{-}4}$	Locally produced plant/crop products to agri-food processing industry	740,84	17%	129,42	29%
$R_{1\text{-}5}$	Locally produced plant/crop products (Veg Food) to Rural HH consumption	154,61	3%	31,73	7%
$R_{1\text{-}6}$	Locally produced plant/crop products (Veg Food) to Urban HH consumption	684,80	15%	140,53	31%
$R_{1\text{-}12}$	Leaching/runoff from agricultural land (to Soil/Groundwater)	715,83	16%		
	Total outputs	4.486,68		447,81	
	Inputs - Outputs	379,88		1.412,53	

Source: Author’s elaboration.

Main input sources of N and P in animal production sub-process consisted of locally produced fodder crops (1,774t N; 135t P), together with imports of feedstuff (1,247t N; 347t P). Fodder crops (37.3 percent of total harvest) were the prime source of nutrients for ruminant breeding, followed by nutrients from grazing pastures (246t N; 56t P). Conversely, industrially produced broilers were totally fed by feedstuff imports. Livestock manure and animal products formed the majority of nutrient outputs. In accordance with the prevailing feeding system of the SA, manure from ruminants was assumed to be reapplied to agricultural land (1,685t N; 195t P), whereas poultry manure was disposed of to the landfill (346t N; 284t P). Animal products, such as meat and milk, accounted for a considerable amount of nutrients (1,115t N; 76t P). Other output derived from manure emissions to the atmosphere comprised 602t of N.

Sheep breeding and broiler industrial farming were the predominant animal productions in the SA. Hence, both animal categories presented the major intake of nutrients, excretion of nutrients in manure, and both caused the largest manure emissions to air, yet broilers and cattle supplied the largest share of nutrients in animal products (meat and milk) (see Tab.6).

Table 6.: Average flows in tonnes year^{-1} of nitrogen and phosphorus in livestock production in Grand Nador in 2010.



Average flows in (t a-1) of N and P in animal production in Grand Nador in 2010

	Intake		Products (meat & milk)		Manure		Air Emissions
	N	P	N	P	N	P	N
Cattle	602	61	274	32	445	52	100
Sheep	1.357	140	285	16	1.072	125	230
Goats	223	21	55	3	168	18	36
Poultry	1.085	309	501	25	346	284	237

Source: Author's elaboration.

Actually, locally produced meat and milk covered domestic household food needs on an 84 percent. Besides, half of the locally produced meat was exported.

The different annual input sources and proportions of N and P in the agro-food processing industry totaled 2,625t N and 284t P, and were derived from agriculture (to the Sucrafor factory) and livestock production, and imports, which accordingly accounted for 28.2, 42.5 and 29.3 percent of N, and 45.6, 26.8 and 27.6 percent of P. Quite noticeable is that 100 percent of fish catches supplying the increasing fish processing industry of the area were coming from either other regions of Morocco or from Europe. On the other hand, annual outputs of N and P were derived from export of processed foods (760t N and 60t P), followed by the agro-food processed products to household urban consumption (395t N and 34t P) and the generated industrial organic solid waste to landfill (279t N and 15t P).

Approximately, 3,236t of N and 553 t of P flowed annually to domestic food consumption from agriculture, agro-food industry, fishing and imports, of which 596t N and 102t P to domestic rural households and 2,640t N and 451t P to domestic urban residents. Imported food products (1,438t N; 266t P) were the largest input of the urban household consumption sub-process as for the whole consumption process, followed by local crop products (685t N; 140t N). Wastewater/sewage from urban households collected by sewer system (1,424t N, 258t P) was the greatest N and P outflow of urban household consumption sub-process, as well as of the entire consumption process. In terms of food self-sufficiency, is worth noting that whereas local crop products only covered 40 percent of vegetables food needs of the local population, local production of meat and milk, as for local fish catches, were supplying 83.6 and 92.5 percent of the domestic household food needs, respectively.

In 2010, the annual average nutrient consumption per capita in Grand Nador was approximately 7.2Kg N and 1.2Kg P, corresponding to ca. 5.7Kg cap^{-1} yr^{-1} of N and 1Kg cap^{-1} yr^{-1} of P for the rural population, and 7.6Kg cap^{-1} yr^{-1} of N and 1.3Kg cap^{-1} yr^{-1} of P for the urban inhabitants, data that is in accordance with that found by Metson et al. (2012a). The most important food nutrients consumed by the GN population were derived from cereals (wheat, maize and barley), meat (basically poultry), milk, vegetables, fish and pulses. Cereals contained 60 percent N and 74 percent P consumed; meat 10.2 percent N and 3.1 percent P; milk 3.7 percent N and 4.3 percent P; vegetables 3.6 percent N and 3.8 percent P; fish 3.3 percent N and 1.7 percent P and pulses 2.8 percent N and 1.6 percent P.

According to our calculations ca. 13.7 percent N and 14.1 percent P in the consumed food ended up as kitchen waste. Therefore, and by subtracting the amounts of nutrients in organic/kitchen waste, the annual averaged intake of nutrients per person was 6Kg N and 1.1Kg P, that translated into 6.3Kg N and 1.1Kg P per urban resident, and 4.8Kg N and 0.8Kg P per rural inhabitant.

The majority of nutrients in consumed food found their way to household waters (ca. 89 percent of N and 87.5 percent of P nutrients), that is untreated household wastewaters contained approximately 1,723t N and 278t P, of which 22 percent of N and 24.7 percent of P originated from rural areas. Emissions to surface waters from rural areas were 143t N and 26t P, whereas from urban areas amounted to 1,211t N and 181t P. The WWTP of Grand Nador discharged annually 47t N and 5t P directly to the lagoon of Nador, and approximately 284t N and 90t P that remained in sewage sludge were disposed of into the landfill. On the other hand, in 2010, organic solid waste (OSW) contained on average 269t of N and 46t of P of which 18 percent derived from rural households. Of the total OSW generated ca. 65 percent of N and P were disposed of in the landfill (see appendix II and III for detailed list of results).

Discussion

Nutrient reduction and recirculation options

The results found in our study agree, in qualitative terms, with those found in similar SFA studies on N and P elsewhere in the world (Antikainen, 2007; Antikainen et al., 2005; Chowdhury et al.,2014; Kalmykova et al., 2012; Li et al., 2010; Neset et al., 2008; Qiao et al., 2011; Yuan et al., 2011) (see appendix VI for detailed information on SFA case studies). In accordance with other authors, such as Chowdhury et al. (2014), we underline the term qualitative, since due to the different nature, scope and boundaries, geographical scale, application of the method and variability in databases used in various studies, we considered inappropriate to attempt comparison of exact figures and quantitative information of N and P flows between different studies.

The assessment also displays the linearity of the nutrient food-related flows studied, what leads to an excessive unproductive accumulation and loss of nutrients that might cause harmful environmental impacts to water, air and soil, as those described in the introduction section (see the introduction section for the environmental impacts related to N and P cycling), as well as contribute in scarcity of the nutrient resources. Therefore, to attain a sustainable nutrient management, future strategies should aim to close the nutrient cycles, through an integrated approach that link key activities in all relevant sub-processes focusing on minimizing excessive N and P inflows and outflows, and recovery and recycling of unproductive lost/accumulated nutrients (Chowdhury et al.,2014; Cordell et al., 2009).

Yet, as stressed by Antikainen (2007, p.37), it should be noted that: “entirely closed cycles are in practice impossible to achieve in our current open economies, since raw materials and resources are needed from abroad and other regions and sectors, which inevitability leads to the openness of the N and P flows as the nutrients are moved in the products. Moreover, sustainable nutrient management is not the only target, and other environmental aims, agricultural and energy policy, employment policy and market situations drive the nutrient flows directly and indirectly”.

Since understanding the key N and P inflows and outflows in GN is vital to identify the priority areas of nutrient management, the study showed that of total nutrients entering the system (7,111t N; 2,430t P), the most significant input flows of N were in the form of imports of fertilizers (2,785t, 39.2 percent); food products to urban HH residents (1,438t, 20.2 percent); feedstuffs (1,247t, 17.5 percent), and food to the agro-food processing industry (770t, 10.8 percent). The major P inflows also occurred through the same components, that is, imports of fertilizers (1,666t, 68.6 percent); feedstuffs (347t, 14.3 percent), and food products to urban HH residents (266, 11 percent). Therefore, future nutrient management decisions should focus on reducing N and P input through these materials. Alternative ways to diminish the N and P inflows to the GN economy would include increasing efficiency, substitution, re-use and recycling.

Regarding the total nutrients that were leaving the system (3,132t N; 268t P), the assessment revealed that significant outflows of N and P were observed to occur through collected untreated sewage/wastewater (1,102t N, 35.2 percent and 165t P, 61.6 percent), manure and fertilizer losses to air (917t N, 29.3 percent) and export of agro-food and crop products (860t N, 27.4 percent and 62t P, 23 percent). The majority of N and P outflows as untreated sewage/wastewater ultimately found their ways to surface water bodies, that is to the Caballo and Selouane rivers that drain into the lagoon of Nador, thus becoming unproductive lost nutrients to other end users, that not only are potentially damaging to the receiving environment, but that also contribute to the scarcity of the N and P resources. Hence, future nutrient management decisions need to include appropriate nutrient recovery and recycling measures to minimize discharge of unproductive/accumulative outflows.

Therefore, a substantial proportion of the total quantity of nutrients (N and P) that entered into the system was retained within the system as stock. Actually, in 2010, GN accumulated about 3,979t N and 2,162t P. That is, of the total amount of N and P that entered GN, about 56 percent of N and 89 percent of P were stored within the system, and the majority were retained in the landfill (1,085t N, 27.2 percent; 419t P, 19.4 percent), in the soil of the crop production sector (1,412t P, 65.3 percent), in the urban household consumption sub-process (1,130t N, 28.4 percent) and in the soil and groundwater of GN (1,008t N, 25.3 percent; 53t P, 2.4 percent).

Nitrogen flows as fodder crops (1,774t) from the crop to the livestock production sub-processes; livestock excreta (1,685t) from the animal to the crop production sub-processes; sewage/wastewater (1,424t) from the urban household consumption sub-process collected by the sewer system, and animal products (1,115t) to the agro-food processing industrial process were the main internal flows of N in the GN urban agglomeration. In this case, only manure flow (1,685t, 23.7 percent of total inflow) was recycled back as organic fertilizer to the agricultural production process.

Phosphorus flows as poultry manure (284t) from the livestock production sub-processes to the landfill; sewage/wastewater (258t) from the urban HH consumption sub-process collected by the sewer system; livestock excreta (195t) from the animal to the crop production sub-processes; local crop products (140t) from the crop to the urban HH consumption sub-processes; fodder crops (135t) from the crop to the livestock production sub-processes, and local crop products (129t) from the crop to the agro-food processing industrial process. Again, only manure flow (195t, 8 percent of total inflow) was recycled back as organic fertilizer to the agricultural production process.

Based on the above analysis and results, we argue that of the four processes studied, agricultural activities were the largest contributors to anthropogenic N and P flows in the urban agglomeration of Grand Nador in 2010. In this sense, Grand Nador responds to the trend observed by Bouwman et al. (2005) by concentrating agricultural activities, involving growing crops and raising livestock, within its bordering urban settlements, and agrees with Chowdhury et al. (2014) remark on that the agricultural production is the main sector when considered either in the regional or in the city scale analysis as it is occasionally found. Moreover, because of its climatic conditions, it must not be forgotten the key influence that exerts the fact that peri-urban areas were dominated by an irrigated agriculture system, which also influenced the application of fertilizers.

Fertilizer import was identified as one of the most significant N and P inflows to the system. Actually, today's modern agriculture is fully dependent on regular inputs of N and P fertilizers (Cordell et al., 2009), and Grand Nador is not an exception. Besides, as Chowdhury et al. (2014) acknowledged, in most of the traditional agricultural management systems in many countries fertilizers are applied to the land without assessing the initial soil nutrient status, as it is most probably the case of Grand Nador, ultimately resulting in over fertilization. Therefore, a measure to diminish N and P inflows could be attained by reducing fertilizer application to match crop needs. That is, by applying fertilizer in amounts that better align nutrient supply (stoichiometric needs) and crop demand (growth). Without surplus or shortage of nutrients, tradeoffs amongst yield, profit and environmental protection in agricultural crop systems could be optimized, and then only light applications would be needed to replace depletion in harvest (Cassman et al., 2002; Childers, 2011; Cordell et al., 2009; FAO, 2006; Ma et al., 2012). Thus, more balanced and efficient use of nutrients are potential means of diminishing inputs and losses of N and P in the crop production sub-process. Yet, this measure requires the previous work of assessing current soil nutrient status (i.e., to perform a soil survey to obtain data on the present fertility of the various soil types of the area) and to establish threshold levels of soil nutrients, quantitative understanding of N and P-use efficiencies (i.e., crop nutrient-uptake efficiencies) and losses in the system, to develop quality control and quality assurance of the production systems, as well as education of farmers, and the economic returns from adoption of improved management practices (Antikainen, 2007; Bouwman et al., 2005; Cassman et al., 2002; Childers, 2011; FAO, 2006; Ma et al., 2012).

With regard to the work on soil nutrient status, we have to acknowledge the initiative of "Grown soil fertility map in Morocco" project («***Carte de fertilité des sols cultivés au Maroc***»; www.fertimap.ma) as part of the national agricultural strategy "Green Morocco Plan" (PMV). It is performed as part of a research and development agreement signed in June 2007 between the Ministry of Agriculture and Maritime Fishing (MAPM) and the Group Chérifien Office of Phosphates (OCP).

This measure would contribute to reduce the excessive accumulation of nutrients in the soil of the crop production sub-process, which was found to be the key place of P stock within the system, retaining a significant 58 percent of the total inflow of P. Besides, by using the available P stock in soil for crop production, not only decreases the risk of P outflow as soil erosion, leaching, or as particulate or dissolved P in runoff water, but also reduces the demand of chemical P fertilizer input, which ultimately helps to reduce the P-resource scarcity problem and increases the farm's financial outlay for fertilizer.

Moreover, as acknowledged by Carpenter et al. (1998), a more efficient use of fertilizers along with an improved handling of animal wastes could also contribute to the reduction of atmospheric deposition. Hence, by diminishing the N and P inflows, it would be reduced the amount of nutrients cycling in the system, and would also decrease in high probability the outputs of nutrients to water, air and soil.

Livestock production was also found to be greatly responsible for anthropogenic nutrient cycling in the Grand Nador system. Animal intake and manure generation along with its emissions were identified among the key inflows (feedstuff imports), outflows (manure emissions) and internal flows (fodder crops, manure, animal products) of the system. Therefore, it requires further attention in the context of nutrient management.

On the one hand, industrially produced poultry, which supplied 66.4 percent (16,700t) of the total tonnage of meat produced (25,146t) in the SA, was fed only by concentrates, what implied not only large imports of feedstuff, but also big amounts of manure and emissions. A significant amount of manure nitrogen was lost due to ammonia volatilization and the solid fraction was landfilled, thus becoming unproductive nutrients since were not recycled back in the agricultural soils.

On the other hand, approximately 37 percent of the local production of crops was associated with the demand of fodder crops for ruminant breeding (33.6 percent of total tonnage of produced meat). Yet, they were pasture based fed on a significant proportion, i.e. food needs were largely covered by free fodder course from rangelands and grazing pastures. Hence, the production of red meat is still very much dependent on the climatic conditions of the year, Nador being a zone prone to droughts; the global effect might influence the affluence of fodder grass and contribute to poorer pasture and to the depletion of forage. In addition to this, a high animal density production might lead to overgrazing. Overgrazed lands are often nutritionally marginal, resulting in lower levels of animal's carcass weight, and thus in lower consumption levels in nutritional standards (Chafai, 2004). That is, availability of poorer food resources might lead to production of red meat of insufficient nutritional quality versus nutritional standards. Furthermore, one of the risks particularly associated with semi-arid regions is land degradation as a result of inappropriate grazing, process that can be further aggravated and accelerated by drought, and is expected to worsen with climate change. Therefore, to avoid the environmental problems (soil erosion, the destruction of vegetation, deterioration of water quality) associated with overgrazing, animal density production should not exceed the productive capacity of the grazing land or pasture, thus ensuring that land is able to recover its vegetation cover.

Ruminant livestock breeding was more connected into a ‘closed’ loop system, from its feeding regime to the fact that its manure was recycled back as organic fertilizer to the agricultural production land. Yet, poultry production was displaying completely linear flows, from its feedstuff imports to its landfilled manure. Therefore, first, current and potential recycling rates of manure to fields should be assessed in order not to surpass the capacity of the soil (agricultural field) to absorb the manure applied. Secondly, in the attempt to close the nutrient cycles, and in case land availability is not large enough for spreading the whole amount of manures generated, appropriate recovery and recycling nutrient measures from poultry manure previous to landfilling should be taken in order not to lose unproductive nutrient outflows.

The urban population of Grand Nador (76.9 percent of the total population of the study area in 2010) represents 68.6 percent of the total population of Nador province (after administrative division in 2009) and 97 percent of the total urban population of the Nador province. Urbanization, improved standards of living and population growth commonly goes along with increasing popularity of meat- and dairy-based diets, so as shown in the latest existing available survey (RdM/HCP, 2005), concomitantly with an increase in food trade, in the present case reinforced by the close geographical position of Nador near the Spanish enclave of Melilla.

According to Ma et al. (2012) and Metson et al. (2012b) urbanization, improved standards of living and population growth are responsible for the rising magnitudes of nutrient flows related to use and waste generation, and the declining ratio of recycled N and P wastes. On the one hand, the production of meat and dairy products requires a much larger nutrient turnover than cereals and vegetables (Brunner and Rechberger, 2004; Cordell et al., 2009). On the other hand, municipal sewage and waste system infrastructures prevent sufficient amounts of nutrients from returning to the areas were food is produced to balance off-takes (Cordell et al., 2009; Montangero, 2006). Actually, import of food products to the urban HH consumption sub-process was identified as one of the main inflows to the GN system. Likewise, wastewater/sewage collected mainly from urban households by the sewer system, though untreated, made one of the majors outflows of the GN system. In addition, wastewater/sewage from urban HH collected by sewer system represented one of the main internal flows.

Therefore, several authors (Chowdhury et al., 2014; Cordell et al., 2009; Li et al., 2010; Metson et al., 2012a; Smil, 2002a, b; Tangsubkul et al, 2005) argue that changing urban populations behavior and consumption patterns, by encouraging them to shift to dietary habits which require less N and P inputs, though difficult in practice, in the long term can significantly reduce nutrient consumption, and notably make part in sustainable nutrient management strategies, and in synergies with other health and environmental sustainability priorities (Metson et al., 2012a). Smil (2002b) stated that it could be one of the most cost-effective measures to reduce agricultural resource input (including water, energy, land and fertilizers) along with contributing to minimize greenhouse gas emissions and other forms of pollution.

Moreover, this shift in the composition of urban diets, increasing the intake of plant products and reducing the intake of animal products or at least aligning them with recommended nutrient daily intake per person, would also decrease nutrient outputs in two ways. First, if humans consume less nutrients, less will also be excreted to wastewaters and solid waste, thus translating in a decline in nutrient outputs to water and soil. Second, less consumption of meat and other animal products would entail less input in the form of fodder, and consequently smaller agricultural production area would be needed to meet the animal's consumption demands, along with less manure and fertilizer amounts. Hence, decreasing nutrient losses to waters, soil and air from the agricultural production system (Neset et al., 2008; Smil, 2002a,b). Actually, Neset et al. (2005) and Tangsubkul et al. (2005) respectively suggest that a shift in diet, from the average western diet to a vegetarian-based diet, could reduce P-fertilizer demand by approximately 20-45 percent, and in Sydney residents could decrease the city's total phosphorus demand by 70 percent. However, as Metson et al. (2012a) notice, as diets vary around the world, so will differ the potential for dietary modifications to enhance global nutrient sustainability, and thus to reduce nutrient demand via dietary shifts will need to be location specific.

Concomitant with shifts in diets, changes in the utilization of food residues and food wastes (which is in part related to urbanization and upscaling effects) should also be adopted by urban population. Several authors have suggested (Kalmykova et al., 2012; Li et al.2010; Ma, 2014; Ma et al. 2012; Metson et al., 2012a) to improve separate collection of food waste enabling to compost the organic material and use of the resulting residue in agriculture as organic fertilizer instead of being dumped in landfills or discharged in surface waters.

Actually, large amounts of N and P were accumulated in the non-controlled landfill of GN. In addition to the collected municipal organic solid waste, disposal of sewage sludge from the WWTP, manure from poultry production and organic solid waste from the agro-food processing industry were also buried on it, thus identifying the landfill as one of the main sinks where N and P accumulate. If it were technically and economically possible to return all nutrients disposed of in the landfill of GN in 2010 to the agricultural soil, these would replace ca. 39 and 25 percent of N and P respectively, of the nutrients in inorganic fertilizers. Moreover, additional attention should be required to ensure that long-term leaching of P and N from the landfill to soil and groundwater table is minimized.

