Development of a Gis based methodology to support decision making for displacement settings' location in developing countries: Application to Niger

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DEVELOPMENT OF A GIS BASED METHODOLOGY TO SUPPORT DECISION MAKING FOR DISPLACEMENT SETTINGS' LOCATIONS IN DEVELOPING COUNTRIES: APPLICATION TO NIGER

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TRAVAIL DE FIN D'ÉTUDES PRÉSENTÉ EN VUE DE L'OBTENTION DU DIPLÔME DE MASTER BIOINGÉNIEUR EN GESTION DES FORÊTS ET DES ESPACES NATURELS

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MASTER THESIS PRESENTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
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Abstract

According to UNHCR, at the end of 2018, there were 70.8 million people forcibly displaced in the world. These people who are escaping from conflicts or the effects of natural disasters need immediate protection and assistance. With climate change arising and conflicts, those numbers are unlikely to decrease in the future. The displacement phenomenon must be managed and organized to avoid the outbreak of new conflicts between the host population and the displaced people and secure the resilience of the host country. The purpose of the present study was to develop a spatial decision support system (SDSS) for FAO to provide technical support to camp management actors so as to support national authorities and other stakeholders to analyze suitable displacement sites in any country. This study aims to contribute to the development of a coherent and adequate policy in order to ensure that the rights of all displaced persons are respected and that their needs are met in a way that preserves their dignity, and to foster the resilience of the environment. This paper presents the multi-criteria decision analysis (MCDA) designed for the selection of new suitable displacement sites, applied to Niger. Different thematic layers -social, geographical and infrastructural- were processed using RStudio. Among those, some translate the suitability of a site, others constraint the analysis by excluding areas right away. Some criteria depend on the context and on the particularities of the host and displaced population. The findings depict that 0.62% of the total area of Niger is suitable for the installation of displacement sites. Each region has the capacity to host displaced people, at different scales. The tool developed can be applied by concerned authorities and stakeholders to visualize the compilation of humanitarian recommendations in geographic information and compare it with today's sites. The flexible and adjustable open source tool enables to focus on any area of interest. Nevertheless, the criteria need to be adjusted to the host and displaced population, taking into account their specificities.

Résumé

Selon le HCR, fin 2018, il y avait 70,8 millions de personnes déplacées de force dans le monde. Les personnes qui fuient des conflits ou les conséquences de catastrophes naturelles ont besoin d’une protection et d’une assistance immédiates. Sous l’effet du changement climatique et des conflits, il est peu probable que ces chiffres diminuent à l'avenir. Le phénomène des déplacements doit être géré et organisé de manière à éviter le déclenchement de nouveaux conflits entre la population hôte et les personnes déplacées et à garantir la résilience du pays hôte. Le but de cette étude est de développer un système d’aide à la décision spatiale permettant à la FAO de fournir un appui technique aux acteurs de la gestion des camps, afin d’aider les autorités nationales et d’autres parties prenantes à analyser les sites appropriés pouvant accueillir des personnes déplacées dans n’importe quel pays. Cette étude a pour objectif de contribuer à l’élaboration d’une politique cohérente et adéquate garantissant le respect des droits de toutes les personnes déplacées, la satisfaction de leurs besoins de manière à garantir leur dignité et la résilience de l’environnement. Ce document présente l'analyse de décision multicritères, conçue pour la sélection de nouveaux sites de déplacement adaptés; le modèle élaboré a été appliqué au Niger. Différentes couches thématiques (sociale, géographique et infrastructurelle) ont été traitées à l'aide de RStudio. Parmi celles-ci, certaines reflètent la pertinence d'un site et d'autres constituent des contraintes qui amènent à exclure d’emblée certaines zones. Certains critères dépendent du contexte, ainsi que des particularités qui caractérisent la population hôte et les personnes déplacées. Les résultats montrent que 0,62% de la superficie totale du Niger est propice à l'installation de sites de déplacement. Chaque région a la capacité d'accueillir des personnes déplacées, à des échelles différentes. L’outil développé peut être utilisé par les autorités et les parties prenantes concernées pour visualiser la compilation de recommandations humanitaires dans des informations géographiques et la comparer aux sites d’aujourd’hui. L'outil open source flexible et ajustable permet de se concentrer sur n'importe quel domaine d'intérêt. Néanmoins, les critères doivent être adaptés à la population hôte et aux personnes déplacées, en tenant compte de leurs spécificités.

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Acronyms

AGBP	**Above Ground Biomass Production**
AOI	Area Of Interest
FAO	Food and Agriculture Organization of the United Nations
IDP	Internally Displaced Persons
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
NGO	Non-governmental Organization
OSM	OpenStreetMap
POC	People of concern
POI	Points Of Interest
POW	Places Of Worship
SAFE	Safe Access to Fuel and Energy
SDSS	Spatial Decision Support System
SEPAL	System for Earth observation data access, Processing and Analysis for Land monitoring
SI	Suitability Index
SMCDA	Spatial Multi-Criteria Decision Analysis
UDHR	Universal Declaration of Human Rights
UNHCR	United Nations High Commissioner for Refugees
WaPOR	Water Productivity Open-access Portal
WHO	World Health Organization
WLC	Weighted Linear Combination method

Chapter one: Introduction

1.1. Study Background

As highlighted on the World Food Day in 2017, “more people have been forced to flee their homes than at any time since the Second World War due to increased conflict and political instability. But hunger, poverty, and an increase in extreme weather events linked to climate change are other important factors contributing to the migration challenge (as cited by the World Health Organization, 2017). As a result of the year 2018, the world’s forcibly displaced population remained yet again at a record high with 70.8 million displaced people (UNHCR, 2019d).

While the ability and the legitimacy to access resources may change, the needs of a displaced person remain. The 25th article of 1948 Universal Declaration of Human Rights stresses that “everyone has the right to a standard of living adequate for health and well-being […], including food, clothing, housing and medical care and necessary social services, […]” (UN, n.d.).

1.2. Problem Statement

The FAO, the specialized Agency of the United Nations for Agriculture and Food Security, has received requests from the UNHCR asking for technical support to inform resilience programming in several countries.

Firstly, at present, there is no flexible and adjustable open source tool enabling automated data processing to advise policy makers on suitable displacement sites using multi-geographical criteria.

Secondly, there is no open source systematic approach enabling to make the link between humanitarian recommendations and their geographic implementation/visualization, applicable to any area of interest.
Nevertheless, several studies have been done on site selection for refugee camps and there is growing research on GIS methods and refugee camps decision. However, they all rely on manual steps for part or all of the analysis.

Thirdly, decision makers must make an informed and multi faced decision in short periods of time. The advantage of automatization and coding is to have a written methodology that can be modified to meet the needs and particularities of a country. Being able to quickly assess the suitability or risks of available sites and the ongoing state of the natural resources can be of a great help. Especially considering that this decision will have consequences on the host population and the natural resources.

1.3. Research Aims and Objectives

The global aim of the present study is to help host countries welcome displaced people in the best conditions knowing where the basic living standards needs could be met and avoid tensions to arise with the host population.

This master thesis is guided by several research questions:

1. Is it possible to map the basic features highlighted by the humanitarian recommendations that should be taken into account when installing a displacement setting (link between humanitarian living criteria and geographical data)?
2. Are there global data enabling the user to work for any area of interest (AOI)?
3. Is it possible to have a systematic methodology where parameters only have to be changed to be applicable to another AOI?
4. Is it possible to make available a practical, adjustable and flexible tool enabling decision-makers take a suitability-linked decision based on landscape/physical features?
5. Does the tool give realistic results when Niger is taken as an example?

1.4. Research development

To answer the requests of technical support to inform resilience programming, the FAO wished to develop a flexible and adjustable open-source tool to give an advice/opinion on displacement settings' locations following a systematic approach. The latter is composed of already thought out features needed to be taken into account when thinking about displacement camps highlighted by humanitarian aid workers.

First, a multi-criteria decision analysis (MCDA) was used to select new suitable displacement sites in Niger. Then, the criteria were divided into two different groups, of which 10 were suitability criteria, 18 constraints criteria. Suitability indexes were calculated for each suitability criterion. After, weights were attributed to each of them, related to the importance given. Finally, the criteria were aggregated using a formula multiplying the constraints criteria mask (0-1) by the suitability criteria weighted by their importance. All the different steps were created and processed in R environment with specific packages dedicated to spatial data analysis and processing. Finally, final results were analyzed and slimmed in the light of population and context dependent constraints criteria.

The System for Earth observation data access, Processing and Analysis for Land monitoring, (hereafter "SEPAL"), developed by the Forestry Department of the FAO, was used to access super-computers enabling heavy data processing. QGIS was used as a generic GIS interface.

1.5. Outline of the Study

Chapter two discusses and gives a brief picture of the displacement situation in the world today. Budgets allocated to the problematic and the role of international organizations are also presented.

The core of this study was the development of a theoretical model based on the humanitarian recommendations regarding the health, security, food, environment factors. The developed model is presented and explained in chapter three.

Chapter four discusses the results of the model. A comparison between the theory (results of the model) and the reality (today's displacement sites) is also presented. Chapter five is the conclusion of this master thesis highlighting the study's limitations and recommendations.

Being a pilot work, the first step was to create the model to be compared remotely with the reality. In the future, this comparison should be done on the field to slim the theoretical criteria and see if they should be modified and in what cases it is relevant.