It should be acknowledged that post-dated to the year of study, Grand Nador is developing a sanitary landfill, entrusted to a Lebanese company, Averda Holding, in the rural commune of Oulad Settout (see Fig.15). The commissioning of this new sanitary landfill, scheduled for 2015, will imply the permanent closure of the old uncontrolled landfill, the equipment of a leachate pond, the construction of a leachate treatment plant, and the formal organization of the sorting activity at the landfill. Therefore, it is expected that this new sanitary landfill will help alleviate, and solve the problems of the saturated uncontrolled landfill, in terms of biogas and toxic smoke emissions, pollution of groundwater due to leaching processes and degradation of the landscape (Agoumi, 2012; Le Matin, 2012).

On the other hand, as previously observed, urbanization has also entailed the use of water-based sanitation systems (i.e. flush toilets, municipal sewage systems, WWTPs), meaning that nutrients contained in human waste are diluted in waterways, and after varying degrees of treatment, discharged into water bodies instead of being returned to the soil, causing myriad water quality problems and eutrophication (Childers, 2011; Cordell et al., 2009, 2011). Besides, as Cordell et al. (2011) remark by diluting the nutrients makes it more expensive to recover them.

Mountadar and Assobhei (2006) acknowledged that many sewage treatment plants have been built in Morocco since 1958, though few are still functional because of monitoring problems, maintenance or inadequacy of the treatment system. In 2005, only about 8-10 percent of its municipal effluent was treated, despite the fact that 70 percent of Moroccans were connected to the sewerage network. In 2010, the treatment ratio improved up to 20 percent of its municipal effluent and around 73 percent of the population was connected to the sewerage network (Globalwaterintel, 2010). Despite not being the case of Grand Nador, since a treatment ratio of 63 percent was estimated for the WWTP of Nador (activated sludge plus tertiary process, nitrogen and phosphorus treatment and UV disinfection) (RdM-ONEP, 2010) it result to be insufficient to treat the received municipal and industrial effluents generated in GN.

Besides, in the meantime, the generated sewage sludge by the WWTP was first stored for drying at the WWTP near the Nador lagoon (without any measures to ensure protection of the environment), secondly discharged to the uncontrolled landfill without any valorization. As demonstrated by Zerrouqi et al. (2011) during the rainy period, significant leaching of N and P from the sludge stocks percolates to the soil and groundwater (the Bou-Areg water table) that end at the Nador Lagoon with concomitant potential pollution effects. Next, slugdes are then disposed of to the landfill, losing unproductive nutrients (N and P) that could be treated and composting into fertilizer to be used in crop production and to amend certain soils (Zerrouqi et al., 2011).

Therefore, given the risk of potential pollution of sewage sludge stocks to the water quality of the lagoon and groundwater, monitoring and careful management of sludge produced by Nador’s WWTP should be implemented, and regulatory measures in the conditions and technical requirements of the sludge storage should be established to ensure safety to the environment. Besides, nutrient recovery could be enhanced by promoting recycling of nutrient in sewage sludge in agriculture. Although the reuse of sewage sludge was restricted in GN due to environmental regulations related to contamination of pathogens and heavy metals in sludges, this barrier could be overcome by using infrastructure systems that avoid mixing human excreta with other wastewater streams, such as industrial wastewater. Industrial and nonresidential wastewater may contain heavy metals and other toxic wastes. Therefore, nutrient recovery and reuse systems will need to separate or render industrial and urban residues contaminated with heavy metals, pharmaceuticals, hormones and infectious bacteria below the presently acceptable levels (Antikainen, 2007; Bouwman et al., 2005; Cordell et al., 2011; Vinnerås et al., 2008; WHO, 2006).

An alternative to attain efficient and cost-effective N and P recovery could be separating human excrement and urine at the source (Cordell et al., 2009, 2011; Huang et al., 2007; Ma et al., 2012; Metson et al., 2012a,b; Montangero, 2006; Rosemarin et al., 2008; Vinnerås, 2002; Vinnerås and Jönsson, 2002). According to Baccini and Brunner (1991), nitrogen, which is taken up mainly as protein in meat and milk products, leaves the human body preferentially as urea dissolved in the urine, whereas the amount of N expelled through the feces does not exceed 20 percent of the total. Similarly, only 30 percent of the phosphorus compounds are contained in the feces, and most of this element leaves the body by means of the urine. Besides, the World Health Organization (2006) states that urine is essentially sterile, thus when is not mixed with faecal matter, e.g. in the toilet, urine can be used safely through simple storage in agriculture. In addition, Kalmykova et al. (2012) explains that urine contents the similar bioavailable nutrients as in mineral fertilizers, and that being almost free of heavy metals and pathogens is easily sanitized by storage, ozone, or ultraviolet (UV) light, thus being ready to be used as a crop fertilizer.

In this line, sustainable sanitation strategies aim to decrease the mixing of water, faeces and urine in order to better contain, sanitize and reuse the water and nutrients back to the agriculture. Actually, Vinnerås and Jönsson (2002) achieved a collection performance of 60 percent of N and 46 percent of P from the wastewater, by using a combination of faecal separation and urine diversion in their study in the Ekoporten block of flats (Sweden), yet they affirmed a potential recovery up to 91 percent of N and 83 percent of P if the urine and the faeces were separately collected from the household wastewater. This option would demand of sustainable and ecological sanitation systems (e.g. dry or urine-diverting toilets) involving less or no water. Yet, it would reduce the enormous investment in new municipal infrastructure (Ma et al., 2012). Besides, ecological sanitation on-site systems are particularly appropriate in rural and peri-urban areas, where households are not connected to sewerage or farmers do not have access to, or cannot afford, chemical fertilizers (Rosemarin et al., 2008; UNEP, 2011). Besides, in a future challenged with energy and water scarcity, climate change and increased population growth, decentralized systems as sustainable sanitation systems are likely to play an important role in future (Cordell et al., 2011).

Last innovations in ecological sanitation systems target on struvite crystalisation (ammonium magnesium phosphate) and recovery, a technological process that efficiently removes phosphorus from wastewater byproducts, resulting in mineral struvite, output that can be directly applied to farm fields providing an alternative source of phosphate fertilizer (Cordell et al., 2009; UNEP, 2011).

Therefore, not only the emissions to the aquatic environment would be reduced due to less nutrient load to the centralized WWTP, but also the use of recycled nutrients from the waste streams to replace chemical fertilizer in crop production would also minimize nutrient inflows. (Chowdhury et al., 2014; Kalmykova et al., 2012; Li et al., 2010; Ma et al., 2012; Vinnerås and Jönsson, 2002).

In sum, to achieve the most complete recirculation of nutrients, an integrated system framework should be implemented, that evaluates and integrates the full range of sustainable N and P recovery and reuse options, starting from small-scale low-cost decentralized systems to large-scale high-tech centralized options, from all interlinked significant process and sub-processes involved in the system.

Finally, it is worth noting the argument introduced by Cordell et al. (2011) that in order to effectively implement all above mentioned management options and achieve a high recovery and reuse scenario, institutional arrangements and other constraints should be correctly addressed and key stakeholders identified. Accordingly, significant physical infrastructure changes will be needed, along with new partnerships and strategic sustainable policies that guide and support the most appropriate nutrient recovery and reuse strategy according to the region, country or international setting in an integrated way.

Uncertainty

Several factors influence our results, among them data inaccuracy, variations in nutrient concentrations and dry weights, and varying quality of data from different nature of sources (see section five on uncertainty analysis). Hence, according to Danius and Burström (2002) since the majority of input data contain inherent uncertainties, arising from different sources, results are inherently uncertain. Besides, there are uncertainties associated to the calculated data.

On the other hand, as acknowledged by Galloway et al. (2004) p.156 "with seven oxidation states, many means for interspecies conversion, and a variety of environmental transport/storage processes, nitrogen has arguably the most complex cycle of all major elements, what makes tracking anthropogenic nitrogen through environmental reservoirs a challenge". Hence, because of nitrogen's tendency to escape to air, the quantification of nitrogen flows is much more uncertain than the quantification of the phosphorus flows, e.g. manure management and fertilizer application makes estimations more difficult (see the introduction section for further detailed information), this is reflected in the uncertainty intervals of these same emission flows (see table 4).

We assume the reliability of the official statistics ("Haut commissariat au plan du Maroc"), for instance, data on harvest, animal production, fish catches, imports and exports. Thus, estimates on N and P flows drawn from these goods are assumed to have a relatively low uncertainty. Yet, uncertainties in estimates on environmental flows such as emissions from both mineral fertilizers and manure are quite high since lack of data prevent from adopting the appropriate emission factors. Large uncertainties also relate to fertilizer and manure volatilization processes, due to lack of specific information on on-farm practices, and on leaching/runoff from agricultural soils (leaching process varies considerably depending on soil type, slope and cultivation methods). Uncertainties were minimized whenever available and accessible by using and making comparisons between different reference sources (for more detailed guidance on uncertainty assessment on volatilization and leaching/runoff processes see volume 1, Chapter 3, IPCC, 2006).

The results from the quantitative uncertainty assessment (see table 7), by applying the method developed by Hedbrandt and Sörme (2001), showed that taking into consideration the uncertainty intervals, in 2010, the N and P inputs to the crop soil ranged from 4,051t to 5,989t for N and from 1,565t to 2,213t for P, whereas the outputs varied between 3,485t and 6,894 t for N and 407t and 493t for P. Based on this, when minimum outputs were subtracted to the maximum inputs, and the other way round, it was found that the uncertainty interval for phosphorus in crop soil (1,072t and 1,806t P) showed a positive surplus, in accordance with the result found (see table 5). Yet, the corresponding uncertainty interval for nitrogen (-2,843t and 2,504t N) showed a range from deficit to surplus of nitrogen. Hence, the crop soil could be in a deficit of N instead of surplus. The same, though for both N and P flows would also happen for the livestock production sub-process, where the corresponding uncertainty interval for P (-198t and 60tP) and for N (-2,324t and 429t N) showed a deficit in the low range and a surplus in the upper range of the interval.

Therefore concluding that it is highly recommended to use a quantitative assessment, in SFA, to support the interpretation of results, and to identify and understand were results could be more uncertain, thus further attention should be paid.

Limitations of this assessment and future research

First of all, it should be noted that because of limited availability and accessibility to data, the descriptions of N and P nutrient cycles of the present study were not entirely complete or correct. For instance, a more accurate analysis of the agro-food industrial process would have been desirable, with more detailed in-situ measurements and specific process information instead of a desktop investigation and literature based estimates, yet lack of specific information and accessibility to these data precluded such an analysis. Moreover, data uncertainty adds more potential of error to the results of the analysis. Therefore, to overcome and address data gaps and reduce data uncertainty it would be necessary to improve the collection of in-situ data and monitoring measures.

On the other hand, the method applied was based on a static analytical model, thus giving a static picture of the N and P flows, and only one-year data was analysed (in 2010). Therefore, since no predictive modeling was developed, no future changes could be predicted. Besides, predicting modeling demands large quantities of initial data, and the interactions between flows add more complexity to the simulation. Hence, to develop a predictive model much more research, as well as much more precise data would be needed.

Studies based on a single year analysis of N and P flows lack understanding about the long-term fate and magnitude of nutrient flows, thus are not capable to identify changing trends of N or P flows over a multiple years, yet some significant nutrient processes may take several years to show their effects. Besides, Chowdhury et al. (2014) argue that the influences of long term changes of the socioeconomic, political, and technological factors on N and P flows could only be considered in multi-year analyses, since they take more than one year to become effective. Yet, the compelling force in determining the fate and magnitude of nutrient flow over several years by these factors can be crucial. Therefore, future research could be developed to analyse the same system over multiple years.

Finally, Cordell et al (2011) and Chowdhury et al. (2014) acknowledge that future research should introduce and consider the significant influence that other global environmental and social challenges might exert on the fate and magnitude of N and P flows through different systems, particularly at the catchment scale, including: climate change and land use change, fossil fuel energy scarcity, water scarcity, population growth, urbanisation trends and eutrophication. Therefore, future research should consider the impact of these changes and their interactions on N and P flows and stocks to better design nutrient management policy to achieve nutrient management sustainability.

Table 7.: Average flows in Kg year^{-1} of nitrogen and phosphorus and their uncertainty intervals, in Grand Nador in 2010.

		Nitrogen				***Phosphorus***			
FLOW			**Average**	**Minimum**	**Maximum**		**Average**	**Minimum**	**Maximum**
I_{15-1}	Atmospheric deposition	kg N yr^{-1}	396.949,00	198.474,50	793.898,00	kg P yr^{-1}	0,00	0,00	0,00
I_{14-1}	Imports of fertilizers	kg N yr^{-1}	2.784.611,00	2.320.509,17	3.341.533,20	kg P yr^{-1}	1.665.732,00	1.388.110,00	1.998.878,40
I_{14-2}	Imports of fodder and feedstuff	kg N yr^{-1}	1.247.495,20	1.039.579,33	1.496.994,24	kg P yr^{-1}	347.161,56	289.301,30	416.593,87
I_{14-4}	Imports of food to agro-food processing industry	kg N yr^{-1}	769.854,75	699.867,95	846.840,22	kg P yr^{-1}	78.332,00	71.210,91	86.165,20
I_{14-5}	Import of food products to Rural HH consumption	kg N yr^{-1}	324.664,47	295.149,52	357.130,92	kg P yr^{-1}	60.107,66	54.643,33	66.118,43
I_{14-6}	Import of food products to Urban HH consumption	kg N yr^{-1}	1.438.044,19	1.307.312,90	1.581.848,61	kg P yr^{-1}	266.236,32	242.033,02	292.859,95
I_{13-4}	Fish local catches to agro-food processing industry	kg N yr^{-1}	0,00	0,00	0,00	kg P yr^{-1}	0,00	0,00	0,00
I_{13-5}	Fish local catches/product to Rural HH consumption	kg N yr^{-1}	27.473,27	24.975,70	30.220,60	kg P yr^{-1}	2.271,81	2.065,28	2.498,99
I_{13-6}	Fish local catches/product to Urban HH consumption	kg N yr^{-1}	121.688,03	110.625,48	133.856,83	kg P yr^{-1}	10.062,59	9.147,81	11.068,85
R_{1-2}	Fodder crops as animal feed	kg N yr^{-1}	1.774.548,27	1.613.225,70	1.952.003,10	kg P yr^{-1}	134.598,63	122.362,39	148.058,49
R_{1-4}	Locally produced plant/crop products to agro-food processing industry	kg N yr^{-1}	740.842,00	673.492,73	814.926,20	kg P yr^{-1}	129.417,00	117.651,82	142.358,70
R_{1-5}	Locally produced plant/crop products (Veg Food) to Rural HH consumption	kg N yr^{-1}	154.605,25	140.550,22	170.065,77	kg P yr^{-1}	31.727,15	28.842,87	34.899,87
R_{1-6}	Locally produced plant/crop products (Veg Food) to Urban HH consumption	kg N yr^{-1}	684.796,75	622.542,50	753.276,43	kg P yr^{-1}	140.529,85	127.754,41	154.582,83
R_{1-12}	Leaching/runoff from agricultural land (to Soil/Groundwater)	kg N yr^{-1}	715.825,50	238.608,50	2.147.476,50	kg P yr^{-1}	0,00	0,00	0,00
R_{2-1}	Manure (as organic fertiliser) to agricultural land	kg N yr^{-1}	1.685.004,51	1.531.822,29	1.853.504,97	kg P yr^{-1}	194.599,97	176.909,06	214.059,96
R_{2-4}	Animal products to agro-food processing industry	kg N yr^{-1}	1.114.742,27	1.013.402,06	1.226.216,50	kg P yr^{-1}	75.958,58	69.053,26	83.554,44
R_{2-11}	Manure (from poultry production) to landfill	kg N yr^{-1}	346.342,03	173.171,02	692.684,07	kg P yr^{-1}	283.655,91	257.869,01	312.021,50
R_{4-5}	Agro-food proccesed pdcts to Rural HH consumption	kg N yr^{-1}	89.273,58	81.157,80	98.200,94	kg P yr^{-1}	7.792,93	7.084,48	8.572,23
R_{4-6}	Agro-food proccesed pdcts to Urban HH consumption	kg N yr^{-1}	395.421,62	359.474,20	434.963,78	kg P yr^{-1}	34.517,43	31.379,48	37.969,17
R_{4-11}	Organic solid waste from agro-food processing industry	kg N yr^{-1}	278.768,93	253.426,30	306.645,83	kg P yr^{-1}	15.496,54	14.087,76	17.046,19
R_{5-8}	Wastewater/sewage from Rural HH collected by sewer system	kg N yr^{-1}	9.458,79	7.111,87	12.580,18	kg P yr^{-1}	1.715,25	1.289,66	2.281,28
R_{5-9}	Organic solid waste (OSW) from Rural HH collected	kg N yr^{-1}	0,00	0,00	0,00	kg P yr^{-1}	0,00	0,00	0,00
R_{5-12}	Non-collected OSW and WW/sewage from Rural HH to soil/groundwater	kg N yr^{-1}	163.796,15	116.997,25	229.314,61	kg P yr^{-1}	29.543,48	21.102,49	41.360,88
R_{6-8}	Wastewater/sewage from Urban HH collected by sewer system	kg N yr^{-1}	1.424.464,92	1.071.026,25	1.894.538,34	kg P yr^{-1}	258.311,72	194.219,34	343.554,59
R_{6-9}	Organic solid waste (OSW) from Urban HH collected	kg N yr^{-1}	175.362,27	131.851,33	233.231,82	kg P yr^{-1}	30.389,62	22.849,34	40.418,19
R_{6-12}	Non-collected OSW and WW/sewage from Urban HH to soil/groundwater	kg N yr^{-1}	128.728,29	91.948,78	180.219,60	kg P yr^{-1}	23.202,47	16.573,19	32.483,46
R_{8-11}	Sludge from WWTP to Landfill	kg N yr^{-1}	284.218,20	189.478,80	426.327,30	kg P yr^{-1}	90.002,43	60.001,62	135.003,65
R_{9-11}	Collected OSW -organic solid waste- to Landfill	kg N yr^{-1}	175.362,27	131.851,33	233.231,82	kg P yr^{-1}	30.389,61	22.849,33	40.418,19
O_{1-15}	Air emissions from fertilizers	kg N yr^{-1}	315.357,20	105.119,07	946.071,59	kg P yr^{-1}	0,00	0,00	0,00
O_{1-14}	Export of locally produced plant/crops products	kg N yr^{-1}	100.707,50	91.552,27	110.778,25	kg P yr^{-1}	11.533,42	10.484,93	12.686,76
O_{2-15}	N losses from manure to the atmosphere	kg N yr^{-1}	602.111,86	301.055,93	1.204.223,71	kg P yr^{-1}	0,00	0,00	0,00
O_{4-14}	Export of agro-food industrial products	kg N yr^{-1}	759.614,70	690.558,82	835.576,17	kg P yr^{-1}	50.176,15	45.614,68	55.193,76
O_{5-13}	Non-collected OSW and WW/sewage from Rural HH to surface water	kg N yr^{-1}	133.210,35	95.150,25	186.494,49	kg P yr^{-1}	23.917,47	17.083,90	33.484,45
O_{6-13}	Non-collected OSW and WW/sewage from Urban HH to surface water	kg N yr^{-1}	70.898,47	53.307,12	94.294,97	kg P yr^{-1}	12.645,12	9.507,61	16.818,01
O_{a8-13}	Collected WW/sewage and treated by the WWTP	kg N yr^{-1}	47.369,70	33.835,50	66.317,58	kg P yr^{-1}	4.736,97	3.383,55	6.631,76
O_{b8-13}	Collected WW/sewage but untreated	kg N yr^{-1}	1.102.335,81	787.382,72	1.543.270,13	kg P yr^{-1}	165.287,57	118.062,55	231.402,60

Conclusion

The flows and stocks of N and P in the urban agglomeration of Grand Nador in 2010 were studied in four processes –production, processing, consumption and waste handling- using SFA as a research method.

The present study attempts to contribute to enlarge the existent literature on nutrient flows in urban areas, providing not only a first example of an SFA application on nutrient food flows of a Moroccan region, but also of a North African country/region. Besides, as being an analysis at a regional scale, which is the least studied scale in the available analysis on nutrient flows, it contributes to fulfill this knowledge gap.

Moreover, the regional system boundaries were not only defined according to the politico-administrative division/borders of the fourteen aggregated communes that formed the urban region of Grand Nador, but also it made them coincide with the sub-watersheds of the rivers that direct their waters to the lagoon of Nador.

Our study concludes, at the regional scale and along the food chain, that the main contributor to the N and P flows was agriculture, which agrees with results found by other authors such as Chowdhury et al. (2014). The major inflows of N and P occurred as imports of fertilisers, feedstuffs, and food products to both urban HH residents and to the agro-food processing industry. The key outflows of N and P occurred mainly as untreated wastewater/sewage, manure and fertiliser losses to air, and export of agro-food and crop products. The majority of the N and P stocks related to landfill, the soil of the crop production sector and the urban HH consumption sub-process. Recycling of N and P occurred solely as manure from the livestock production sector to the crop production sector.