Because the model is detailed in the present study and scripts are open source and available, further improvements advised by experts and field workers can easily be taken into account to fine-tune the model to the specificities of the country or region of interest. Nevertheless, note that the present model is not meant to be exhaustive due to the complexity of the phenomenon but criteria could be easily added if considered pertinent and documented by available data.

This study is relevant and important since settling displaced people on inappropriate sites can result in further displacement causing further loss and distress to the people and may put them at further risk (UNHCR, 2019d). It can also foster conflicts between the host and the displaced populations as well as put strain on the environment and natural resources.

Hopefully, this study will trigger interest and future research to further validate and investigate the proposed frameworks, which would be highly beneficial to the safety and well-being of the displaced persons; as well as the harmony with the host population.

Chapter two: The displacement situation today

2.1. Background

Although international migration is today the subject of great concern and attention, migration has always been a part of the history of humankind and accompanies the evolution of societies. Nevertheless, at the end of 2018 there were 70.8 million people forcibly displaced worldwide; that is 2.3 million more than just a year earlier (UNHCR, 2019d). It is the 7th consecutive year that numbers are on the rise (Grandi, 2019) and it is the highest number the UN Refugee Agency has seen in nearly 70-year existence (UNHCR, 2019).

“Those numbers of displaced people are still growing reflecting a world without peace or more specifically a world in which we have become unable to make peace” as Filippo Grandi (2019), the High Commissioner for the UNHCR warned. Mr. Grandi also said that “these figures are further confirmation of a long-term trend in the number of people needing safety from war, conflict and persecution” (UNHCR, 2019d).

Two thirds of all refugees come from just five countries: Syria (6.7 million), Afghanistan (2.7 million), South Sudan (2.3 million), Myanmar (1.1 million), Somalia (900 000). Hosting displaced people should be an imperative and collective effort. Nevertheless, refugees are disproportionately hosted by poor and middle-income countries next to their own. Indeed in 2018, one third of the global refugee population were in the Least Developed countries. The six major hosting countries included: Turkey that hosted the most refugees (3.7 million) followed by Pakistan (1.4 million), Uganda (1.2 million), Sudan (1.1 million), Germany (1.1 million) and Iran (676 400). In 2018, the Global Compact on Refugees was adopted, which calls for action across the international community, that is governments as well as individuals, companies and NGOs (UNHCR, 2019d).

As opposed to the mainstream thoughts, out of 70.8 million forcibly displaced in 2018, 58 per cent or 41.3 million were Internally Displaced People (IDPs) and the 42 other per cents were refugees (25.9 million) and asylum seekers (3.5 million). Half of all refugees are children (UNHCR, 2019d).

To give an idea of the budgets and funding allocated to the displacement situation, the final annual budget for the year 2018 was $8,220.5 million as of 31 July 2018. For the year 2019, as of 31 January 2019, the current annual budget stood at $8,698.6 million (Executive Committee of the High Commissioner’s Programme, 2019).

2.2. Forced migration

A forced migrant is defined by the International Organization for Migration in its second edition of 2011 as, "a person subject to a migratory movement in which an element of coercion exists, including threats to life and livelihood, whether arising from natural or man-made causes (e.g. movements of refugees and internally displaced persons as well as people displaced by natural or environmental disasters, chemical or nuclear disasters, famine or development projects)" (as cited by the European Commission, n.d.).
In studying forced or involuntary displacement, a distinction is often made between conflict induced and disaster induced displacement.

The map in figure 1 shows the displacements by conflicts and disasters for the year 2018. It can be seen that most of the displacements are mostly happening in developing countries. It is linked to the presence of crises that often go with poverty and instability. In Africa, displacements are mostly due to conflicts whereas in Asia and India, disasters are the main cause of displacements. In America, both are happening.