Therefore, the analysis revealed the openness of the studied system of GN, displaying the linearity of the nutrient food-related flows studied. This led not only to an excessive unproductive accumulation and loss of nutrients, that might cause harmful environmental impacts to water, air and soil related to N and P cycling, but also contributed to increasing scarcity of the nutrient resources, essential from the standpoint of ensuring food security. Hence, these findings may have important implications for targeting emission reduction and environmental management.

Future strategies to attain a sustainable nutrient management should aim to close the nutrient cycles. Thus, to achieve the most complete recirculation of nutrients an integrated system framework (as expressed by Cordell et al., 2011) should be implemented. This integrated approach should link key activities in all relevant sub-processes, focusing on minimizing excessive N and P inflows and outflows, and in maximizing recovery and recycling of unproductive lost/accumulated nutrients. Accordingly, since a single solution does not exist, the full range of sustainable N and P recovery and reuse options should be evaluated and integrated, starting from small-scale low-cost decentralized systems to large-scale high-tech centralized options, from all interlinked significant process and sub-processes involved in the system. Among them, the most prominent include the reduction in the use/application of synthetic fertilisers to avoid over fertilization, by means of optimizing nutrient use efficiency and use of available soil nutrient stocks, along with sound soil cultivation practices; diet mitigation, by changing human consumption patterns towards diets which contain fewer N- and P-intensive foods, thus vegetarian-based diets, and to optimize animal density production. Concomitantly with this N and P reducing measures, options to enhance the recovery and recycling of nutrients from the different organic waste streams, generated throughout the food production and consumption system (from human and animal excreta to food and crop wastes), prior to landfill need to be promoted as well. Thus, we draw attention to actions such as: recycling farming residues, assessing manure recycling rates to fields, producing composts from organic waste streams (from industrial organic waste by-products to households food waste, sludge or other biodegradable fraction of municipal solid wastes) and separately collecting urine and feces at source by implementing sustainable sanitation strategies. Finally, secondary recovery of nutrients from available landfill waste should also be promoted.

The recovery and recycling of N and P from food waste streams offer the opportunity to better manage the relationship between food systems and nutrient cycling, as well as to achieve a more compatible development of urban areas with their hinterlands, through preventing and/or minimizing environmental problems caused by excessive N and P accumulation or loss, and the reliance on energy intensive industrial fertilisers and reverse P-nutrient mining.

With reference to the method applied and particularly with the study of nutrient flows, it must be borne in mind that nitrogen cycle properties, of high mobility and tendency to escape to air, make difficult to trace and quantify accurately some of the flows, hence increasing the uncertainty of SFA analysis and results. Therefore, to support the interpretation of the results and improve the accuracy and quality of data analysis, the use of quantitative uncertainty analysis is greatly recommended.

Finally, it is worth noting the argument introduced by Cordell et al. (2011, p 748) that in order to effectively implement all above mentioned management options and achieve a high recovery and reuse scenario, institutional arrangements and other constraints should be correctly addressed and key stakeholders identified. Accordingly, significant physical infrastructure changes will be needed, along with new partnerships and strategic sustainable policies that guide and support the most appropriate nutrient recovery and reuse strategy according to the region, country or international setting in an integrated way. Yet, a major challenge for Morocco, and specifically Nador, given the difficulties in terms to its governance structure and operation, already explained in the previous second chapter.

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Conclusions

The present study has sought to identify and quantify the major nitrogen and phosphorus food-related flows and stocks of the urban agglomeration of Grand Nador (GN), in North-East Morocco, for the year 2010, and for the four processes of production, processing, consumption and disposal. Using Substance Flow Analysis as a research method, this task has been directed to answer one of the main questions of this thesis, that is, whether and to what extent, food chains in urban systems do influence the possible openness and linearity of the N and P cycles.

The general results of this study show that agriculture was the largest contributor to anthropogenic N and P flows in GN. The major inflows of N and P were in the form of imports of fertilizer, foodstuffs, and food products for both urban household residents and to the agro-food processing industry. The key outflows of N and P occurred mainly as untreated wastewater/sewage from urban HH –which ultimately found its way to surface water bodies-; manure and fertilizer losses to air, and export of agro-food and crop products. The majority of the N and P stocks concentrated in landfills, in the soils of the crop production sector, and in the urban HH consumption sub-process. Recycling of N and P occurred solely as manure from the livestock production sub-process to the crop production sub-process as organic fertilizer.

Therefore, the analysis revealed the openness of the GN urban system displaying the linearity of the nutrient food-related flows studied. One of the determinants of openness is the high international, intranational, and interregional degree of the GN market. In 2010, imports were the major inflows of N and P to the GN system. Yet, these interrelations have a profound historical motivation since Nador's sociopolitical and historical heritage forced the region to live on outside flows in order to survive. Historical relationships with Melilla, in particular, contributed to turn Nador into an exchange and crossing area, between an international foreland and a national and local hinterland. Hence, the influence that urban histories have on metabolic flows must be also acknowledged. Additionally, as Hammer et al. (2003) argue, on a regional level, trade flows assume a higher relevance in the quantification of urban flows. The other determinant is the low recycling and recovery rate of many waste fractions. In this regard, as it has been repeatedly stated, urbanization and improved standards of living and population growth are responsible for the rising magnitudes of nutrient flows related to use and waste generation, and the declining ratio of recycled N and P wastes. On one hand, urbanization has led to an increasing distance between agriculture and the final consumer; on the other, through municipal sewage and urban waste infrastructures, it has prevented sufficient amounts of nutrients from returning to agricultural areas were food is produced to balance off intakes. Actually, for the specific process of household consumption, imported food products were the largest input flows whereas wastewater/sewage from urban households collected by sewer system accounted for the greatest N and P outflows. Hence, the results of the assessment proved the total influence of urban food chains on the openness and linearity of the N and P cycles.

With regard to food self-sufficiency, it is worth noting that whereas local production of meat and milk, as well as of local fish catches, were supplying 83.6 and 92.5 percent, respectively, of the domestic household food needs, local crops only covered 40 percent of the vegetable food needs of the local population. Consequently, vegetable imports accounted for approximately the remaining 60 percent. Furthermore, of the region's total crop production, 36.4 percent was intended as fodder for livestock, 38.7 percent accounted for beet crops, (assumed to be 100 percent supplied to the agro-processing factory of Sucrafor), and 14.8 and 7.8 were intended for domestic household consumption and export respectively. Conversely, nearly half of regionally produced meat was exported.

This finding has a second lecture in terms of N and P flows. Since, the region exported these flows, a surplus production of N- and P-intensive foods, i.e., meat products, occurred; compared to less intensive imported food nutrients. As it has been argued, meat- and dairy-products require a much larger nutrient turnover than cereals and vegetables to be produced. Livestock breeding amplifies the requirement for nutrients, since a larger agricultural production area and more fertilizer input are required to produce fodder crops for animals. Concomitantly, more manure is excreted to wastewaters and solid waste is produced. Therefore, presumably the greater the required and applied quantity of N and P nutrients, the greater the amount of unproductive nutrients that might get lost or accumulate in the environmental sinks region, causing potential harmful impacts to water, air and soil related to N and P cycling, and also contributing to increasing scarcity (primarily p-mining) of the nutrient resources.

All these insights point to the fact that GN's agricultural sector is oriented to animal production which may reflect not only important dietary changes in urban populations, as it happens elsewhere in the rapidly growing urban areas of the developing world, but also unsustainable farming and livestock practices that overload the carrying capacity of land. Therefore, the development of sustainable agricultural-farm nutrient practices will be an important strategy in the future of GN. In addition, the high share of imported products that were consumed in the region, together with the decreasing reuse of N and P within the system of food production, consumption and waste handling, results in a more nutrient resource-demanding consumption than it would be advisable from a sustainability point of view. This leads to an excessive and unproductive accumulation and loss of P and N nutrients that might cause harmful environmental impacts to water, air and soils. Ultimately, this process would strengthen the increasing P-resource scarcity problem, essential from the standpoint of ensuring food security. Therefore, these findings may have important implications for targeting emission reductions and thus improving the environmental management of these flows.

Therefore, a closer food chain cycle between the city and its hinterland, that would most certainly imply a diet based on regional self-supply of food and less or reduced trade flows of foods, will not only lead to regional nutrient conservation, but also more circular urban patterns, both necessary for the future sustainability of nutrient management and urban systems.

Future strategies to attain a sustainable nutrient management should thus aim to close the nutrient cycles in order to produce more circular patterns of flows. As Antikainen (2007) states, our current market economies make impossible to achieve in practice completely closed cycles, since nutrients are displaced in products and raw material exchanges, leading inevitability to the openness of N and P flows. However, to achieve the most complete recirculation of nutrients a more integrated system framework (as expressed by Cordell et al., 2011) becomes necessary. This integrated approach should link key activities in all relevant sub-processes, focusing on minimizing excessive N and P inflows and outflows, and in maximizing recovery and recycling of unproductive lost/accumulated nutrients. Accordingly, since a single solution does not exist, the full range of sustainable N and P recovery and reuse options should be evaluated and integrated, starting from small-scale, low-cost decentralized systems to large-scale high-tech centralized options, from all interlinked significant processes and sub-processes involved in the system. Among them, the most prominent, for the specific case of GN, include the reduction in the use/application of synthetic fertilizers to avoid over fertilization, by means of optimizing nutrient use efficiency and use of available soil nutrient stocks, along with sound soil cultivation practices. In this regard the initiative “Grown soil fertility map in Morocco” (http://www.fertimap.ma/) attempts to work in this direction. Other important targets would be shifting the composition of location specific urban diets to habits requiring less N and P inputs, i.e., increasing the intake of plant and cereal product and reducing the intake of animal products, and optimizing animal density production -key in the case of Grand Nador due to its livestock production orientation-. Together with N and P reducing measures, options to enhance the recovery and recycling of nutrients from the different organic waste streams generated throughout the food production, and consumption system (from human and animal excreta to food and crop wastes) prior to landfill need to be promoted as well. Thus, we draw attention to actions such as recycling farming residues; assessing absorption capacity of manure recycling rates to fields; producing composts from organic waste streams (from industrial organic waste by-products to households food waste, sludge or other biodegradable fraction of municipal solid wastes), and separately collecting urine and feces at source by implementing sustainable sanitation strategies. Finally, secondary recovery of nutrients from available landfill waste should also be favored.

The results found by the nutrient flows assessment are in accordance with those found in SFA studies on N and P elsewhere in the world, and confirmed by several other studies (e.g. Antikainen, 2007; Antikainen et al., 2005; Chowdhury et al., 2014; Kalmykova et al., 2012; Li et al., 2010; Neset et al., 2008; Qiao et al., 2011; Yuan et al., 2011). However, once more it has to be emphasized that conclusions drawn from SFA results largely depend on the defined spatial and temporal system boundaries, thus the results of the analysis may change depending on these predefined system boundaries.

The results of this quantitative exercise lead to the conclusion that reduction, recovery and recycling of N and P nutrients from food-related flows offer the opportunity to better manage the relationship between food systems and nutrient cycling, as well as to achieve a more compatible development of urban areas with their hinterlands.

To answer the question of the influence that urban histories have on metabolic flows, the present study has sought to explore the sociopolitical and historical context of the urban agglomeration of Grand Nador -based on the notion of UM inspired by Political Ecology- in an attempt to reveal the role that sociopolitical and historical factors play on the structure, functioning and processes of urban systems, and in particular on the nutrient food-related flows studied.

Results showed that sociopolitical and historical factors seem to have a marked impact on the city's structure, functioning and flows. We have argued how the relatively late appearance of the urban phenomenon in the Nador region has been the outcome of historical change fueled by political contestation. Likewise, it has been argued how the current spatial organization and complexity of the urban structure of the city of Nador and its urban agglomeration, probably unique in Morocco, has been the result of historical and sociopolitical processes strongly marked by the Spanish occupation heritage in the first half of the 20th century and the marginalization policies followed by the Moroccan ruling elite after the independence of the country. The Nador-Melilla nexus, located at the root of this polynuclear urban complex, created an urban complementarity first based on military matters and later on the smuggling trade. trade.

Furthermore, the urban region of GN was identified as a clear example of cities in developing countries confronted with environmental problems due to infrastructural deficits. That is, the uneven provision, access and use of public urban facilities derived from the region's urban growth. Uneven urban development not only aggravated the socio-spatial inequalities and the social well-being between the center and the periphery of Nador's region, but it also involved different and particular patterns of waste disposal with their corresponding pathways of environmental pollution. Hence, we find different parallel metabolisms for the same waste coexisting in the same city-region. For instance, urbanization entails the use of water based sanitation systems (i.e., flush toilets, municipal sewage systems, WWTPs), yet the uneven connection to sewerage in Nador has resulted in the proliferation of cesspools, and the presence of solid and/or liquid waste (and of the nutrients contained) in open fields and in rivers and streams that end at the Nador's lagoon, with its consequent high risk of surface water and groundwater contamination. Besides, low wastewater treatment rates have resulted in nutrients contained in human waste diluted in waterways and discharged into water bodies (i.e. the lagoon of Nador) instead of being returned into the soil causing water quality problems as well as eutrophication.

Therefore, urban governance, along with the development and renewal of these urban infrastructures becomes fundamental in the regulation of a sustainable relationship between nature and societies, and hence it becomes vital in the promotion of urban sustainability. Accordingly, and as an example, the application and use of decentralized sustainable and ecological sanitation on-site systems, in the rural, peri-urban and urban areas of GN, where households are not connected to sewerage, could not only minimize nutrient outflows and inflows by reduced emissions to the aquatic environment and recycled use of nutrients back to the agriculture replacing chemical fertilizers, but also reduce socio-spatial inequalities and improve the social well-being of GN urban region. Moreover, it would reduce the enormous investment in new municipal infrastructure thus attenuating the environmental costs of urban dispersion.

With reference to the suitability of the chosen conceptual framework to study the urban flow system of Gran Nador -a specific objective of the present research-, I consider the conceptual framework of UM suitable for studies of the urban system, although enhanced interdisciplinary dialogue and knowledge-building is necessary and fundamental for future assessments of how to work out more circular urban systems.

The main drawback throughout this research has been, most prominently, the access and collection of data. Sometimes data at the local/regional level was scarce and means of data collection and/or access was limited. In other cases, complete and sufficient data was inaccessible. Therefore, data sources were highly heterogeneous varying from international institutions and official national and regional statistical publications to unpublished reports authored by municipal and regional level institutions and provided by the experts working at these institutions which were interviewed. These data limitations, on both quantity and quality, made the research process more difficult and more time-consuming, since I had to make use of approximations, surrogates and proxies, as well as to resort to the adoption of different assumptions and estimation methods provided by other authors in their case studies or by other institutions. Consequently, data shortcomings were identified as a major reason for the limited available studies at the regional scale of analysis, and the likely reason of why studies at the regional scale are the least available. Yet, I must acknowledge the enormous help provided local experts.

In this regard, this research study contributes to expand the existing literature on nutrient flows in urban areas by providing what we believe is the first example of a SFA application on nutrient food flows not only in a Moroccan region, but also of a North African country/region as well. Besides, since the spatial system boundary of the case study is defined at a regional scale, which is the least studied scale in the available analysis on nutrient flows, our work may also contribute to fill this knowledge gap in SFA studies. Third, this thesis also contributes to provide a sociopolitical and historical framework to the biophysical assessment of nutrient flows for the urban metabolism of food in Grand Nador, in an attempt to provide strong insights of the significant influence that urban histories have on its metabolic flows. Hence, the importance to study them to fully understand the quantitative assessment, since both analysis complement each other.

Finally, this work also attempts to provide insights on the importance of analyzing the region's ability to support the volume and intensity of its socio-economic activities from an ecological point of view. As stated above, agriculture was the largest contributor to anthropogenic N and P flows. Therefore, it is important not only to determine highly consuming urban regions of meat and dairy products, and try to shift the composition of these location specific urban diets to habits requiring less N and P inputs, but also to target the peri-urban regions where meat is produced, in order to determine whether unequal ecological distributional flows of N and P may unfold between production and consumption regions. That is, livestock producer regions may become N and P hot spots, since they endure the highest share of unproductive lost and accumulation of nutrients of the whole food chain, thus having to face the problems of environmental degradation with the consequences of the accumulation and loss of nutrients; yet these regions are not always the higher meat consumers. Therefore, optimizing animal density production, by assessing absorption capacity of manure recycling rates to fields and applying practices of recycling farming residues, will be critical to not surpass the carrying capacity of the land's region. Nevertheless, further research is needed in order to test these primary insights.

As a common added difficulty in environmental sciences, interdisciplinary know-how and understanding are required. The present study has attempted to show not only the importance of quantitative perspectives or biophysics to understand metabolic flows and be able to modify future dynamics, but also the significance of sociopolitical approaches to urban space. In this regard, the different perspectives and conceptualizations of UM across the different disciplines complement each other, and thus sound interdisciplinary research will be a must to draw a complete picture on urban sustainability and its challenges.

The SFA method, despite being data-demanding and work-intensive, in our case it only provided results for a single year. Obviously this makes difficult the understanding of long-term fates and magnitudes of nutrient flows. Therefore, results are not usually sufficient for decision-making or to make any specific recommendations. In this regard, the useful information about the relative magnitude of the flows and losses yielded by SFA analysis could be enhanced by performing the same system analysis over the long term or multiple years. Besides, it can be supported with other tools and methods, such as LCA analysis -to calculate the environmental impact of substance flows- for a more complete sustainability study. Still, SFA can help to monitor whether the goal of a more sustainable society is being met.

Moreover, it would be appropriate to further extend the present analysis by integrating the dimensions of energy and water. In projections of global population growth, rising demand and competition for resources, with unpredictable impacts for the functioning of our societies and the environment, is expected to occur, particularly in low and middle- income nations. Therefore, by better understanding the Energy-Water-Food Nexus complex and dynamic interdependencies and interactions -each affects the other in substantive ways-, potential trade-offs and synergies can be anticipated and potential tensions avoided, so that our natural limited resources can be used and managed sustainably, by designing, appraising and prioritizing response options that are viable across different sectors and scales. Again, in this the consideration of the historical and sociopolitical frameworks is of the utmost importance.

With reference to these last two points, the establishment of a standardize MFA/SFA grounded methodology that assists in the detection, monitoring and analysis of urban flows at different scales or spatial levels at the same time, should be firmly emphasized in order to improve the analysis towards drawing a complete sustainability picture of the city. The analysis on every spatial scale proves to be a useful tool in the effort to meet the sustainability challenge.

On the other hand, the influences of long term changes of socioeconomic, political and technological factors on N and P flows can be crucial in determining the fate and magnitude of these nutrient flows over several years on specific locations. The SFA does not study monetary flows or the wider historical and sociopolitical contexts. Again, the application of a single methodology for the sustainability study tends to be always incomplete or insufficient, thus requiring of other supporting methods to draw a complete sustainability picture. Yet, further research is needed to conclude the close dependency of the metabolic flows on urban history, as well as their influence on the future of cities. To the best of our knowledge, today no studies exist on N and P nutrient food-related flows that include the analysis of the wider sociopolitical and historical context of the region studied. Studies such as Antikainen (2007) in Finland, Barles (2007) in Paris, France, or Neset (2005) in Linköping, Sweden, do examine the historical development of the nutrient flows, yet from a quantitative perspective, i.e. putting numbers to the historical changes in N and P flows but do not fully incorporate a discussion of the relevance of such historical approaches for current problems.

To finish, I think important to note one last observation. After the present study, my personal impression is that we should begin to rethink the rural-urban dichotomy and approach it differently, since both worlds are parts of a whole, even more when our future strategies to attain sustainable nutrient management aim to close the nutrient cycles to better manage the relationship between food systems and nutrient cycling, and simultaneously achieve more circular urban systems. Urban systems depend on the food resources produced and provided by rural systems, yet rural systems are dependent on urban food demand and in a future on its urban organic waste to be used as fertilizer.

Besides, Lerner and Eakin (2011) argue that the historic division of urban and rural no longer characterizes the increasingly important emergent hybrid spaces, consisting of a mosaic of urban and rural worlds that have been evolving, in recent years, especially in the developing world. These landscapes, referred to as ‘peri-urban’, ‘rur-urban’, ‘rural-urban interface’ and ‘urban fringe’, i.e. not rural but not yet urban, also described as ‘a transition zone between city and countryside’, reflect a diversity of spaces in which organic spatial heterogeneity and multi-functionality coexist (i.e., food provisioning activities, urban forms, culture and livelihoods coexist). Furthermore, as we have attempted to show for the case of Nador, it is in these spaces where, according to Lerner and Eakin (2011), there is also a potential to address the challenges of sustaining food security, environmental integrity and economic growth.