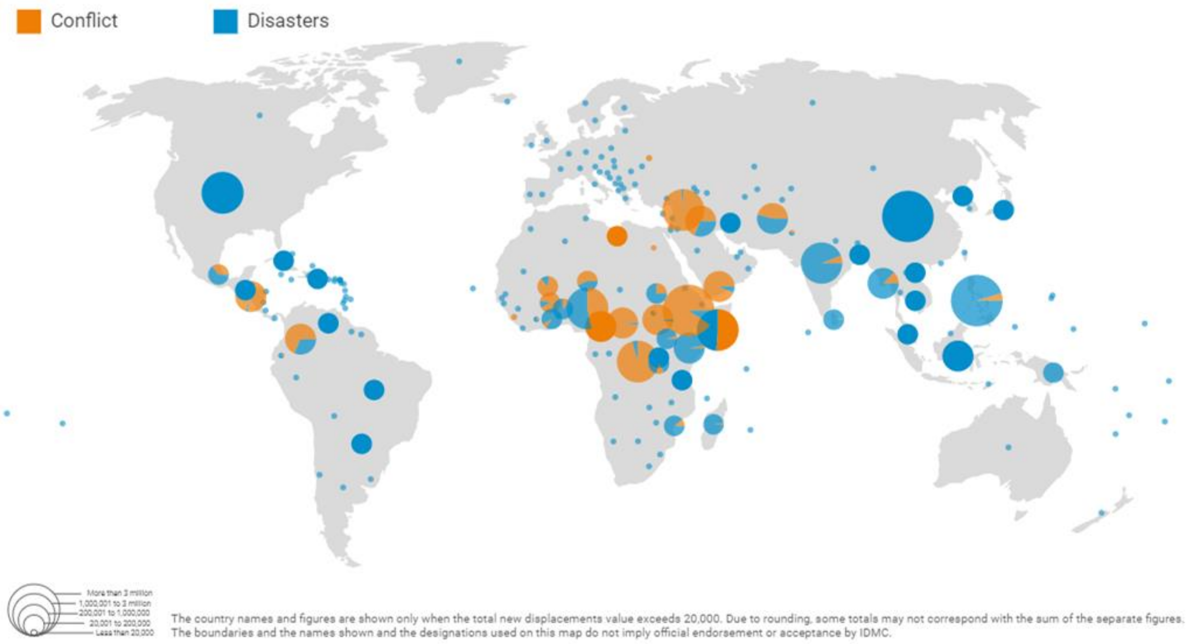

Figure 1. Displacements in 2018 by conflicts and disasters, from UNHCR, 2019.

2.3. People of concern

In the present study, the people of concern are refugees, internally displaced persons (IDP) and returnees defined here below.

Refugees include individuals recognized under the 1951 Convention relating to the Status of Refugees; its 1967 Protocol; the 1969 OAU Convention Governing the Specific Aspects of Refugee Problems in Africa; those recognized in accordance with the UNHCR Statute; individuals granted complementary forms of protection; or those enjoying temporary protection (UNHCR, n.d.b)

Internally displaced persons (IDPs) are people or groups of individuals who have been forced to leave their homes or places of habitual residence, in particular as a result of, or in order to avoid the effects of armed conflict, situations of generalized violence, violations of human rights, or natural or man-made disasters, and who have not crossed an international border. For the purposes of UNHCR's statistics, this population only includes conflict-generated IDPs to whom the Office extends protection and/or assistance (UNHCR, n.d.b).

Returnees refer to refugees who have returned back voluntarily to their country of origin or place of habitual residence (UNHCR, 2006).

2.4. International organizations

Governments of the host countries are the ones deciding where displaced people will settle (N. Dominici, personal interview, May 21, 2019) because the "states bear the primary responsibility for the protection of refugees, in conformity with their obligations under international refugee law, including regional treaties which concern them" (UNHCR, 2014).

Nevertheless, UNHCR works closely with governments, advising and supporting them as needed (UNHCR, 2014). Therefore, UNHCR can be asked by a government to give them an opinion or advice on a situation (N. Dominici, personal interview, May 21, 2019). Indeed, one of UNHCR's core responsibilities is to enable and support comprehensive and durable solutions for refugees and IDPs to allow them to rebuild their lives and live in dignity and safety (UNHCR, 2019d).

Even if the UNHCR depends on the decision that the government will take regarding the places to install displacement settings, it is a first step to show where there could be risk or suitability associated with land use and natural resources (N. Dominici, personal interview, May 21, 2019).

As figure 2 shows below, UNHCR coordinates the humanitarian response helped by other international organizations in their field of specialties.

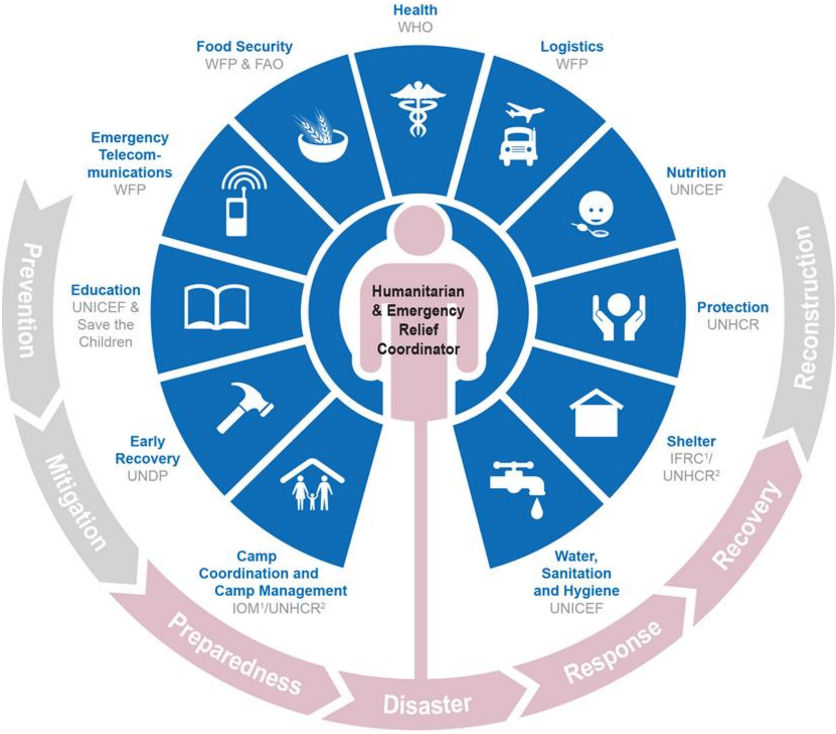

Figure 2. The cluster approach for the organization of humanitarian aid.

The FAO is one of the specialized agencies of the United Nations for food and agriculture that can be asked to give technical support to the UNHCR concerning its field of work.

FAO offers products (open access tools) and outreach services to unite international efforts to eliminate hunger in the world and follows the aim to free humanity from hunger and malnutrition and to manage food systems effectively at the global level. Everyone must have access to quality food in sufficient quantity and regularly to have the opportunity to lead a healthy and active life. The agency uses its knowledge and expertise to help fight disease and increase livelihood resilience (FAO, 2017).

Chapter three: Materials and Methods

3.1. Study area

The methodology is elaborated for the Republic of Niger (hereafter "Niger"), a West African landlocked country. It is bounded by seven states (Figure 3): on the northwest by Algeria, on the northeast by Libya, on the east by Chad, on the south by Nigeria and Benin, and on the west by Burkina Faso and Mali.

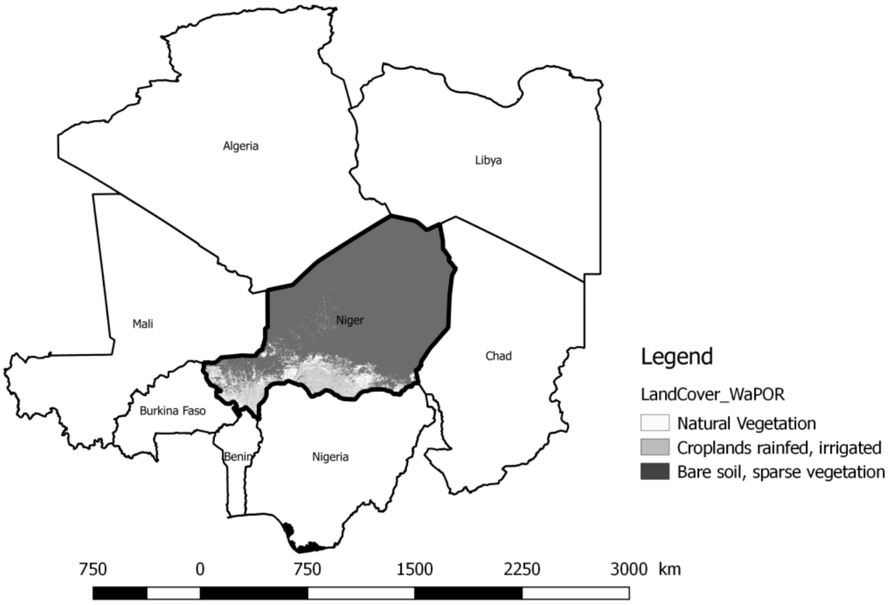

Figure 3. Niger borders seven countries.

Niger has a geographic area of 1,267,000 square kilometers (World Population Review, 2019), and includes seven regions: Agadez, Diffa, Dosso, Maradi, Tahoua, Tillaberi and Zinder (figure 4). The capital city is Niamey with a surface area of 255 km² (Institut national de la statistique Niger, 2013) included in the Tillaberi region (FAO, 2003). In 2018, Niger had an estimated population of 22,442,948 persons (The World Bank, n.d.a). This vast Sahelian country is situated on the southern edge of the Sahara Desert, and three quarters of its territory are covered by the desert (FAO, 2015). It is one of the hottest countries in the world (EROS-USGS, n.d.).