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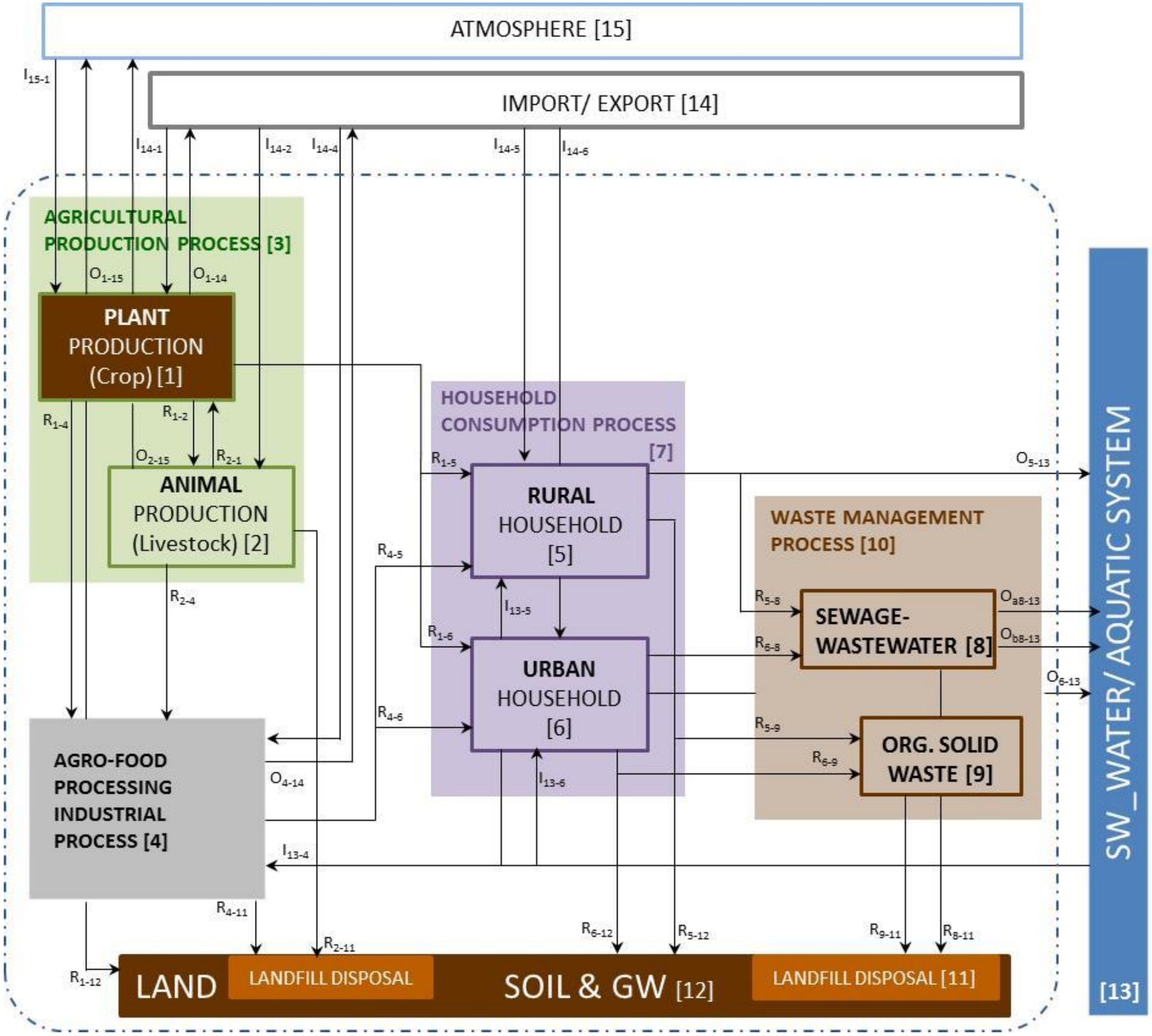
Appendices:

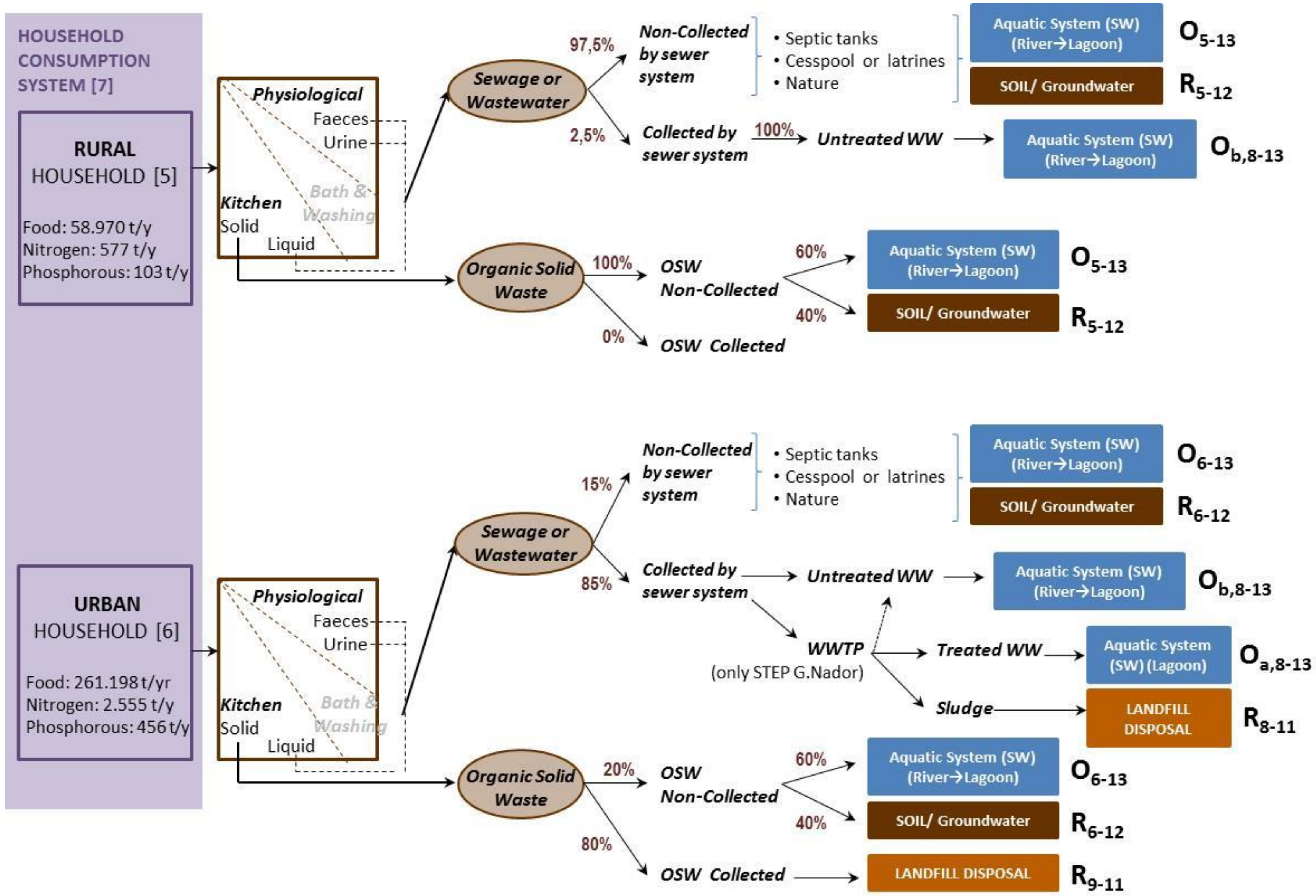
Appendix 1.: Flow diagram representation of the system analysed and Schematic representation of the Consumption-Waste Processes 182
Appendix 2.: NITROGEN and PHOSPHORUS flows diagram of the Urban food metabolism and N and P flows diagram of the Consumption-Waste Processes of Grand Nador in 2010.. 184
Appendix 3.: Flow and stock values of the nutrient (N and P) food-related flows of Grand Nador in 2010.. 187
Appendix 4.: Values of PARAMETERS of model equations for the nutrient (N and P) food-related flow model of Grand Nador.. 190
Appendix 5.: Uncertainty Flow values for nutrient (N and P) Food-related flows of Grand Nador in 2010.. 230
Appendix 6.: Case study list 233

Appendix 1.: Flow diagram representation of the system analysed

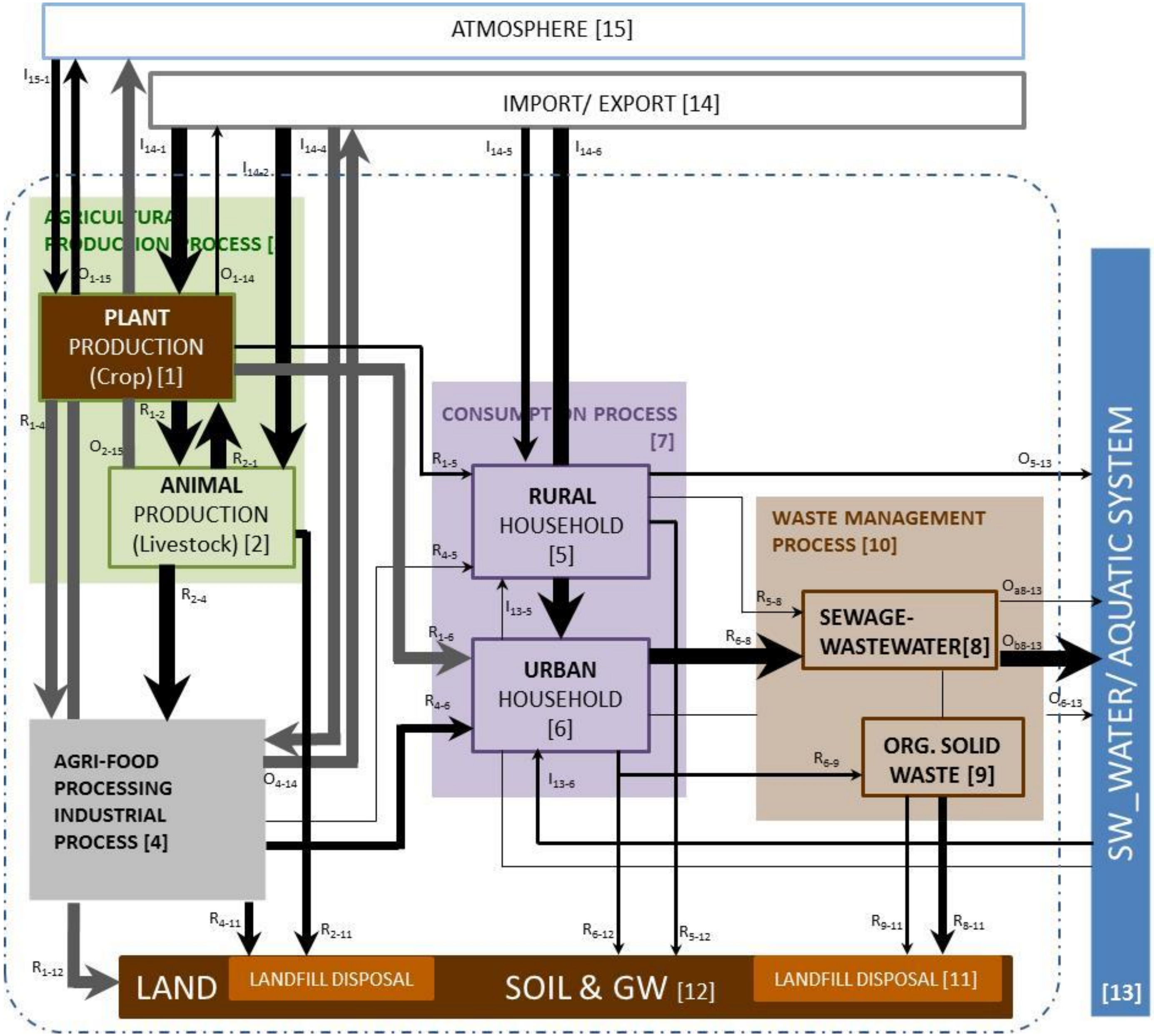


$I_{15\text{-}1}$: Atmospheric Deposition
$I_{14\text{-}1}$: Imports of fertilizers
$I_{14\text{-}2}$: Imports of fodder and feedstuff
$I_{14\text{-}4}$: Imports of food to agro-food p.Ind.
$I_{14\text{-}5}$: Imports of food pdcts. to Rural HH.
$I_{14\text{-}6}$: Imports of food pdcts. to Urban HH.
$I_{13\text{-}4}$: Fish local catches to agro-food p.Ind.
$I_{13\text{-}5}$: Fish local catches/pdct. to Rural HH.
$I_{13\text{-}6}$: Fish local catches/pdct. to Urban HH.
$R_{1\text{-}2}$: Fodder crops as animal feed
$R_{1\text{-}4}$: Locally produced plant/crop pdcts. to agro-food p.Ind.
$R_{1\text{-}5}$: Locally produced plant/crop pdcts. to Rural HH consumpt.
$R_{1\text{-}6}$: Locally produced plant/crop pdcts. to Urban HH consumpt.
$R_{1\text{-}12}$: Leaching/runoff from agric. land
$R_{2\text{-}1}$: Manure to agricultural land
$R_{2\text{-}4}$: Animal pdcts. to agro-food p.Ind.
$R_{2\text{-}11}$: Manure (poultry) to landfill
$R_{4\text{-}5}$: Agro-food pdcts. to Rural HH Cons.
$R_{4\text{-}6}$: Agro-food pdcts to Urban HH Cons.
$R_{4\text{-}11}$: OSW from agro-food p.Ind. (Landfill)
$R_{5\text{-}8}$: WW/S from Rural HH to sewerage
$R_{5\text{-}9}$: OSW from Rural HH collected
$R_{5\text{-}12}$: Non-collected OSW and WW/S from Rural HH to soil & GW
$R_{6\text{-}8}$: WW/S from Urban HH to sewerage
$R_{6\text{-}9}$: OSW from Urban HH collected
$R_{6\text{-}12}$: Non-collected OSW and WW/S from Urban HH to soil & GW
$R_{8\text{-}11}$: Sludge from WWTP to Landfill
$R_{9\text{-}11}$: Collected OSW to Landfill
$O_{1\text{-}15}$: Air Emissions from fertilizer
$O_{2\text{-}15}$: Air Emissions from manure
$O_{1\text{-}14}$: Export of locally produced plant/crop pdcts.
$O_{4\text{-}14}$: Export of agro-food industrial pdcts.
$O_{5\text{-}13}$: Non-collected OSW and WW/S from Rural HH to surface waters.
$O_{6\text{-}13}$: Non-collected OSW and WW/S from Urban HH to surface waters.
$O_{a8\text{-}13}$: Collected WW/S and treated by the WWTP.
$O_{b8\text{-}13}$: Collected WW/S but untreated

Schematic representation of the Consumption-Waste Processes

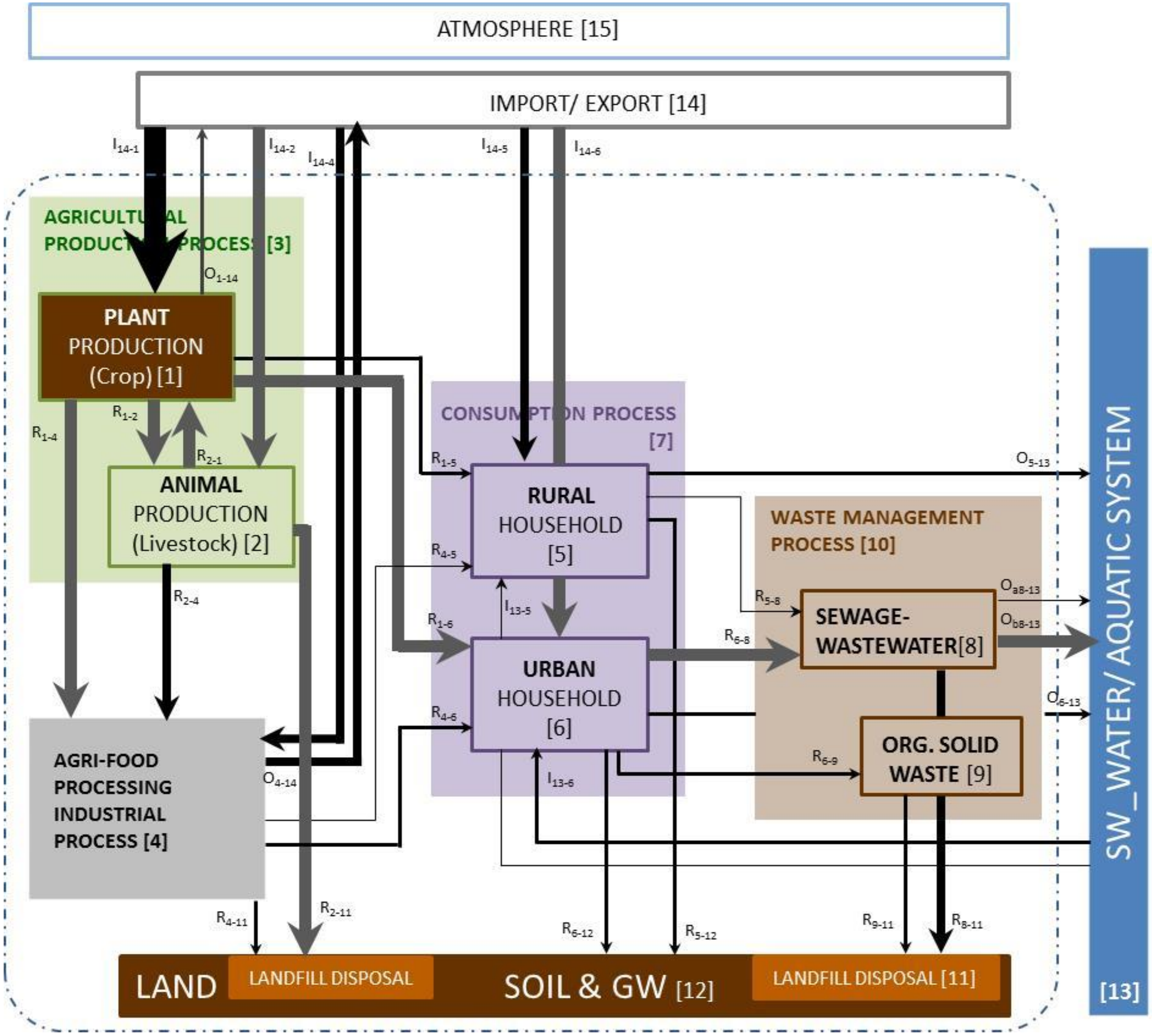


Appendix 2.: NITROGEN flows diagram of the Urban food metabolism of Grand Nador in 2010



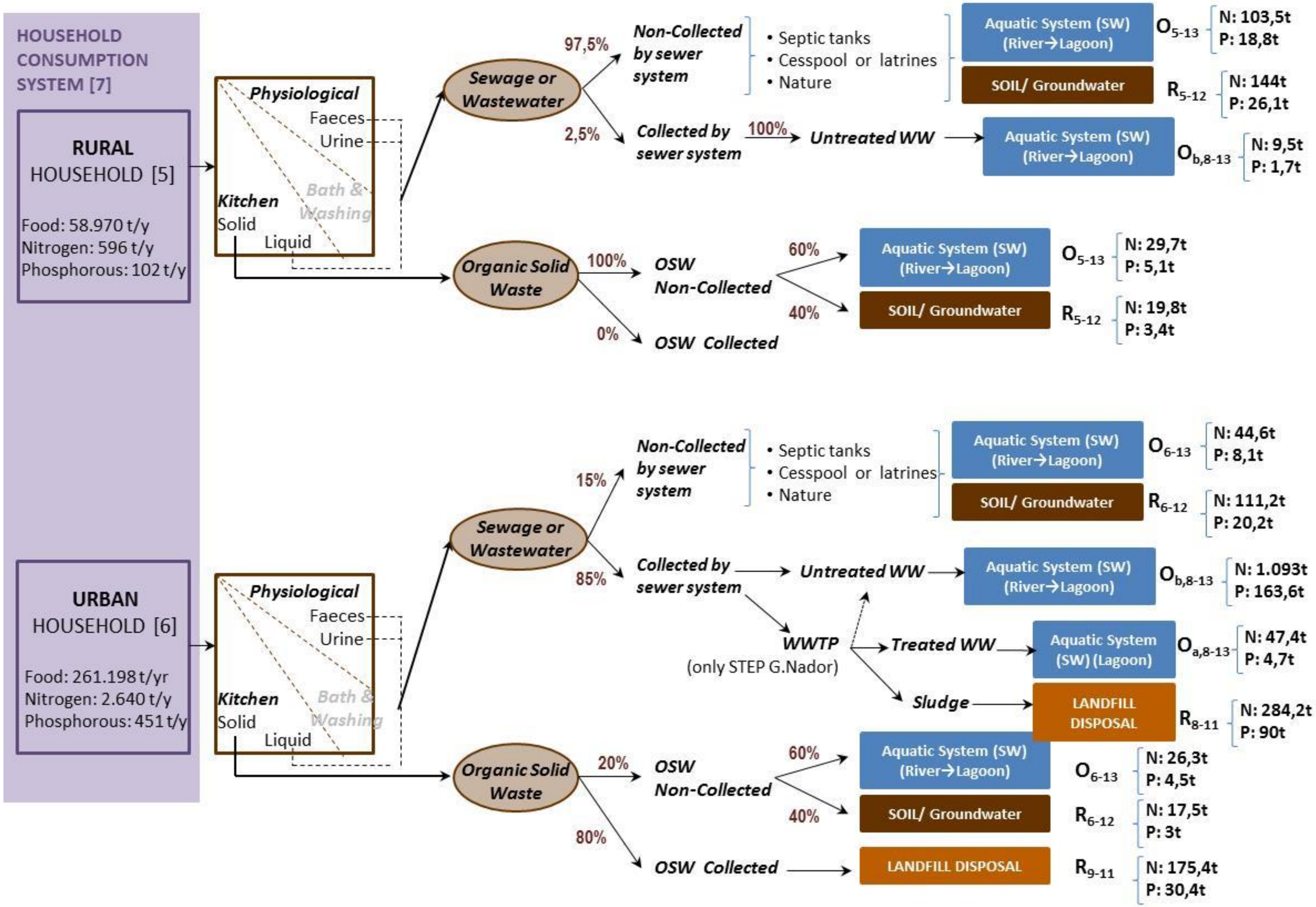
$I_{N,14-1}$:	2.785 t.
$R_{N,1-2}$:	1.774 t.
$R_{N,2-1}$:	1.685 t.
$I_{N,14-6}$:	1.438 t.
$R_{N,6-8}$:	1.424 t.
$I_{N,14-2}$:	1.247 t.
$R_{N,2-4}$:	1.115 t.
$O_{N,b8-13}$:	1.102 t.
$I_{N,14-4}$:	770 t.
$O_{N,4-14}$:	760 t.
$R_{N,1-4}$:	741 t.
$R_{N,1-12}$:	716 t.
$R_{N,1-6}$:	685 t.
$O_{N,2-15}$:	602 t.
$I_{N,15-1}$:	397 t.
$R_{N,4-6}$:	395 t.
$R_{N,2-11}$:	346 t.
$I_{N,14-5}$:	324 t.
$O_{N,1-15}$:	315 t.
$R_{N,8-11}$:	284 t.
$R_{N,4-11}$:	278 t.
$R_{N,9-11}$:	175 t.
$R_{N,6-9}$:	175 t.
$R_{N,5-12}$:	164 t.
$R_{N,1-5}$:	155 t.
$O_{N,5-13}$:	133 t.
$R_{N,6-12}$:	129 t.
$I_{N,13-6}$:	122 t.
$O_{N,1-14}$:	101 t.
$R_{N,4-5}$:	89 t.
$O_{N,6-13}$:	71 t.
$O_{N,a8-13}$:	47 t.
$I_{N,13-5}$:	27 t.
$R_{N,5-8}$:	9 t.

PHOSPHORUS flows diagram of the Urban food metabolism of Grand Nador in 2010.



$I_{P,14-1}$:	1.666 t.
$I_{P,14-2}$:	347 t.
$R_{P,2-11}$:	284 t.
$I_{P,14-6}$:	266 t.
$R_{P,6-8}$:	258 t.
$R_{P,2-1}$:	194t.
$O_{P,b8-13}$:	165 t.
$R_{P,1-6}$:	141 t.
$R_{P,1-2}$:	135 t.
$R_{P,1-4}$:	129 t.
$R_{P,8-11}$:	90 t.
$I_{P,14-4}$:	78 t.
$R_{P,2-4}$:	76 t.
$I_{P,14-5}$:	60 t.
$O_{P,4-14}$:	50 t.
$R_{P,4-6}$:	34 t.
$R_{P,1-5}$:	32 t.
$R_{P,6-9}$:	30 t.
$R_{P,9-11}$:	30 t.
$R_{P,5-12}$:	29 t.
$O_{P,5-13}$:	24 t.
$R_{P,6-12}$:	23 t.
$R_{P,4-11}$:	15 t.
$O_{P,6-13}$:	13 t.
$O_{P,1-14}$:	11 t.
$I_{P,13-6}$:	10 t.
$R_{P,4-5}$:	8 t.
$O_{P,a8-13}$:	5 t.
$I_{P,13-5}$:	2 t.
$R_{P,5-8}$:	2 t.

NITROGEN and PHOSPHORUS flows diagram of the Consumption-Waste Processes of Grand Nador in 2010



Appendix 3.: Flow and stock values of the nutrient (N and P) food-related flows of Grand Nador in 2010

No.	Name - Description	Nitrogen	Unit	Phosphorus	Unit
	Sistem boundary	3.979.174,33	kg N yr^{-1}	2.161.607,23	kg P yr^{-1}
Stocks					
B1	Plant/Crop production sub-process	379.882,05	kg N yr^{-1}	1.412.525,92	kg P yr^{-1}
B2	Animal/Livestock production sub-process	-726.157,20	kg N yr^{-1}	-72.454,28	kg P yr^{-1}
B3	***Agricultural production process***	***-346.275,15***	***kg N yr^{-1}***	***1.340.071,65***	***kg P yr^{-1}***
B4	***Agri-Food processing industrial process***	***1.102.360,18***	***kg N yr^{-1}***	***175.724,53***	***kg P yr^{-1}***
B5	Rural Household consumption sub-process	289.551,28	kg N yr^{-1}	46.723,36	kg P yr^{-1}
B6	Urban Household consumption sub-process	840.496,65	kg N yr^{-1}	126.797,25	kg P yr^{-1}
B7	***Household consumption process (HH)***	***1.130.047,93***	***kg N yr^{-1}***	***173.520,61***	***kg P yr^{-1}***
B8	Sewage-Wastewater sub-process	0,00	kg N yr^{-1}	0,00	kg P yr^{-1}
B9	Organic Solid Waste (MSW) sub-process	0,00	kg N yr^{-1}	0,00	kg P yr^{-1}
B10	***Waste Management process***	***-0,01***	***kg N yr^{-1}***	***0,00***	***kg P yr^{-1}***
B11	***Landfill disposal***	***1.084.691,44***	***kg N yr^{-1}***	***419.544,49***	***kg P yr^{-1}***
B12	***Land - soil and Groundwater (GW)***	***1.008.349,94***	***kg N yr^{-1}***	***52.745,96***	***kg P yr^{-1}***
B13	***Surface Water/ aquatic system***	***1.353.814,33***	***kg N yr^{-1}***	***206.587,13***	***kg P yr^{-1}***
B14	***Import/Export***	***-5.704.347,41***	***kg N yr^{-1}***	***-2.355.859,97***	***kg P yr^{-1}***
B15	***Atmosphere***	***520.520,05***	***kg N yr^{-1}***	***0,00***	***kg P yr^{-1}***

No.	Name - Description	Nitrogen	Unit	Phosphorus	Unit
Flows					
I_{15-1}	**Atmospheric deposition**	396.949,00	kg N yr^{-1}		kg P yr^{-1}
I_{14-1}	**Imports of fertilizers**	2.784.611,00	kg N yr^{-1}	1.665.732,00	kg P yr^{-1}
I_{14-2}	**Imports of fodder and feedstuff**	1.247.495,20	kg N yr^{-1}	347.161,56	kg P yr^{-1}
I_{14-4}	**Imports of food to agri-food processing industry**	769.854,75	kg N yr^{-1}	78.332,00	kg P yr^{-1}
I_{14-5}	**Import of food products to Rural HH consumption**	324.664,47	kg N yr^{-1}	60.107,66	kg P yr^{-1}
I_{14-6}	**Import of food products to Urban HH consumption**	1.438.044,19	kg N yr^{-1}	266.236,32	kg P yr^{-1}
I_{13-4}	**Fish local catches to agri-food processing industry**	0,00	kg N yr^{-1}	0,00	kg P yr^{-1}
I_{13-5}	**Fish local catches/product to Rural HH consumption**	27.473,27	kg N yr^{-1}	2.271,81	kg P yr^{-1}
I_{13-6}	**Fish local catches/product to Urban HH consumption**	121.688,03	kg N yr^{-1}	10.062,59	kg P yr^{-1}
R_{1-2}	**Fodder crops as animal feed**	1.774.548,27	kg N yr^{-1}	134.598,63	kg P yr^{-1}
R_{1-4}	**Locally produced plant/crop products to agri-food processing industry**	740.842,00	kg N yr^{-1}	129.417,00	kg P yr^{-1}
R_{1-5}	**Locally produced plant/crop products (Veg Food) to Rural HH consumption**	154.605,25	kg N yr^{-1}	31.727,15	kg P yr^{-1}
R_{1-6}	**Locally produced plant/crop products (Veg Food) to Urban HH consumption**	684.796,75	kg N yr^{-1}	140.529,85	kg P yr^{-1}
R_{1-12}	**Leaching/runoff from agricultural land (to Soil/Groundwater)**	715.825,50	kg N yr^{-1}		kg P yr^{-1}
R_{2-1}	**Manure (as organic fertiliser) to agricultural land**	1.685.004,51	kg N yr^{-1}	194.599,97	kg P yr^{-1}
R_{2-4}	**Animal products to agri-food processing industry**	1.114.742,27	kg N yr^{-1}	75.958,58	kg P yr^{-1}
R_{2-11}	**Manure (from poultry production) to landfill**	346.342,03	kg N yr^{-1}	283.655,91	kg P yr^{-1}
R_{4-5}	**Agri-food proccesed pdcts to Rural HH consumption**	89.273,58	kg N yr^{-1}	7.792,93	kg P yr^{-1}
R_{4-6}	**Agri-food proccesed pdcts to Urban HH consumption**	395.421,62	kg N yr^{-1}	34.517,43	kg P yr^{-1}
R_{4-11}	**Organic solid waste from agri-food processing industry**	278.768,93	kg N yr^{-1}	15.496,54	kg P yr^{-1}

No.	Name - Description	Nitrogen	Unit	Phosphorus	Unit
Flows					
$R_{5\text{-}8}$	**Wastewater/sewage from Rural HH collected by sewer system**	9.458,79	kg N yr^{-1}	1.715,25	kg P yr^{-1}
$R_{5\text{-}9}$	**Organic solid waste (OSW) from Rural HH collected**	0,00	kg N yr^{-1}	0,00	kg P yr^{-1}
$R_{5\text{-}12}$	**Non-collected OSW and WW/sewage from Rural HH to soil/groundwater**	163.796,15	kg N yr^{-1}	29.543,48	kg P yr^{-1}
$R_{6\text{-}8}$	**Wastewater/sewage from Urban HH collected by sewer system**	1.424.464,92	kg N yr^{-1}	258.311,72	kg P yr^{-1}
$R_{6\text{-}9}$	**Organic solid waste (OSW) from Urban HH collected**	175.362,27	kg N yr^{-1}	30.389,62	kg P yr^{-1}
$R_{6\text{-}12}$	**Non-collected OSW and WW/sewage from Urban HH to soil/groundwater**	128.728,29	kg N yr^{-1}	23.202,47	kg P yr^{-1}
$R_{8\text{-}11}$	**Sludge from WWTP to Landfill**	284.218,20	kg N yr^{-1}	90.002,43	kg P yr^{-1}
$R_{9\text{-}11}$	**Collected OSW -organic solid waste- to Landfill**	175.362,27	kg N yr^{-1}	30.389,61	kg P yr^{-1}
$O_{1\text{-}15}$	**Air emissions from fertilizers**	315.357,20	kg N yr^{-1}		kg P yr^{-1}
$O_{1\text{-}14}$	**Export of locally produced plant/crops products**	100.707,50	kg N yr^{-1}	11.533,42	kg P yr^{-1}
$O_{2\text{-}15}$	**N losses from manure to the atmosphere**	602.111,86	kg N yr^{-1}		kg P yr^{-1}
$O_{4\text{-}14}$	**Export of agri-food industrial products**	759.614,70	kg N yr^{-1}	50.176,15	kg P yr^{-1}
$O_{5\text{-}13}$	**Non-collected OSW and WW/sewage from Rural HH to surface water**	133.210,35	kg N yr^{-1}	23.917,47	kg P yr^{-1}
$O_{6\text{-}13}$	**Non-collected OSW and WW/sewage from Urban HH to surface water**	70.898,47	kg N yr^{-1}	12.645,12	kg P yr^{-1}
$O_{a8\text{-}13}$	**Collected WW/sewage and treated by the WWTP**	47.369,70	kg N yr^{-1}	4.736,97	kg P yr^{-1}
$O_{b8\text{-}13}$	**Collected WW/sewage but untreated**	1.102.335,81	kg N yr^{-1}	165.287,57	kg P yr^{-1}

Appendix 4.: Values of PARAMETERS of model equations for the nutrient (N and P) food-related flow model of Grand Nador

Symbol	Description	Qty	Unit	Reference	Year
$n_{population}$	number of total inhabitants of Grand Nador	451.779	inhabitant	RGPH, 2004; HCP-Projections 2005-2030; MRO, 2010	2004; 2010
n_{pop_urban}	number of urban inhabitants of Grand Nador	347.249	inhabitant	RGPH, 2004; HCP-Projections 2005-2030; MRO, 2010	2004; 2010
n_{pop_rural}	number of rural inhabitants of Grand Nador	104.530	inhabitant	RGPH, 2004; HCP-Projections 2005-2030; MRO, 2010	2004; 2010
$a_{N,\ atm\_dep}$	Atmospheric N deposition	7	kg N ha^{-1} $year^{-1}$	BIP_Biodiversity Indicators Partnership	2011
S_{area}	number of hectares of the agricultural production land	56.707	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{area_irr}	number of ha of the agricultural production land irrigated	27.317	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{area_rfd}	number of ha of the agricultural production land rainfed	29.390	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{cereal_irr}	sown area irrigated cereal	7.128	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{cereal_rfd}	sown area rainfed cereal	25.975	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{fodder_irr}	sown area irrigated fodder	3.273	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{fodder_rfd}	sown area rainfed fodder	16	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010

Symbol	Description	Qty	Unit	Reference	Year
S_{pulses_irr}	sown area irrigated pulses	5	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{pulses_rfd}	sown area rainfed pulses	15	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{veg_irr}	sown area irrigated vegetables and horticulture	2.280	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{veg_rfd}	sown area rainfed vegetables and horticulture	160	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{oliv_irr}	sown area irrigated olives	4.833	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{oliv_rfd}	sown area rainfed olives	3.000	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{winegr_irr}	sown area irrigated wine grapes	1.544	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{winegr_rfd}	sown area rainfed wine grapes	0	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{arboth_irr}	sown area irrigated arboriculture other	749	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
$S_{arbothl\_rfd}$	sown area rainfed arboriculture other	224	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
S_{citrus_irr}	sown area irrigated citrus fruits	2.096	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010

Symbol	Description	Qty	Unit	Reference	Year
$S_{\text{citrus\_rfd}}$	sown area rainfed citrus fruits	0	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
$S_{\text{beet ind\_irr}}$	sown area irrigated sugar beet industrial crop	5.125	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
$S_{\text{beet ind\_rfd}}$	sown area rainfed sugar beet industrial crop	0	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
$S_{\text{Oth c\_irr}}$	sown area irrigated other crops	284	ha	Annuaire Statistique de la Región de l'Oriental 2011 et 2009	2010
$r_{\text{fert\_cereal\_irr}}$	percentage area of irrigated cereal fertilized	90%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_cereal\_rfd}}$	percentage area of rainfed cereal fertilized	20%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_fodder\_irr}}$	percentage area of irrigated fodder fertilized	100%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_fodder\_rfd}}$	percentage area of rainfed fodder fertilized	50%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_pulses\_irr}}$	percentage area of irrigated pulses fertilized	90%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_pulses\_rfd}}$	percentage area of rainfed pulses fertilized	20%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_veg\_irr}}$	percentage area of irrigated vegetables and horticulture fertilized	90%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_veg\_rfd}}$	percentage area of rainfed vegetables and horticulture fertilized	80%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_olive\_irr}}$	percentage area of irrigated olives fertilized	60%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_olive\_rfd}}$	percentage area of rainfed olives fertilized	30%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006

Symbol	Description	Qty	Unit	Reference	Year
$r_{\text{fert\_winegr\_irr}}$	percentage area of irrigated wine grapes fertilized	100%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_winegr\_rfd}}$	percentage area of rainfed wine grapes fertilized	60%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_arboth\_irr}}$	percentage area of irrigated other arboriculture fertilized	60%	%	Assumption	
$r_{\text{fert\_arboth\_rfd}}$	percentage area of rainfed other arboriculture fertilized	30%	%	Assumption	
$r_{\text{fert\_citrus\_irr}}$	percentage area of irrigated citrus fruits fertilized	100%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_citrus\_rfd}}$	percentage area of rainfed citrus fruits fertilized	0%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_beet ind\_irr}}$	percentage area of irrigated sugar beet industrial crop fertilized	100%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_beet ind\_rfd}}$	percentage area of rainfed sugar beet industrial crop fertilized	0%	%	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$r_{\text{fert\_Oth c\_irr}}$	percentage area of irrigated other crops fertilized	90%	%	Assumption	
$a_{\text{N, mfert\_cereal}}$	annual synthetic N fertiliser application rate per cereal	60,00	kg N ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{\text{N, mfert\_fodder}}$	annual synthetic N fertiliser application rate per fodder	50,00	kg N ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{\text{N, mfert\_pulses}}$	annual synthetic N fertiliser application rate per pulses	30,00	kg N ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{\text{N, mfert\_veg}}$	annual synthetic N fertiliser application rate per vegetables and horticulture	70,00	kg N ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{\text{N, mfert\_olive}}$	annual synthetic N fertiliser application rate per olives	80,00	kg N ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{\text{N, mfert\_winegr}}$	annual synthetic N fertiliser application rate per wine grapes	150,00	kg N ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{\text{N, mfert\_arboth}}$	annual synthetic N fertiliser application rate per other arboriculture	80,00	kg N ha^{-1} $year^{-1}$	Assumption	

Symbol	Description	Qty	Unit	Reference	Year
$a_{N,\ mfert\_citrus}$	annual synthetic N fertiliser application rate per citrus fruits	170,00	kg N ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{N,\ mfert\_beet\ ind}$	annual synthetic N fertiliser application rate per sugar beet industrial	160,00	kg N ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{N,\ mfert\_Oth\ c}$	annual synthetic N fertiliser application rate per other crops	70,00	kg N ha^{-1} $year^{-1}$	Assumption	
$a_{P,\ mfert\_cereal}$	annual synthetic P fertiliser application rate per cereal	40,00	kg P ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{P,\ mfert\_fodder}$	annual synthetic P fertiliser application rate per fodder	60,00	kg P ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{P,\ mfert\_pulses}$	annual synthetic P fertiliser application rate per pulses	40,00	kg P ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{P,\ mfert\_veg}$	annual synthetic P fertiliser application rate per vegetables and horticulture	60,00	kg P ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{P,\ mfert\_olive}$	annual synthetic P fertiliser application rate per olives	20,00	kg P ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{P,\ mfert\_winegr}$	annual synthetic P fertiliser application rate per wine grapes	100,00	kg P ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{P,\ mfert\_arboth}$	annual synthetic P fertiliser application rate per other arboriculture	20,00	kg P ha^{-1} $year^{-1}$	Assumption	
$a_{P,\ mfert\_citrus}$	annual synthetic P fertiliser application rate per citrus fruits	50,00	kg P ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{P,\ mfert\_beet\ ind}$	annual synthetic P fertiliser application rate per sugar beet industrial	100,00	kg P ha^{-1} $year^{-1}$	FAO, 2006. Utilisation des engrais par culture au Maroc	2006
$a_{P,\ mfert\_Oth\ c}$	annual synthetic P fertiliser application rate per other crops	60,00	kg P ha^{-1} $year^{-1}$	Assumption	
$n_{cattle\ irrigation}$	number of cattles raised on irrigated perimeters and slaughtered	4.000	head	Annuaire Statistique de la Region de l'Oriental-2011	2011
$n_{cattle\ rainfed}$	number of cattles raised on rainfed area and in the periphery of irrigated perimeters and slaughtered	9.500	head	Annuaire Statistique de la Region de l'Oriental-2011	2011
$n_{sheep\ irrigation}$	number of sheep raised on irrigated perimeters and slaughtered	120.000	head	Annuaire Statistique de la Region de l'Oriental-2011	2011