Rainfall increases as one proceeds southward, dividing naturally the country into three zones:

- a "Saharian zone" or desert zone in the north, which represents 65% of the national territory. Precipitations are scarce and add up to 100 mm per year (Rabe, 2011);
- an intermediate zone or "Sahelian-sudanian zone" in the central part, covering about 21.9% of Niger, with an annual rainfall between 300 mm to 600 mm (Rabe, 2011). It is mainly covered by an extensive pastoral zone, where nomadic pastoralists raise cattle. The ground is mostly covered by steppes or short grass savannas with shrubs and sparsely scattered trees (EROS-USGS, n.d.);

- a “Sudanian zone” in the south, representing approximately 0.9% of the national territory, where the annual rainfall is less than 600 mm (Rabe, 2011). It is a cultivated zone where the greater part of the population, both nomadic and settled, is concentrated (Encyclopedia Britannica, 2019). It is in this third region that nearly 98% of the arable land are concentrated, which means that the land potential for agriculture is very unevenly distributed among Niger’s regions (EROS-USGS, n.d.)

Niger’s terrain is characterized by small variations with an average elevation of 500 m and low local relief (EROS-USGS, n.d.).

Due to climatic conditions, more than 75% of the population occupy a quarter of the territory (FAO, 2016a). Moreover, with one of the highest fertility rates in the world [that is, 7.2 births per woman in 2017 (The World Bank, 2017b)] and one of the highest population growth rates in the subregion [that is 3.9% annually (The World Bank, 2018)], Niger is facing profound imbalances of the ecosystem, which accelerate the degradation of land and the environment (FAO, 2016a).

Furthermore, Niger is affected by climate change. Since most of the inhabitants derive their income from agriculture and stock raising, they are highly vulnerable to periodic droughts and desertification (EROS-USGS, n.d.). Recurrent climatic hazards like droughts, floods, locust infestations and desertification put the population at risk of chronic food insecurity (The World Bank, 2017a).

As a result, Niger was the last of 189 countries in the list of the Human Development Index (HDI) of 2018 (UNDP, 2018), which reflects the country’s overall achievement in its social and economic dimensions: health of people, their level of education attainment and their standard of living (The Economic Times, n.d.).

Niger has kept its original traditional religions over the centuries as well as adopted Islam, and later Christianity. Sunni Islam is by far the largest religion in the country, with a massive 81.1% of the population following this religion. Shiite Islam is the second largest religion, with 6.5% of the population adhering to the religion (Worldatlas, n.d.).

Niger is facing instability and insecurity notably due to the neighbouring countries’ conflicts and to two big crises: the Sahel and Lake Chad crises. Despite a stable political climate in 2017, the security situation in the Diffa region has been volatile since the arrival of Boko Haram. Niger has also been plagued by jihadist attacks and drug trafficking in the Tillaberi and North Tahoua regions (The World Bank, 2017a).

With that background, Niger is prone to having displaced people inside its borders as well as refugees coming from neighbouring countries. Therefore, managing the displaced people policy in a country whose resources are already scarce should be planned beforehand.

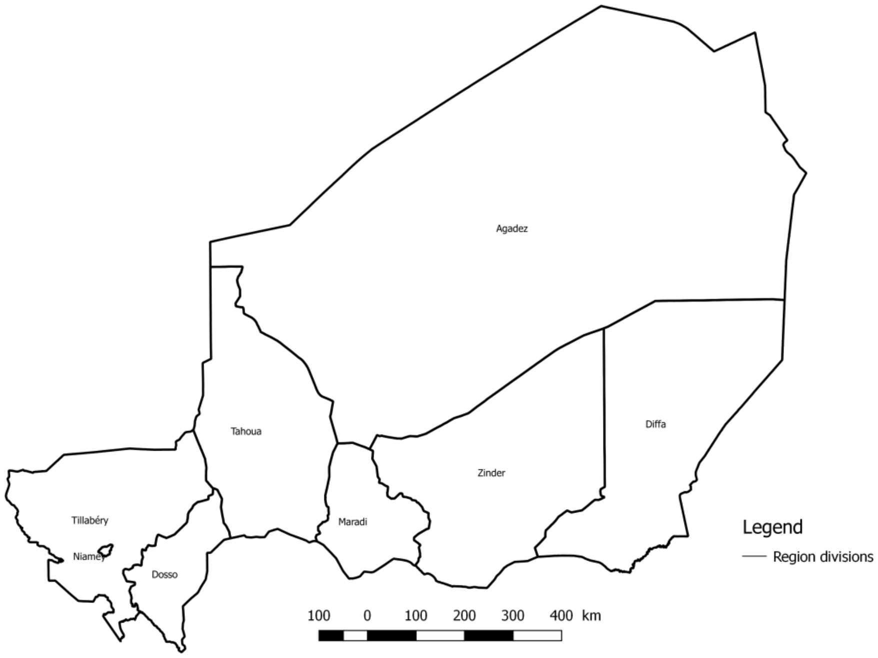

Figure 4. Niger has 7 regions: Agadez, Diffa, Dosso, Maradi, Tahoua, Tillabéri and Zinder; its capital city is Niamey.