Symbol	Description	Qty	Unit	Reference	Year
$n_{\text{sheep rainfed}}$	number of sheep raised on rainfed area and in the periphery of irrigated perimeters and slaughtered	180.000	head	Annuaire Statistique de la Region de l'Oriental-2011	2011
$n_{\text{goats irrigation}}$	number of goats raised on irrigated perimeters and slaughtered	45.000	head	Annuaire Statistique de la Region de l'Oriental-2011	2011
$n_{\text{goats rainfed}}$	number of goats raised on rainfed area and in the periphery of irrigated perimeters and slaughtered	11.000	head	Annuaire Statistique de la Region de l'Oriental-2011	2011
n_{poultry}	number of broilers raised and slaughtered_industrial system	8.280.000	head	Annuaire Statistique de la Region de l'Oriental-2011	2011
$a_{\text{feed\_Cattle irr}}$	annual average feed requirement per cattle raised under irrigation perimeters	3.000	Kg of fodder crops year^{-1} head^{-1}	Chafai, 2004	2004
$a_{\text{feed\_Cattle rfd}}$	annual average feed requirement per cattle raised under rainfed area	1.500	Kg of fodder crops year^{-1} head^{-1}	Chafai, 2004	2004
$a_{\text{feed\_Sheep irr}}$	annual average feed requirement per sheep raised under irrigated perimeters or surrounding areas	200	Kg of fodder crops year^{-1} head^{-1}	Chafai, 2004	2004
$a_{\text{feed\_Sheep rfd}}$	annual average feed requirement per sheep raised under rainfed area	200	Kg of fodder crops year^{-1} head^{-1}	Chafai, 2004	2004
$a_{\text{feed\_Goat irr}}$	annual average feed requirement per goat raised under irrigated perimeters or surrounding areas	160	Kg of fodder crops year^{-1} head^{-1}	Chafai, 2004	2004
$a_{\text{feed\_Goat rfd}}$	annual average feed requirement per goat raised under rainfed area	160	Kg of fodder crops year^{-1} head^{-1}	Chafai, 2004	2004
$C_{\text{N, feed\_Alfalfa\_H}}$	nitrogen content in Alfalfa Hay 89,4% DM	0,02912	kg N/ Kg Alfalfa hay 89,4% DM	Feedipedia-Animal Feed Resources Information System	2014
$C_{\text{P, feed\_Alfalfa\_H}}$	phosphrous content in Alfalfa Hay 89,4% DM	0,0026	kg P/ Kg Alfalfa hay 89,4% DM	Feedipedia-Animal Feed Resources Information System	2014
$C_{\text{N, feed\_Alfalfa\_F}}$	nitrogen content in Alfalfa Fresh 19,9% DM	0,03296	kg N/ Kg Alfalfa fresh 19,9% DM	Feedipedia-Animal Feed Resources Information System	2014

Symbol	Description	Qty	Unit	Reference	Year
$C_{P,\ feed\_Alfalfa\_F}$	phosphrous content in Alfalfa Fresh 19,9% DM	0,0025	kg P/ Kg Alfalfa fresh 19,9% DM	Feedipedia-Animal Feed Resources Information System	2014
$C_{N,\ feed\_Barley}$	nitrogen content in Barley hay 85% DM	0,01392	kg N/ Kg Barley hay 85% DM	Feedipedia-Animal Feed Resources Information System	2014
$C_{P,\ feed\_Barley}$	phosphrous content in Barley hay 85% DM	0,0028	kg P/ Kg Barley hay 85% DM	Feedipedia-Animal Feed Resources Information System	2014
$a_{N.\ req.\_broiler}$	daily N requirement needed to produce a broiler suitable for slaughter	0,00312	kg N/broiler day	NRP-Nutrient requirements of poulty, 1994	1994
$a_{P.\ req.\_broiler}$	daily P requirement needed to produce a broiler suitable for slaughter	0,000888	kg P/ broiler day	NRP-Nutrient requirements of poulty, 1994	1994
$n_{\text{broiler feeding days}}$	duration of the broiler production cycle	42	days	NRP-Nutrient requirements of poulty, 1994	1994
$DM_{Alfalfa\_H}$	Percentage of dry matter in Alfalfa Hay	89,4	%	Feedipedia-Animal Feed Resources Information System	2014
$DM_{Alfalfa\_F}$	Percentage of dry matter in Alfalfa Fresh	19,9	%	Feedipedia-Animal Feed Resources Information System	2014
DM_{Barley_H}	Percentage of dry matter in Barley Hay	84,9	%	Feedipedia-Animal Feed Resources Information System	2014
$Alfalfa\_{\text{Locally harvested}}$	Alfalfa fodder crop locally produced and harvested	268.300.000	kg $year^{-1}$	ASRO, 2009; 2011	2009; 2011
w_{cattle}	average live weight of cattle before slaughtered	388	kg $head^{-1}$	Chafai, 2004	2004
w_{sheep}	average live weight of sheep before slaughtered	35	kg $head^{-1}$	Boujenane-MAPM/DERD_2008	2008
w_{goat}	average live weight of goat before slaughtered	36	kg $head^{-1}$	El Amiri et al., 2011	2011
$w_{poultry}$	average live weight of poultry before slaughtered	2,09	kg $head^{-1}$	NRP-Nutrient requirements of poulty, 1994	1994
$C_{N,body\_cattle}$	Nitrogen content of cattle body	3,0133	gN/ 100 g product	West African Food Composition Table - Table de composition des aliments d’Afrique de l’Ouest. FAO, Rome, 2012.	2012

Symbol	Description	Qty	Unit	Reference	Year
$C_{N,body\_sheep}$	Nitrogen content of sheep body	2,72	gN/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{N,body\_goat}$	Nitrogen content of goat body	2,72	gN/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{N,body\_poultry}$	Nitrogen content of poultry body	2,896	gN/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{P,body\_cattle}$	phosphorus content of cattle body	174,00	mg P/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{P,body\_sheep}$	phosphorus content of sheep body	149,50	mg P/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{P,body\_goat}$	phosphorus content of goat body	149,50	mg P/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012

Symbol	Description	Qty	Unit	Reference	Year
$C_{P,body\_poultry}$	phosphorus content of poultry body	145,50	mg P/ 100 g product	West African Food Composition Table - Table de composition des aliments d’Afrique de l’Ouest. FAO, Rome, 2012.	2012
n_{milk}	milk produced	21.800.000	kg	Annuaire Statistique de la Region de l'Oriental-2011	2011
$C_{N, milk}$	nitrogen content of milk	0,5329	gN/ 100g product	West African Food Composition Table - Table de composition des aliments d’Afrique de l’Ouest. FAO, Rome, 2012.	2012
$C_{P, milk}$	phosphorus content of milk	105,5	mg P/ 100g product	West African Food Composition Table - Table de composition des aliments d’Afrique de l’Ouest. FAO, Rome, 2012.	2012
$m_{livestock}$	annual amount of total N manure excreted by poultry in "with litter" MMS	1.958.403,35	kg N yr^{-1}	computed	
$m_{poultry}$	annual amount of total N manure excreted by ruminants and left on pastures	584.332,19	kg N yr^{-1}	computed	
EF_1	emission factor for direct N_2O emissions from mineral fertilisers N additions	0,01	Kg N_2O-N (Kg N yr^{-1})	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006
$EF_{3,PRP}$	emission factor for direct N_2O emissions from urine and dung N deposited on pasture, range by grazing animals_Cattle	0,02	kg N_2O-N (kg N $input)^{-1}$	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006

Symbol	Description	Qty	Unit	Reference	Year
EF_{3,PRP_SO}	emission factor for direct N_2O emissions from urine and dung N deposited on pasture, range by grazing animals-Sheep and Goat	0,01	kg N_2O-N (kg N input)$^{-1}$	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006
EF_3	emission factor for direct N_2O emissions from manure management systems	0,001	kg N_2O-N (kg N excreted)$^{-1}$	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006
EF_4	emission factor for indirect N_2O emissions for N volatilization and re-deposition	0,01	kg N_2O–N (kg NH_3–N + NO_X–N volatilized)$^{-1}$	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006
EF_5	emission factor for indirect N_2O emissions from N leaching and runoff processes	0,0075	kg N_2O–N (kg N leached and runoff)$^{-1}$	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006
$Frac_{LossMS}$	fraction value for total N loss from manure management system "Poultry with litter"	40,73%	%	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006
$Frac_{GASF}$	fraction of synthetic fertilizer N application that volatilizes as NH_3 and NOx	0,10	(kg NH_3-N + NOx-N) (kg N applied)$^{-1}$	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006
$Frac_{GasM}$	fraction of urine and dung N deposited by grazing animals that volatilizes as NH_3 and NOx	0,20	kg N volatilized (kg N deposited)$^{-1}$	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006
$Frac_{GasMS}$	fraction of poultry managed manure N that volatilizes as NH_3 and NOx in the MMS, rate of volatilization	40%	%	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006
$Frac_{LEACH-(H)}$	fraction of N losses by leaching/runoff processes	0,30	kg N (kg N additions)$^{-1}$	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4.	2006

Symbol	Description	Qty	Unit	Reference	Year
a_{pc_ahimex}	Production capacity of fishing factory AHIMEX	4.400.000	kg $year^{-1}$	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
$a_{pc\_congelmar}$	Production capacity of fishing factory CONGELMAR	660000,00	kg $year^{-1}$	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
$a_{pc\_coprinco}$	Production capacity of fishing factory COPRINCO	2640000,00	kg $year^{-1}$	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
$a_{pc\_huilmar}$	Production capacity of fishing factory HUILMAR	4620000,00	kg $year^{-1}$	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
$a_{pc\_imbadex}$	Production capacity of fishing factory IMBADEX	3300000,00	kg $year^{-1}$	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
$a_{pc\_m.servisur}$	Production capacity of fishing factory MARISCO SERVISUR	1540000,00	kg $year^{-1}$	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
$a_{pc\_m.fruit}$	Production capacity of fishing factory MER FRUIT	4400000,00	kg $year^{-1}$	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
a_{pc_pescam}	Production capacity of fishing factory PESCAM	2200000,00	kg $year^{-1}$	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010

Symbol	Description	Qty	Unit	Reference	Year
$a_{pc\_P.mer}$	Production capacity of fishing factory PETIT MER	1760000,00	kg year^{-1}	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
$a_{pc\_r.fish}$	Production capacity of fishing factory RIFO FISH	440000,00	kg year^{-1}	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
$a_{pc\_r.mar}$	Production capacity of fishing factory RESTINGA MAR	3520000,00	kg year^{-1}	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
$a_{pc\_s.anwal}$	Production capacity of fishing factory SAMAK ANWAL	880000,00	kg year^{-1}	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
$a_{pc\_m.mare}$	Production capacity of fishing factory MIOB MARE	880000,00	kg year^{-1}	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
a_{pc_sonop}	Production capacity of fishing factory SONOP	1320000,00	kg year^{-1}	Rapport Statistiques 2010. La pêche côtière et artisanale au Maroc. Office National des Pêches	2010
r_{op_cpty}	Ratio of operational capacity of fishing processing industry	60%	%	Runge et al. (2011)	2011
r_{waste_fish}	average ratio of waste production by fishing processing industry	30%	%	Runge et al. (2011)	2011
$C_{N\_pelagic}$	nitrogen content of pelagic fish	3,1683	gN/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012

Symbol	Description	Qty	Unit	Reference	Year
$C_{N\_Demersal}$	nitrogen content of demersal fish	2,884	gN/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{P\_pelagic}$	phosphorus content of pelagic fish	280,00	mg P/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{P\_Demersal}$	phosphorus content of demersal fish	191,86	mg P/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
n_{meat_cattle}	total quantity of beef meat from cattle production	2.195.000	kg $year^{-1}$	Annuaire Statistique de la Region de l'Oriental-2011	2011
n_{meat_sheep}	total quantity of mutton meat from sheep production	5.236.000	kg $year^{-1}$	Annuaire Statistique de la Region de l'Oriental-2011	2011
n_{meat_goat}	total quantity of goat meat from goat production	1.015.000	kg $year^{-1}$	Annuaire Statistique de la Region de l'Oriental-2011	2011
$n_{meat\_poultry}$	total quantity of poultry meat from broiler production	16.700.000	kg $year^{-1}$	Annuaire Statistique de la Region de l'Oriental-2011	2011
$C_{N,meat\_cattle}$	nitrogen content of beef cattle	3,013	gN/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{N,meat\_sheep}$	nitrogen content of mutton meat	2,72	gN/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012

Symbol	Description	Qty	Unit	Reference	Year
$C_{N,meat\_goat}$	nitrogen content of goat meat	2,72	gN/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{N,meat\_poultry}$	nitrogen content of poulty meat	2,896	gN/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{P,meat\_cattle}$	phosphorus content of beef cattle	174,00	mg P/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{P,meat\_sheep}$	phosphorus content of mutton meat	149,50	mg P/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{P,meat\_goat}$	phosphorus content of goat meat	149,50	mg P/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$C_{P,meat\_poultry}$	phosphorus content of poulty meat	145,50	mg P/ 100 g product	West African Food Composition Table - Table de composition des aliments d'Afrique de l'Ouest. FAO, Rome, 2012.	2012
$n_{consump\_apples}$	amount of apples consumed per person and year in Morocco	12,2	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2009

Symbol	Description	Qty	Unit	Reference	Year
$n_{consump\_bananas}$	amount of bananas consumed per person and year in Morocco	8	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_dates}$	amount of dates consumed per person and year in Morocco	2,8	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_citrus\ oth}$	amount of citrus other consumed per person and year in Morocco	0,3	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_grapes}$	amount of grapes consumed per person and year in Morocco	9,9	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_lemons}$	amount of lemons consumed per person and year in Morocco	0,5	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_oranges}$	amount of oranges consumed per person and year in Morocco	28,6	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_pineapples}$	amount of pineapples consumed per person and year in Morocco	0,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_fruits\ oth}$	amount of fruits other consumed per person and year in Morocco	25,3	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_wheat}$	amount of wheat consumed per person and year in Morocco	175,4	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_barley}$	amount of barley consumed per person and year in Morocco	28,9	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_maize}$	amount of maize consumed per person and year in Morocco	37,6	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_rye}$	amount of rye consumed per person and year in Morocco	0,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_oats}$	amount of oats consumed per person and year in Morocco	0,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_rice}$	amount of rice consumed per person and year in Morocco	1,2	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_millet}$	amount of millet consumed per person and year in Morocco	0,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_sorghum}$	amount of sorghum consumed per person and year in Morocco	1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010

Symbol	Description	Qty	Unit	Reference	Year
$n_{consump\_potatoes}$	amount of potatoes consumed per person and year in Morocco	33,5	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_sweet\ potatoes}$	amount of sweet potatoes consumed per person and year in Morocco	0,4	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_sugarcrop}$	amount of sugarcrop consumed per person and year in Morocco	41,6	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_sugar}$	amount of sugar consumed per person and year in Morocco	41,5	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_sweeteners\ oth}$	amount of sweeteners other consumed per person and year in Morocco	0,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_honey}$	amount of honey consumed per person and year in Morocco	0,2	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_beans}$	amount of beans consumed per person and year in Morocco	0,9	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_peas}$	amount of peas consumed per person and year in Morocco	1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_pulses\ oth}$	amount of pulses other consumed per person and year in Morocco	5,3	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_nuts}$	amount of nuts consumed per person and year in Morocco	4,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_coconuts}$	amount of coconuts consumed per person and year in Morocco	0,4	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_sesameseed}$	amount of sesameseed consumed per person and year in Morocco	0,2	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_olives}$	amount of olives consumed per person and year in Morocco	2	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_soyabean\ oil}$	amount of soyabean oil consumed per person and year in Morocco	6	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_olive\ oli}$	amount of olive oil consumed per person and year in Morocco	3,6	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_groundnut\ oli}$	amount of groundnut oil consumed per person and year in Morocco	0,6	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010

Symbol	Description	Qty	Unit	Reference	Year
$n_{consump\_sunflowerseed\ oli}$	amount of sunflowerseed oil consumed per person and year in Morocco	1,4	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_rape\ and\ mustard\ oil}$	amount of rape and mustard oil consumed per person and year in Morocco	0,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_oilcrops\ oil\ oth}$	amount of oilcrops oil other consumed per person and year in Morocco	0,7	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_tomatoes}$	amount of tomatoes consumed per person and year in Morocco	23,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_onions}$	amount of onions consumed per person and year in Morocco	24,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_vegetables\ oth}$	amount of vegetables other consumed per person and year in Morocco	84	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_coffee}$	amount of coffee consumed per person and year in Morocco	1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_cocoa\ beans}$	amount of cocoa beans consumed per person and year in Morocco	0,5	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_tea}$	amount of tea consumed per person and year in Morocco	1,7	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_pepper}$	amount of pepper consumed per person and year in Morocco	0,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_pimento}$	amount of pimento consumed per person and year in Morocco	0,6	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_spices\ oth}$	amount of spices other consumed per person and year in Morocco	1,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_wine}$	amount of wine other consumed per person and year in Morocco	0,7	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_beer}$	amount of beer other consumed per person and year in Morocco	2,6	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_beverages\ Alcoholic}$	amount of beverages alcoholic other consumed per person and year in Morocco	0,2	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010

Symbol	Description	Qty	Unit	Reference	Year
$n_{consump\_bovine\ meat}$	amount of bovine meat consumed per person and year in Morocco	6,4	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_mutton\ \&\ goat\ meat}$	amount of mutton & goat meat consumed per person and year in Morocco	4,9	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_poultry\ meat}$	amount of poultry meat consumed per person and year in Morocco	17,3	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_meat,\ other}$	amount of meat, other consumed per person and year in Morocco	1,5	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_offals,\ edible}$	amount of offals, edible consumed per person and year in Morocco	1,8	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_butter,\ ghee}$	amount of butter, ghee consumed per person and year in Morocco	1,7	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_fat\ animals\ raw}$	amount of fat animals raw consumed per person and year in Morocco	0,7	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_eggs}$	amount of eggs consumed per person and year in Morocco	5,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_milk}$	amount of milk consumed per person and year in Morocco	47,3	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_freshwater\ fish}$	amount of freshwater fish consumed per person and year in Morocco	0,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_demersal\ fish}$	amount of demersal fish consumed per person and year in Morocco	1,6	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_pelagic\ fish}$	amount of pelagic fish consumed per person and year in Morocco	7,1	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_marine\ fish\ oth}$	amount of marine fish other consumed per person and year in Morocco	1,7	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010
$n_{consump\_crustaceans}$	amount of crustaceans consumed per person and year in Morocco	0,6	kg (cap year)$^{-1}$	FAOSTAT Food Supply	2010

Symbol	Description	Qty	Unit	Reference	Year
$r_{food\ exp\_rural}$	rural food budget coefficient	0,84	---	ENRNVM, 2006/2007. "Enquête National sur les revenues et les niveaux de vie des Ménages 2006/2007". Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2006/ 2007
$r_{food\ exp\_urban}$	urban food budget coefficient	1,12	---	ENRNVM, 2006/2007. "Enquête National sur les revenues et les niveaux de vie des Ménages 2006/2007". Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2006/ 2007
$C_{N\_food\ apple}$	nitrogent content in food apples consumed by the population of Grand Nador	0,05	gN 100g pdct^{-1}	FAO. West African Food Composition Table	2012
$C_{N\_food\ bananas}$	nitrogent content in food bananas consumed by the population of Grand Nador	0,21	gN 100g pdct^{-1}	FAO. West African Food Composition Table	2012
$C_{N\_food\ dates}$	nitrogent content in food dates consumed by the population of Grand Nador	0,29	gN 100g pdct^{-1}	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ citrus\ oth}$	nitrogent content in food citrus other consumed by the population of Grand Nador	0,16	gN 100g pdct^{-1}	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ grapes}$	nitrogent content in food grapes consumed by the population of Grand Nador	0,12	gN 100g pdct^{-1}	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011

Symbol	Description	Qty	Unit	Reference	Year
$C_{N\_food\ lemons}$	nitrogent content in food lemons consumed by the population of Grand Nador	0,10	gN 100g pdct^{-1}	SFK. Souci, Fachmann and Kraut. 2000. Food Composition and Nutrition Tables	2000
$C_{N\_food\ oranges}$	nitrogent content in food oranges consumed by the population of Grand Nador	0,14	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ pineapples}$	nitrogent content in food pineapples consumed by the population of Grand Nador	0,07	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ fruits\ oth}$	nitrogent content in food fruits other consumed by the population of Grand Nador	0,14	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ wheat}$	nitrogent content in food wheat consumed by the population of Grand Nador	1,83	gN 100g pdct^{-1}	Sika et al., 1995	1995
$C_{N\_food\ barley}$	nitrogent content in food barley consumed by the population of Grand Nador	1,30	gN 100g pdct^{-1}	Sika et al., 1995	1995
$C_{N\_food\ maize}$	nitrogent content in food maize consumed by the population of Grand Nador	1,34	gN 100g pdct^{-1}	Sika et al., 1995	1995
$C_{N\_food\ rye}$	nitrogent content in food rye consumed by the population of Grand Nador	3,04	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ oats}$	nitrogent content in food oats consumed by the population of Grand Nador	2,02	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ rice}$	nitrogent content in food rice consumed by the population of Grand Nador	1,24	gN 100g pdct^{-1}	Sika et al., 1995	1995
$C_{N\_food\ millet}$	nitrogent content in food millet consumed by the population of Grand Nador	1,89	gN 100g pdct^{-1}	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011