3.2. Spatial Decision Support System concept (SDSS)

3.2.1. Introduction

Decision making is a process involving a sequence of activities that starts with recognition of a decision problem and ends with recommendation for a decision (Zucca, Sharifi, & Fabbri, 2008).

The decision-making process regarding the location of displacement settings is typically multi-faceted. Criteria related to environmental, social and services factors have to be defined and combined with the help of experts' knowledge consultation. As Rauschmayer & Wittmer suggested, a participatory process involving stakeholders is central to this decision-making scope (as cited in Lejeune, Gheysen, Ducenne, & Rondeux, 2010). With the emergence of geographic information systems (GIS), suitability analysis has become a modeling practice that facilitates the process of multi-criteria decision-making (MCDM) by simulating the suitability of a land unit in supporting a physical or socioeconomic phenomenon (Chow, & Sadler, 2010). According to Zucca et al. (2008) and Lejeune et al. (2010), multi-criteria decision analysis (MCDA) or spatial multi-criteria decision analysis (SMCDA) techniques are most appropriate to help decision makers in such a context.

In this study, a spatial decision support system (SDSS) is developed to answer the technical support requests made to FAO by UNHCR. Indeed, the latter needs an efficient tool to advise governments on choosing suitable displacement sites in any country taking into account multiple humanitarian based criteria. Therefore, the present study, using RStudio, intends to contribute to the elaboration of a coherent, adequate and though-through policy for displacement camps that ensures the well-being of both the displaced and the host populations and minimizes environmental impacts.

The development of the methodology is based on three major steps.

1. Identification and definition of relevant criteria
2. Selection of data translating the identified criteria into geographic information
3. Aggregation of the criteria
    3.1. Determination of suitability criteria values and their corresponding suitability indexes (SI)
    3.2. Determination of constraints criteria values
    3.3. Combination of all suitability and constraints criteria in a model, pondering each of the suitability criteria according to their attributed importance resulting in a suitability map

First of all, the title of the study needed to be narrowed down. Indeed, developing a methodology using remote sensing and GIS to quickly be able to guide governments on sites that would be suitable to welcome displaced people (refugees, IDPs and returnees) in developing countries was too broad to start with. Therefore, an area of interest was determined: Niger. A methodology was elaborated on the basis of this country; it produced results, which were analyzed and compared with existing sites.

Niger was chosen for two reasons:

- The FAO forestry department had ongoing studies on Niger
- Given the country's characteristics presented in the previous point (
- 3.1. Study area), Niger appeared to be a good example illustrating the challenge that decision makers could be faced to.

3.2.2. Criteria definition

The determination of important criteria to take into account when planning a displacement camp is one of the most important and trickiest steps. It was guided mainly by:
-the Emergency Handbook of the UNHCR (UNHCR, 2015),
-the SPHERE Handbook (Sphere Association, 2018),
-the Camp Management Toolkit (International Organization for Migration, Norwegian Refugee Council, & UNHCR, 2015).
Expert knowledge consultation also helped identifying other relevant criteria and explaining their importance.

The overview of the chosen criteria is presented in table 1.

For a structural purpose and for better understanding, the criteria are categorized relating to their nature. The first category gathers social features: criteria linked to the social lives of humans. The second category brings together geographic features: criteria linked to natural elements and landscape. The third category groups together infrastructure related features: criteria linked to the work of humans.

Table 1. Overview of the criteria highlighted by the literature, humanitarian handbooks and experts' knowledge consultation to take into account for the selection of a displacement site.

Category	Criteria	Geographic information
Social	Religion	Localization of places of worship
	Ethnicity	N.A.
	Conflicts	N.A.
	Land tenure	N.A.
	Population density	Gridded population count (number of people per pixel)
Geographical	Water	Quantity of precipitation
		Distance to water (surface and underground)
	Slope steepness	Slope value
	Above ground biomass production (AGBP)	Quantity of AGB produced yearly
	Land cover	Presence of wetlands
		Presence of water bodies
		Presence of croplands
	Country's boundaries	Distance to boundaries
	Altitude	Altitude value
	Land use	Presence of military bases
		Presence of nature reserves or national parks
Infrastructural	Roads	Distance to roads
	Electricity grids	Distance to electricity grids
	Towns	Distance to towns
	Health infrastructures	Distance to health infrastructures
	Education infrastructures	Distance to education infrastructures

3.2.2.1. Social category

As said in a guidance note of the FAO (2016b), "No conflicts can be resolved without a people-centred lens". Even if social criteria are difficult to map and sometimes cannot be mapped, they must have their importance/place into the decision-making process.