Symbol	Description	Qty	Unit	Reference	Year
$C_{N\_food\ sorghum}$	nitrogent content in food sorghum consumed by the population of Grand Nador	1,87	gN 100g $pdct^{-1}$	Sika et al., 1995	1995
$C_{N\_food\ potatoes}$	nitrogent content in food potatoes consumed by the population of Grand Nador	0,33	gN 100g $pdct^{-1}$	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ sweet\ potatoes}$	nitrogent content in food sweet potatoes consumed by the population of Grand Nador	0,25	gN 100g $pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ sugarcrop}$	nitrogent content in food sugarcrop consumed by the population of Grand Nador	0,26	gN 100g $pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ sugar}$	nitrogent content in food sugar consumed by the population of Grand Nador	0,00	gN 100g $pdct^{-1}$	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ sweeteners\ oth}$	nitrogent content in food sweeteners other consumed by the population of Grand Nador	0,00	gN 100g $pdct^{-1}$	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ honey}$	nitrogent content in food honey consumed by the population of Grand Nador	0,05	gN 100g $pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ beans}$	nitrogent content in food beans consumed by the population of Grand Nador	3,86	gN 100g $pdct^{-1}$	Sika et al., 1995	1995
$C_{N\_food\ peas}$	nitrogent content in food peas consumed by the population of Grand Nador	3,71	gN 100g $pdct^{-1}$	Sika et al., 1995	1995
$C_{N\_food\ pulses\ oth}$	nitrogent content in food pulses other consumed by the population of Grand Nador	3,56	gN 100g $pdct^{-1}$	Sika et al., 1995	1995

Symbol	Description	Qty	Unit	Reference	Year
$C_{N\_food\ nuts}$	nitrogent content in food nuts consumed by the population of Grand Nador	2,82	gN 100g pdct^{-1}	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ coconuts}$	nitrogent content in food coconuts consumed by the population of Grand Nador	0,00	gN 100g pdct^{-1}	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ sesameseed}$	nitrogent content in food sesameseed consumed by the population of Grand Nador	2,84	gN 100g pdct^{-1}	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ olives}$	nitrogent content in food olives consumed by the population of Grand Nador	0,22	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ soyabean\ oil}$	nitrogent content in food soyabean oil consumed by the population of Grand Nador	0,00	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ olive\ oil}$	nitrogent content in food olive oil consumed by the population of Grand Nador	0,00	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ groundnut\ oil}$	nitrogent content in food groundnut oil consumed by the population of Grand Nador	0,00	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ sunflowerseed\ oil}$	nitrogent content in food sunflowerseed oil consumed by the population of Grand Nador	0,00	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ rape\ and\ mustard\ oil}$	nitrogent content in food rape and mustard oil consumed by the population of Grand Nador	0,00	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ oilcrops\ oil\ oth}$	nitrogent content in food oilcrops oil other consumed by the population of Grand Nador	0,00	gN 100g pdct^{-1}	SFK Food Composition and Nutrition Tables, 2000	2000

Symbol	Description	Qty	Unit	Reference	Year
$C_{N\_food\ tomatoes}$	nitrogent content in food tomatoes consumed by the population of Grand Nador	0,16	gN 100g $pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{N\_food\ onions}$	nitrogent content in food onions consumed by the population of Grand Nador	0,18	gN 100g $pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{N\_food\ vegetables\ oth}$	nitrogent content in food vegetables other consumed by the population of Grand Nador	0,29	gN 100g $pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ coffee}$	nitrogent content in food coffee consumed by the population of Grand Nador	1,79	gN 100g $pdct^{-1}$	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ cocoa\ beans}$	nitrogent content in food cocoa beans consumed by the population of Grand Nador	3,17	gN 100g $pdct^{-1}$	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ tea}$	nitrogent content in food tea consumed by the population of Grand Nador	4,07	gN 100g $pdct^{-1}$	SFK Food Composition and Nutrition Tables, 2000	2000
$C_{N\_food\ pepper}$	nitrogent content in food pepper consumed by the population of Grand Nador	1,75	gN 100g $pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ pimento}$	nitrogent content in food pimento consumed by the population of Grand Nador	0,18	gN 100g $pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ spices\ oth}$	nitrogent content in food spices other consumed by the population of Grand Nador	1,54	gN 100g $pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011

Symbol	Description	Qty	Unit	Reference	Year
$C_{N\_food\ wine}$	nitrogent content in food wine consumed by the population of Grand Nador	0,01	gN 100g $pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ beer}$	nitrogent content in food beer consumed by the population of Grand Nador	0,07	gN 100g $pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ beverages\ alcoholic}$	nitrogent content in food beverages alcoholic consumed by the population of Grand Nador	0,00	gN 100g $pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{N\_food\ bovine\ meat}$	nitrogent content in food bovine meat consumed by the population of Grand Nador	3,01	gN 100g $pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{N\_food\ mutton\ \&\ goat\ meat}$	nitrogent content in food mutton & goat meat consumed by the population of Grand Nador	2,72	gN 100g $pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{N\_food\ poultry\ meat}$	nitrogent content in food poultry meat consumed by the population of Grand Nador	2,90	gN 100g $pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{N\_food\ meat\ oth}$	nitrogent content in food meat other consumed by the population of Grand Nador	2,84	gN 100g $pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{N\_food\ offals,\ edible}$	nitrogent content in food offals, edible consumed by the population of Grand Nador	2,66	gN 100g $pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{N\_food\ butter,\ ghee}$	nitrogent content in food butter, ghee consumed by the population of Grand Nador	0,55	gN 100g $pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{N\_food\ fat\ animals\ raw}$	nitrogent content in food fat animals raw consumed by the population of Grand Nador	0,00	gN 100g $pdct^{-1}$	SFK Food Comp Tables , 2000	2000

Symbol	Description	Qty	Unit	Reference	Year
$C_{N\_food\ eggs}$	nitrogent content in food eggs consumed by the population of Grand Nador	2,02	gN 100g $pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{N\_food\ milk}$	nitrogent content in food milk consumed by the population of Grand Nador	0,53	gN 100g $pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{N\_food\ freshwater\ fish}$	nitrogent content in food freshwater fish consumed by the population of Grand Nador	2,95	gN 100g $pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{N\_food\ demersal\ fish}$	nitrogent content in food demersal fish consumed by the population of Grand Nador	2,88	gN 100g $pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{N\_food\ pelagic\ fish}$	nitrogent content in food pelagic fish consumed by the population of Grand Nador	3,17	gN 100g $pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{N\_food\ marine\ fish\ oth}$	nitrogent content in food marine fish other consumed by the population of Grand Nador	3,03	gN 100g $pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{N\_food\ crustaceans}$	nitrogent content in food crustaceans consumed by the population of Grand Nador	2,76	gN 100g $pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ apple}$	phosphorus content in food apples consumed by the population of Grand Nador	11,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ bananas}$	phosphorus content in food bananas consumed by the population of Grand Nador	24,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ dates}$	phosphorus content in food dates consumed by the population of Grand Nador	62,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011

Symbol	Description	Qty	Unit	Reference	Year
$C_{P\_food\ citrus\ oth}$	phosphorus content in food citrus other consumed by the population of Grand Nador	19,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ grapes}$	phosphorus content in food grapes consumed by the population of Grand Nador	20,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ lemons}$	phosphorus content in food lemons consumed by the population of Grand Nador	20,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ oranges}$	phosphorus content in food oranges consumed by the population of Grand Nador	20,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ pineapples}$	phosphorus content in food pineapples consumed by the population of Grand Nador	9,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ fruits\ oth}$	phosphorus content in food fruits other consumed by the population of Grand Nador	20,92	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ wheat}$	phosphorus content in food wheat consumed by the population of Grand Nador	375,00	mg P 100g $Pdct^{-1}$	Sika et al., 1995	1995
$C_{P\_food\ barley}$	phosphorus content in food barley consumed by the population of Grand Nador	350,00	mg P 100g $Pdct^{-1}$	Sika et al., 1995	1995
$C_{P\_food\ maize}$	phosphorus content in food maize consumed by the population of Grand Nador	301,00	mg P 100g $Pdct^{-1}$	Sika et al., 1995	1995
$C_{P\_food\ rye}$	phosphorus content in food rye consumed by the population of Grand Nador	337,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000

Symbol	Description	Qty	Unit	Reference	Year
$C_{P\_food\ oats}$	phosphorus content in food oats consumed by the population of Grand Nador	342,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ rice}$	phosphorus content in food rice consumed by the population of Grand Nador	240,00	mg P 100g $Pdct^{-1}$	Sika et al., 1995	1995
$C_{P\_food\ millet}$	phosphorus content in food millet consumed by the population of Grand Nador	285,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ sorghum}$	phosphorus content in food sorghum consumed by the population of Grand Nador	284,00	mg P 100g $Pdct^{-1}$	Sika et al., 1995	1995
$C_{P\_food\ potatoes}$	phosphorus content in food potatoes consumed by the population of Grand Nador	50,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ sweet\ potatoes}$	phosphorus content in food sweet potatoes consumed by the population of Grand Nador	43,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ sugarcrop}$	phosphorus content in food sugarcrop consumed by the population of Grand Nador	45,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	
$C_{P\_food\ sugar}$	phosphorus content in food sugar consumed by the population of Grand Nador	0,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ sweeteners\ oth}$	phosphorus content in food sweeteners other consumed by the population of Grand Nador	0,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ honey}$	phosphorus content in food honey consumed by the population of Grand Nador	4,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012

Symbol	Description	Qty	Unit	Reference	Year
$C_{P\_food\ beans}$	phosphorus content in food beans consumed by the population of Grand Nador	383,50	mg P 100g $Pdct^{-1}$	Sika et al., 1995	1995
$C_{P\_food\ peas}$	phosphorus content in food peas consumed by the population of Grand Nador	393,00	mg P 100g $Pdct^{-1}$	Sika et al., 1995	1995
$C_{P\_food\ pulses\ oth}$	phosphorus content in food pulses other consumed by the population of Grand Nador	358,88	mg P 100g $Pdct^{-1}$	Sika et al., 1995	1995
$C_{P\_food\ nuts}$	phosphorus content in food nuts consumed by the population of Grand Nador	420,67	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ coconuts}$	phosphorus content in food coconuts consumed by the population of Grand Nador		mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ sesameseed}$	phosphorus content in food sesameseed consumed by the population of Grand Nador		mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ olives}$	phosphorus content in food olives consumed by the population of Grand Nador	17,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ soyabean\ oil}$	phosphorus content in food soyabean oil consumed by the population of Grand Nador	0,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ olive\ oil}$	phosphorus content in food olive oil consumed by the population of Grand Nador	0,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011

Symbol	Description	Qty	Unit	Reference	Year
$C_{P\_food\ groundnut\ oil}$	phosphorus content in food groundnut oil consumed by the population of Grand Nador	0,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ sunflowerseed\ oil}$	phosphorus content in food sunflowerseed oil consumed by the population of Grand Nador	0,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ rape\ and\ mustard\ oil}$	phosphorus content in food rape and mustard oil consumed by the population of Grand Nador	0,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ oilcrops\ oil\ oth}$	phosphorus content in food oilcrops oil other consumed by the population of Grand Nador	0,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ tomatoes}$	phosphorus content in food tomatoes consumed by the population of Grand Nador	28,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ onions}$	phosphorus content in food onions consumed by the population of Grand Nador	33,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	
$C_{P\_food\ vegetables\ oth}$	phosphorus content in food vegetables other consumed by the population of Grand Nador	53,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ coffee}$	phosphorus content in food coffee consumed by the population of Grand Nador	160,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ cocoa\ beans}$	phosphorus content in food cocoa beans consumed by the population of Grand Nador	656,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000

Symbol	Description	Qty	Unit	Reference	Year
$C_{P\_food\ tea}$	phosphorus content in food tea consumed by the population of Grand Nador	314,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ pepper}$	phosphorus content in food pepper consumed by the population of Grand Nador	166,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ pimento}$	phosphorus content in food pimento consumed by the population of Grand Nador	17,00	mg P 100g $Pdct^{-1}$	USDA Database (National Nutrient Database for Standard Reference Release 27)	2011
$C_{P\_food\ spices\ oth}$	phosphorus content in food spices other consumed by the population of Grand Nador	284,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ wine}$	phosphorus content in food wine consumed by the population of Grand Nador	21,50	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ beer}$	phosphorus content in food beer consumed by the population of Grand Nador	28,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ beverages\ alcoholic}$	phosphorus content in food beverages alcoholic consumed by the population of Grand Nador	24,75	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ bovine\ meat}$	phosphorus content in food bovine meat consumed by the population of Grand Nador	174,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ mutton\ \&\ goat\ meat}$	phosphorus content in food mutton & goat meat consumed by the population of Grand Nador	149,50	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ poultry\ meat}$	phosphorus content in food poultry meat consumed by the population of Grand Nador	145,50	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012

Symbol	Description	Qty	Unit	Reference	Year
$C_{P\_food\ meat\ other}$	phosphorus content in food meat other consumed by the population of Grand Nador	154,60	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ offals,\ edible}$	phosphorus content in food offals, edible consumed by the population of Grand Nador	263,67	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ butter,\ ghee}$	phosphorus content in food butter, ghee consumed by the population of Grand Nador	90,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ fat\ animals\ raw}$	phosphorus content in food fat animals raw consumed by the population of Grand Nador	0,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ eggs}$	phosphorus content in food eggs consumed by the population of Grand Nador	198,00	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ milk}$	phosphorus content in food milk consumed by the population of Grand Nador	105,50	mg P 100g $Pdct^{-1}$	FAO. West African Food Composition Table	2012
$C_{P\_food\ freshwater\ fish}$	phosphorus content in food freshwater fish consumed by the population of Grand Nador	232,06	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ demersal\ fish}$	phosphorus content in food demersal fish consumed by the population of Grand Nador	191,86	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ pelagic\ fish}$	phosphorus content in food pelagic fish consumed by the population of Grand Nador	280,00	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ marine\ fish\ oth}$	phosphorus content in food marine fish other consumed by the population of Grand Nador	235,93	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000
$C_{P\_food\ crustaceans}$	phosphorus content in food crustaceans consumed by the population of Grand Nador	224,33	mg P 100g $Pdct^{-1}$	SFK Food Comp Tables , 2000	2000

Symbol	Description	Qty	Unit	Reference	Year
$r_{N\&P\_minus}$	reduction ratio of nutritional quality in food waste from food	25%	%	Faerge et al. (2001)	2001
K_{N_feces}	fraction of nitrogen of food consumed leaving human body through feces	0,07	---	Magid et al., 2006. Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas: A technical theoretical framework applied to the medium-sized town Hillerod, Denmark	2006
K_{P_feces}	fraction of phosphorus of food consumed leaving human body through feces	0,20	---	Magid et al., 2006. Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas: A technical theoretical framework applied to the medium-sized town Hillerod, Denmark	2006
K_{N_urine}	fraction of nitrogen of food consumed leaving human body through urine	0,74	---	Magid et al., 2006. Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas: A technical theoretical framework applied to the medium-sized town Hillerod, Denmark	2006

Symbol	Description	Qty	Unit	Reference	Year
K_{P_urine}	fraction of phosphorus of food consumed leaving human body through urine	0,61	---	Magid et al., 2006. Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas: A technical theoretical framework applied to the medium-sized town Hillerod, Denmark	2006
$K_{N\_kitchen\ W}$	fraction of nitrogen of food refuse that is flushed out during food cleaning and dish washing	0,07	---	Magid et al., 2006. Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas: A technical theoretical framework applied to the medium-sized town Hillerod, Denmark	2006
$K_{P\_kitchen\ W}$	fraction of phosphorus of food refuse that is flushed out during food cleaning and dish washing	0,08	---	Magid et al., 2006. Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas: A technical theoretical framework applied to the medium-sized town Hillerod, Denmark	2006
$K_{N\_kitchen\_OSW}$	fraction of nitrogen of food refuse and food leftovers that is discarded as solid food waste	0,11	---	Magid et al., 2006. Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas: A technical theoretical framework applied to the medium-sized town Hillerod, Denmark	2006

Symbol	Description	Qty	Unit	Reference	Year
$K_{P\_kitchen\_OSW}$	fraction of phosphorus of food refuse and food leftovers that is discarded as solid food waste	0,11	---	Magid et al., 2006. Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas: A technical theoretical framework applied to the medium-sized town Hillerod, Denmark	2006
$a_{N\_Rur\_WW}$	nitrogent content in wastewater/sewage from food consumed by rural population of GN	378.351,41	kg N year^{-1}	calculated	
$a_{P\_Rur\_WW}$	phosphorus content in wastewater/sewage from food consumed by rural population of GN	68.610,05	kg P year^{-1}	calculated	
$a_{N\_Rur\_OSW}$	nitrogen in organic solid waste from food consumed by the rural population of GN	49.489,00	kg N year^{-1}	calculated	
$a_{P\_Rur\_OSW}$	phosphorus in organic solid waste from food consumed by the rural population of GN	8.576,26	kg P year^{-1}	calculated	
$a_{N\_Urb\_WW}$	nitrogent content in wastewater/sewage from food consumed by urban population of GN	1.675.841,08	kg N year^{-1}	calculated	
$a_{P\_Urb\_WW}$	phosphorus content in wastewater/sewage from food consumed by urban population of GN	303.896,14	kg P year^{-1}	calculated	
$a_{N\_Urb\_OSW}$	nitrogen in organic solid waste from food consumed by the urban population of GN	219.202,84	kg N year^{-1}	calculated	
$a_{P\_Urb\_OSW}$	phosphorus in organic solid waste from food consumed by the urban population of GN	37.987,02	kg P year^{-1}	Calculated	

Symbol	Description	Qty	Unit	Reference	Year
$r_{\_Rur\_sewerage}$	ratio of rural inhabitants connected to sewerage	0,025	---	Enquête national sur les revenus et les niveaux de vie des ménages 2006-2007.Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2006/ 2007
$r_{\_Urb\_sewerage}$	ratio of urban inhabitants connected to sewerage	0,85	---	Enquête national sur les revenus et les niveaux de vie des ménages 2006-2007.Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2006/ 2007
$WW_{\_UrbPop}$	wastewater generated by the urban population of Grand Nador	5.714.186,64	m^3 $year^{-1}$	calculated	
$WW_{UrbPop\_sewerage}$	wastewater generated by the urban population of Grand Nador that is collected by the sewer system	4.857.058,64	m^3 $year^{-1}$	calculated	
$WW_{\_WWTP}$	volume of treated wastewater by the WWTP of Grand Nador	4.736.970,00	m^3 $year^{-1}$	calculated	
$a_{WW\_Urb\&connect}$	average daily wastewater production by urban population connected to the drinking water network	50	l $inhab^{-1}$ $year^{-1}$	ONEP 2009 projet d'adduction regionales d'AEP Urbaine et Rural. Evaluation environnementale du projet. Rapport provisoire version du 08 Septembre 2009. OFFICE NATIONAL DE L'EAU POTABLE	2009

Symbol	Description	Qty	Unit	Reference	Year
$a_{WW\_Urb\&Non\text{-}connect}$	average daily wastewater production by urban population non-connected to the drinking water network	20	l $inhab^{-1}$ $year^{-1}$	ONEP 2009 projet d'adduction regionales d'AEP Urbaine et Rural. Evaluation environnementale du projet. Rapport provisoire version du 08 Septembre 2009. OFFICE NATIONAL DE L'EAU POTABLE	2009
$n_{UrbPop\_drinkNet}$	urban population connected to the drinking water network	297.592	inhabitants	Enquête national sur les revenus et les niveaux de vie des ménages 2006-2007.Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2006/ 2007
$n_{UrbPop\_Non\text{-}drinkNet}$	urban population non-connected to the drinking water network	49.657	inhabitants	Enquête national sur les revenus et les niveaux de vie des ménages 2006-2007.Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2006/ 2007
$WWTP_{\_cap}$	capacity of the WWTP of Grand Nador	20.600	m^3 day-^{1}	ONEP, 2010. Depollution de la Marchica. Assainissement du Grand Nador, Interception, Transfert et Epuration des Eaux Usées. Extension des réseaux d'assainissement liquide des Municipalités et Centres du Grand Nador. Royaume du Maroc. Office National de l'Eau Potable.	2010
$r_{\_OpCap}$	operational capacity of the WWTP of Grand Nador	63%	%	calculated	

Symbol	Description	Qty	Unit	Reference	Year
C_{N_WWin}	concentration of nitrogen on water quality at the entrance of the WWTP	70	$mg\ l^{-1}$	ONEP, 2010. Depollution de la Marchica. Assainissement du Grand Nador, Interception, Transfert et Epuration des Eaux Usées. Extension des réseaux d'assainissement liquide des Municipalités et Centres du Grand Nador. Royaume du Maroc. Office National de l'Eau Potable.	2010
C_{P_WWin}	concentration of phosphorus on water quality at the entrance of the WWTP	20	$mg\ l^{-1}$	ONEP, 2010. Depollution de la Marchica. Assainissement du Grand Nador, Interception, Transfert et Epuration des Eaux Usées. Extension des réseaux d'assainissement liquide des Municipalités et Centres du Grand Nador. Royaume du Maroc. Office National de l'Eau Potable.	2010
C_{N_WWout}	nitrogen concentration in water quality at the exit of the WWTP	10	$mg\ l^{-1}$	ONEP, 2010. Depollution de la Marchica. Assainissement du Grand Nador, Interception, Transfert et Epuration des Eaux Usées. Extension des réseaux d'assainissement liquide des Municipalités et Centres du Grand Nador. Royaume du Maroc. Office National de l'Eau Potable.	2010

Symbol	Description	Qty	Unit	Reference	Year
C_{P_WWout}	phosphorus concentration in water quality at the exit of the WWTP	1	$mg\ l^{-1}$	ONEP, 2010. Depollution de la Marchica. Assainissement du Grand Nador, Interception, Transfert et Epuration des Eaux Usées. Extension des réseaux d'assainissement liquide des Municipalités et Centres du Grand Nador. Royaume du Maroc. Office National de l'Eau Potable.	2010
r_{ST_Rur}	fraction of wastewater evacuated through Septic Tank in rural area	0,14	---	Enquête national sur les revenus et les niveaux de vie des ménages 2006-2007.Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2007
$r_{CessLat\_Rur}$	fraction of wastewater evacuated through Cesspols or latrines in rural area	0,444	---	Enquête national sur les revenus et les niveaux de vie des ménages 2006-2007.Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2007
r_{Nat_Rur}	fraction of wastewater evacuated directly into nature in rural area	0,391	---	Enquête national sur les revenus et les niveaux de vie des ménages 2006-2007.Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2007

Symbol	Description	Qty	Unit	Reference	Year
r_{ST_Urb}	fraction of wastewater evacuated through Septic Tank in urban area	0,053	---	Enquête national sur les revenus et les niveaux de vie des ménages 2006-2007.Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2007
$r_{CessLat\_Urb}$	fraction of wastewater evacuated through Cesspols or latrines in urban area	0,069	---	Enquête national sur les revenus et les niveaux de vie des ménages 2006-2007.Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2007
r_{Nat_Urb}	fraction of wastewater evacuated directly into nature in urban area	0,028	---	Enquête national sur les revenus et les niveaux de vie des ménages 2006-2007.Rapport de synthèse. Direction de la Statistique. Royaume du Maroc Haut-Commissariat au Plan	2007
$K_{ST\_Soil\&GW}$	coefficient of nutrient deposition in Soil & Groundwater from Septic Tank	0,65	---	Erni, 2007	2007
$K_{CessLat\_Soil\&GW}$	coefficient of nutrient deposition in Soil & Groundwater from Cesspols or latrines	0,3	---	Erni, 2007	2007
$K_{Nat\_Soil\&GW}$	coefficient of nutrient deposition in Soil & Groundwater from direct discharge into nature	0,4	---	Erni, 2007	2007
K_{ST_SurfW}	coefficient of nutrient deposition in surface water from Septic Tank	0,12	---	Erni, 2007	2007
$K_{CessLat\_ SurfW}$	coefficient of nutrient deposition in surface water from Cesspols or latrines	0,05	---	Erni, 2007	2007

Symbol	Description	Qty	Unit	Reference	Year
$K_{Nat\_ SurfW}$	coefficient of nutrient deposition in surface water from direct discharge into nature	0,6	---	Erni, 2007	2007
$r_{\_Urb\_OSW\_collect}$	average collection rate of solid waste/garbatge at urban municipalities	80%	%	Runge et al. (2011)	2011

Appendix 5.: Uncertainty Flow values for nutrient (N and P) Food-related flows of Grand Nador in 2010

No.	**Name - Description**	**Unit**	**Nitrogen**			**Unit**	**Phosphorus**		
			Average	**Minimum**	**Maximum**		**Average**	**Minimum**	**Maximum**
	Sistem boundary		3.979.174,33	3.838.532,88	3.595.295,74		2.161.607,23	1.852.374,42	2.517.966,33
Stocks									
B1	***Plant/Crop production sub-process***	kg N yr^{-1}	379.882,05	565.714,96	-905.661,67	kg P yr^{-1}	1.412.525,92	1.157.922,66	1.720.351,71
B2	***Animal/Livestock production sub-process***	kg N yr^{-1}	-726.157,20	-366.646,26	-1.527.631,90	kg P yr^{-1}	-72.454,28	-92.167,64	-44.983,55
B3	***Agricultural production process***	kg N yr^{-1}	***-346.275,15***	***199.068,70***	***-2.433.293,57***	kg P yr^{-1}	***1.340.071,65***	***1.065.755,01***	***1.675.368,17***
B4	***Agri-Food processing industrial process***	kg N yr^{-1}	***1.102.360,18***	***1.002.145,62***	***1.212.596,20***	kg P yr^{-1}	***175.724,53***	***159.749,58***	***193.296,99***
B5	***Rural Household consumption sub-process***	kg N yr^{-1}	289.551,28	322.573,87	227.228,94	kg P yr^{-1}	46.723,36	53.159,91	34.962,90
B6	***Urban Household consumption sub-process***	kg N yr^{-1}	840.496,65	1.051.821,60	501.660,92	kg P yr^{-1}	126.797,25	167.165,23	63.206,55
B7	***Household consumption process (HH)***	kg N yr^{-1}	***1.130.047,93***	***1.374.395,48***	***728.889,86***	kg P yr^{-1}	***173.520,61***	***220.325,14***	***98.169,45***
B8	***Sewage-Wastewater sub-process***	kg N yr^{-1}	0,00	67.441,10	-128.796,49	kg P yr^{-1}	0,00	14.061,28	-27.202,13
B9	***Organic Solid Waste (MSW) sub-process***	kg N yr^{-1}	0,00	0,00	0,00	kg P yr^{-1}	0,00	0,00	0,00
B10	***Waste Management process***	kg N yr^{-1}	***-0,01***	***67.441,10***	***-128.796,49***	kg P yr^{-1}	***0,00***	***14.061,28***	***-27.202,13***
B11	***Landfill disposal***	kg N yr^{-1}	***1.084.691,44***	***747.927,45***	***1.658.889,02***	kg P yr^{-1}	***419.544,49***	***354.807,72***	***504.489,52***
B12	***Land - soil and Groundwater (GW)***	kg N yr^{-1}	***1.008.349,94***	***447.554,53***	***2.557.010,71***	kg P yr^{-1}	***52.745,96***	***37.675,68***	***73.844,34***
B13	***Surface Water/ aquatic system***	kg N yr^{-1}	***1.353.814,33***	***969.675,59***	***1.890.377,17***	kg P yr^{-1}	***206.587,13***	***148.037,62***	***288.336,83***
B14	***Import/Export***	kg N yr^{-1}	***-5.704.347,41***	***-4.880.307,78***	***-6.677.992,77***	kg P yr^{-1}	***-2.355.859,97***	***-1.989.198,94***	***-2.792.735,32***
B15	***Atmosphere***	kg N yr^{-1}	***520.520,05***	***207.700,49***	***1.356.397,30***	kg P yr^{-1}	---		

No.	**Name - Description**	**Unit**	**Nitrogen**			**Unit**	**Phosphorus**		
FLOW			**Average**	**Minimum**	**Maximum**		**Average**	**Minimum**	**Maximum**
I_{15-1}	Atmospheric deposition	kg N yr^{-1}	396.949,00	198.474,50	793.898,00	kg P yr^{-1}	0,00		
I_{14-1}	Imports of fertilizers	kg N yr^{-1}	2.784.611,00	2.320.509,17	3.341.533,20	kg P yr^{-1}	1.665.732,00	1.388.110,00	1.998.878,40
I_{14-2}	Imports of fodder and feedstuff	kg N yr^{-1}	1.247.495,20	1.039.579,33	1.496.994,24	kg P yr^{-1}	347.161,56	289.301,30	416.593,87
I_{14-4}	Imports of food to agri-food processing industry	kg N yr^{-1}	769.854,75	699.867,95	846.840,22	kg P yr^{-1}	78.332,00	71.210,91	86.165,20
I_{14-5}	Import of food products to Rural HH consumption	kg N yr^{-1}	324.664,47	295.149,52	357.130,92	kg P yr^{-1}	60.107,66	54.643,33	66.118,43
I_{14-6}	Import of food products to Urban HH consumption	kg N yr^{-1}	1.438.044,19	1.307.312,90	1.581.848,61	kg P yr^{-1}	266.236,32	242.033,02	292.859,95
I_{13-4}	Fish local catches to agri-food processing industry	kg N yr^{-1}	0,00			kg P yr^{-1}	0,00		
I_{13-5}	Fish local catches/product to Rural HH consumption	kg N yr^{-1}	27.473,27	24.975,70	30.220,60	kg P yr^{-1}	2.271,81	2.065,28	2.498,99
I_{13-6}	Fish local catches/product to Urban HH consumption	kg N yr^{-1}	121.688,03	110.625,48	133.856,83	kg P yr^{-1}	10.062,59	9.147,81	11.068,85
R_{1-2}	Fodder crops as animal feed	kg N yr^{-1}	1.774.548,27	1.613.225,70	1.952.003,10	kg P yr^{-1}	134.598,63	122.362,39	148.058,49
R_{1-4}	Locally produced plant/crop products to agri-food processing industry	kg N yr^{-1}	740.842,00	673.492,73	814.926,20	kg P yr^{-1}	129.417,00	117.651,82	142.358,70
R_{1-5}	Locally produced plant/crop products (Veg Food) to Rural HH consumption	kg N yr^{-1}	154.605,25	140.550,22	170.065,77	kg P yr^{-1}	31.727,15	28.842,87	34.899,87
R_{1-6}	Locally produced plant/crop products (Veg Food) to Urban HH consumption	kg N yr^{-1}	684.796,75	622.542,50	753.276,43	kg P yr^{-1}	140.529,85	127.754,41	154.582,83
R_{1-12}	Leaching/runoff from agricultural land (to Soil/Groundwater)	kg N yr^{-1}	715.825,50	238.608,50	2.147.476,50	kg P yr^{-1}	0,00		
R_{2-1}	Manure (as organic fertiliser) to agricultural land	kg N yr^{-1}	1.685.004,51	1.531.822,29	1.853.504,97	kg P yr^{-1}	194.599,97	176.909,06	214.059,96
R_{2-4}	Animal products to agri-food processing industry	kg N yr^{-1}	1.114.742,27	1.013.402,06	1.226.216,50	kg P yr^{-1}	75.958,58	69.053,26	83.554,44
R_{2-11}	Manure (from poultry production) to landfill	kg N yr^{-1}	346.342,03	173.171,02	692.684,07	kg P yr^{-1}	283.655,91	257.869,01	312.021,50
R_{4-5}	Agri-food proccesed pdcts to Rural HH consumption	kg N yr^{-1}	89.273,58	81.157,80	98.200,94	kg P yr^{-1}	7.792,93	7.084,48	8.572,23
R_{4-6}	Agri-food proccesed pdcts to Urban HH consumption	kg N yr^{-1}	395.421,62	359.474,20	434.963,78	kg P yr^{-1}	34.517,43	31.379,48	37.969,17

No.	**Name - Description**	**Unit**	**Nitrogen**			**Unit**	**Phosphorus**		
FLOW			**Average**	**Minimum**	**Maximum**		**Average**	**Minimum**	**Maximum**
R_{4-11}	Organic solid waste from agri-food processing industry	kg N yr^{-1}	278.768,93	253.426,30	306.645,83	kg P yr^{-1}	15.496,54	14.087,76	17.046,19
R_{5-8}	Wastewater/sewage from Rural HH collected by sewer system	kg N yr^{-1}	9.458,79	7.111,87	12.580,18	kg P yr^{-1}	1.715,25	1.289,66	2.281,28
R_{5-9}	Organic solid waste (OSW) from Rural HH collected	kg N yr^{-1}	0,00			kg P yr^{-1}	0,00		
R_{5-12}	Non-collected OSW and WW/sewage from Rural HH to soil/groundwater	kg N yr^{-1}	163.796,15	116.997,25	229.314,61	kg P yr^{-1}	29.543,48	21.102,49	41.360,88
R_{6-8}	Wastewater/sewage from Urban HH collected by sewer system	kg N yr^{-1}	1.424.464,92	1.071.026,25	1.894.538,34	kg P yr^{-1}	258.311,72	194.219,34	343.554,59
R_{6-9}	Organic solid waste (OSW) from Urban HH collected	kg N yr^{-1}	175.362,27	131.851,33	233.231,82	kg P yr^{-1}	30.389,62	22.849,34	40.418,19
R_{6-12}	Non-collected OSW and WW/sewage from Urban HH to soil/groundwater	kg N yr^{-1}	128.728,29	91.948,78	180.219,60	kg P yr^{-1}	23.202,47	16.573,19	32.483,46
R_{8-11}	Sludge from WWTP to Landfill	kg N yr^{-1}	284.218,20	189.478,80	426.327,30	kg P yr^{-1}	90.002,43	60.001,62	135.003,65
R_{9-11}	Collected OSW -organic solid waste- to Landfill	kg N yr^{-1}	175.362,27	131.851,33	233.231,82	kg P yr^{-1}	30.389,61	22.849,33	40.418,19
O_{1-15}	Air emissions from fertilizers	kg N yr^{-1}	315.357,20	105.119,07	946.071,59	kg P yr^{-1}	0,00		
O_{1-14}	Export of locally produced plant/crops products	kg N yr^{-1}	100.707,50	91.552,27	110.778,25	kg P yr^{-1}	11.533,42	10.484,93	12.686,76
O_{2-15}	N losses from manure to the atmosphere	kg N yr^{-1}	602.111,86	301.055,93	1.204.223,71	kg P yr^{-1}	0,00		
O_{4-14}	Export of agri-food industrial products	kg N yr^{-1}	759.614,70	690.558,82	835.576,17	kg P yr^{-1}	50.176,15	45.614,68	55.193,76
O_{5-13}	Non-collected OSW and WW/sewage from Rural HH to surface water	kg N yr^{-1}	133.210,35	95.150,25	186.494,49	kg P yr^{-1}	23.917,47	17.083,90	33.484,45
O_{6-13}	Non-collected OSW and WW/sewage from Urban HH to surface water	kg N yr^{-1}	70.898,47	53.307,12	94.294,97	kg P yr^{-1}	12.645,12	9.507,61	16.818,01
O_{a8-13}	Collected WW/sewage and treated by the WWTP	kg N yr^{-1}	47.369,70	33.835,50	66.317,58	kg P yr^{-1}	4.736,97	3.383,55	6.631,76
O_{b8-13}	Collected WW/sewage but untreated	kg N yr^{-1}	1.102.335,81	787.382,72	1.543.270,13	kg P yr^{-1}	165.287,57	118.062,55	231.402,60

Appendix 6.: Case study list

	Author/s	Year of publication	Type	Dimension/ Subsystems	Substance/s analysed	Geographical scale/ Area of study		Study period	Methodology	Uncertainty analysis
						Scale	Location			
1	**Antikainen**	2007	PhD	Forest; Food; Energy; Waste	N and P	Country	Finland	At the end of the 1990s	SFA	Yes (Hedbrant and Sörme method)
2	**Antikainen et al.**	2005	Article	Food	N and P	Country	Finland	At the end of the 1990s	SFA	Yes (Hedbrant and Sörme method)
3	**Asmala and Saikku**	2010	Article	Rainbow Trout aquaculture Production	N and P	Country	Finland	2004-2007	SFA	Yes (Hedbrant and Sörme method)
4	**Baker et al.**	2007	Article	Food consumption	N and P	Household	Minneapolis-St.Paul metropolitan area (Minnesota)	---	spreadsheet accounting model	No
5	**Barles**	2007	Article	Food	N	City	Paris (France)	1801-1914	Not specified	No
6	**Belevi**	2002	Paper N.P.	Waste	N and P	City	Kumasi (Ghana)	---	MFA	No
7	**Bouwman et al.**	2005	Article		N	Global		1970-1995/[P]2030	IMAGE model	---
8	**Bouwman et al.**	2009	Article		N and P	Global		1970-2000/2000-2050	IMAGE 2.4 model	---
9	**Boyer et al.**	2002	Article		N	Regional	Northeastern U.S.A.	early 1990's	N budget	---
10	**Chen et al .**	2008	Article	Food-Agriculture	P	Country	China	2004	SFA	Yes, brief qualitative
11	**Chen et al .**	2010	Article	Agriculture	N and P	Country	China		SFA	Yes
12	**Childers et al.**	2011	Article	Food	P	Global			P cycle	---
13	**Chowdhury et al.**	2014	Article	P Cycle	P	Different	City, regional and country scales	---	SFA	No, qualitative
14	**Cooper and Carliell-Marquet**	2013	Article	Food	P	National	United Kingdom	2009	SFA (STAN program)	Yes (STAN program)
15	**Cordell et al.**	2009	Article	Food	P	Global			SFA	---
16	**Cordell et al.**	2013	Article	Food	P	National	Australia	2007	SFA	No
17	**Erni**	2007	MSc. Thesis	Water	N and P	City	Kumasi (Ghana)	2005-2006	MFA (SIMBOX simulation program)	Yes (Monte Carlo simulations)
18	**Faerge et al.**	2001	Article	Food	N and P	Province	Bangkok	1996	Nutrient balance modeling	Yes, qualitative

	Author/s	Year of publication	Type	Dimension/ Subsystems	Substance/s analysed	Geographical scale/ Area of study		Study period	Methodology	Uncertainty analysis
						Scale	Location			
19	**Forkes**	2007	Article	Food	N	City	Toronto (Canadá)	3 years; 15-year period (1990-2004)	Nitrogen balance	No
20	**Fowler et al.**	2013	Article		N	Global			Nitrogen cycle	---
21	**Galloway and Cowling**	2002	Article	Food and Energy	N	Global		100 years	Nitrogen cycle	---
22	**Galloway et al.**	2004	Article		N	Global		1860/1990/[P]2050	Nitrogen cycle	Yes, qualitative
23	**Galloway et al.**	2008	Article	Food	N	Global		2004	Nitrogen cycle	---
24	**Kalmykova et al.**	**2012**	Article	Food/Waste	P	City-Region	Gothenburg (Sweden)	2009	MFA	No, brief qualitative
25	**Li et al.**	2010	Article	Extraction, fabrication/manufacturing, use, waste management	P	City	Hefei, China	2008	SFA	No, qualitative
26	**Liu et al.**	2008	Article		P	Global		2000/2003/2004	SFA	Yes, qualitative
27	**Ma**	2014	Ph.D. Thesis	Food	N and P	National/ City	China/ Beijing	1980-2005/ 1978-2008	NUFER	Yes, qualitative
28	**Ma et al.**	2008	Article	N flows related to human activities	N	City	Huizhou, South China	1998	Material accounting and Export coefficient	No
29	**Ma et al.**	2012	Article	Anthropogenic P	P	National	China	1984-2008	SFA	No, qualitative
30	**Matsubae-Yokoyama, et al.**	2009	Article	Iron and Steel Industry	P	National	Japan	2002	SFA and Input-Output analysis	No
31	**Metson et al.**	2012b	Article	Soil, vegetation, animals, water	P	City-Region	Greater Phoenix metropolitan area (Arizona, USA)		Mass balance approach	Yes, qualitative
32	**Montangero**	2006	Ph.D. Thesis	Environmental sanitation and	N and P	City-Region	Hanoi (Vietnam)	---	MFA	Yes, Monte Carlo simulation.
33	**Montangero et al.**	2007	Article	Waste	N and P	City	Hanoi (Vietnam)	---	MFA	Yes, Monte Carlo simulation.

	Author/s	Year of publication	Type	Dimension/ Subsystems	Substance/s analysed	Geographical scale/ Area of study		Study period	Methodology	Uncertainty analysis
						Scale	Location			
34	**Neset**	2005	Ph.D. Thesis	Food consumption	P	City	Linköping (Sweden)	1870-2000	SFA (SIMBOX modelling)/MMFA	Yes
35	**Neset et al.**	2008	Article	Food consumption	P	City	Linköping (Sweden)	1870-2000	SFA (SIMBOX modelling)/MMFA	Yes
36	**Qiao et al.**	2011	Article	Food	P	Megacities	Beijing and Tianjin (northern China)	2008	MFA	No, brief qualitative
37	**Risku-Norja and Mäenpää**	2007	Article	Food	---	National	Finland	1998	MFA and Input-Output modeling	No
38	**Saikku et al.**	2007	Article	Energy	N and P	National	Finland	1900-2003	SFA	No, brief qualitative
39	**Senthilkumar et al.**	2012	Article	P flows in agriculture, industry, domestic, import and export sectors.	P	National	France	1990-2006	SFA	No
40	**Smil**	2000	Article		P	Global		Annually_mid-1990s	P cycle	---
41	**Smil**	2002c	Article	Agroecosystem	N	Global		Annually	N cycle	Yes, qualitative
42	**Sokka et al.**	2004	Article	Waste	N and P	National	Finland	1952-1999/1995-1999	SFA	Yes, qualitative
43	**Thaler et al.**	2013	Article	Food (agricultural production and consumption)	N and P	National	Austria	2001-2006	MFA	Si H&S
44	**Villalba et al.**	2008	Article	Industry	P	Global		2004	SFA	---
45	**Vladimirovna**	2013	MSc. Thesis	Soil P accumulation	P	Regional	Akershus, Rogaland and Sor-Trondelag (Norway)	1950-2011	SFA	Yes, Monte Carlo simulation.
46	**Wu et al.**	2012	Article	Agriculture and consumption		Regional	Feixi County (Central China)	2008	SFA	Yes, qualitative
47	**Yuan et al.**	2011	Article	Agriculture, Chemical industry, animal feeding, human consumption and waste	P	Regional	Shucheng County (China)	2008	SFA	Yes, qualitative
48	**Yuan et al.**	2011	Article	Agriculture, industry, human consumption and waste	P	City	Chaohu	2008	SFA	No