1. Religion

Religion is a sensitive and complex topic. Nevertheless, religious beliefs of displaced people and the host population are critical to analyze and consider when installing a displacement camp into a host country. The peace and security of both displaced people and the host community are at stake.

According to 18 USCS § 1093, the term "religious group" means “a set of individuals whose identity as such is distinctive in terms of common religious creed, beliefs, doctrines, practices, or rituals” (USLegal, n.d.).
In this study, the places of worship are the translation of the religion criterion into geographic data. However, there are not included in the quantitative analysis. Therefore, the results gotten from the spatial modeling step should be analyzed furthermore, using the places of worship as a tool to understand where religions are present in a country and to check the compatibility between host communities and displaced people.

2. Ethnic groups

Another important feature to take into account is the compatibility of ethnic groups in the host community and in the displaced population.

According to the Encyclopedia Britannica (n.d.), “an ethnic group is a social group or category of the population that, in a larger society, is set apart and bound together by common ties of race, language, nationality, or culture”.

Esri's ConnectED Initiative (2018) can be used to get a first idea of the major religion of an area. In addition, the Art & Life in Africa map (Gundlach, 2013) enables the user to view the different societies and demographics as well as the ethnic groups in Africa. Furthermore, some research on the area of interest delivered useful data for Niger: the major peoples, the percentages of religions, and the principal languages, among others (University of Iowa, 2013).

In the present study, this ethnic group criterion is left for the analysis of a human eye and knowledge.

3. Conflicts

Another social criterion found important is the absence of existing conflicts. Any context of war or civil war must be taken into account. And the site chosen should be located at a sufficient distance from conflict zones and other potentially sensitive areas (UNHCR, 2015).

Conflicts can arise quickly and be difficult to detect. The Armed Conflict Location & Event Data Project (ACLED) is a disaggregated conflict analysis and crisis mapping project (ACLED, 2019) that enables the user to better understand a context or the situation of a country.
In the present study, the conflicts criterion was also left for the analysis of a human eye and knowledge.

4. Land tenure

Land being acknowledged as one of the root causes of conflict, decision makers should pay close attention to it as it leads to increased competition for resources, particularly when displacement is involved (FAO, 2016b).

With regard to land tenure, it is important to consider both the legality and the social legitimacy of the host population who enjoy access to the land. Moreover, as mentioned in the Emergency Handbook of the UNHCR (2015), “refugees should enjoy exclusive use of the site in which they live, by agreement with national and local authorities”.

Land tenure is highlighted as an important criterion in the present study. Nevertheless, it is left for the analysis of a human eye and knowledge as it is difficult to make a decision remotely.

5. Population density

Finally, in order to take into consideration factors as the carrying capacity of land, the risk of degradation of natural resources and the possibility of integration of the displaced population in a region, population density was seen as an useful criterion.

This criterion was not included as a quantitative geographical criterion but rather analyzed after getting the results of the model to exclude areas that have a population density already high.

3.2.2.2. Geographical category

The following criteria can cause many conflicts with the host population, since it is linked to natural resources.

1. Water

Water is one of the basic constituent of life as it is essential for the food security and nutrition (to hydrate, drink, cook and eat) and the health (to clean and be clean) of every human. Moreover, as said in the Camp Management Toolkit (IOM, NRC, UNHCR, 2015), the availability of water is likely to be the most important criterion in determining a site’s suitability, because short supply can cause outbreaks of disease and death, as well as conflict. Being one of the most important criteria to take into account, it is yet the most difficult one to consider.

a) Difficulties encountered

There were three difficulties linked to this resource:

-no straightforward way was found to locate/quantify water resources

-availability of water - access and quantity - is difficult to consider with remote sensing

-no solution was found to verify the quality of water through remote sensing

It was then necessary to find a way to address these difficulties.

Firstly, with regard to locating water resources, experts were consulted, and they helped to solve the question. They all suggested that water was available through different sources and could be used in different ways. “The usual best option for water resources is ground water, but surface water is also used” (A. Dekrout, personal interview, May 16, 2019). Besides, “surface water from lakes and rivers can be used for agriculture or uses such as laundry and cleaning toilets” (C. Touzé, personal communication, May 17, 2019). Furthermore, precipitations and rainwater collection can be considered as a potential water resource in a displacement camp. “Big surfaces of roofs can be used to collect the water if it does not rain a lot” (C. Touzé, personal communication, May 17, 2019). Therefore “combining several types of geographic information, thus different types of water resources, is necessary” (C. Touzé and M.-J. Lambert, personal communication, May 17 and 20, 2019).

This information brought the idea of splitting the criterion into two subcriteria: water resources from precipitation, on one hand, and from surface and ground water, on the other hand. These subcriteria are further developed in the point b) below.

Secondly, with regard to water quantity, the first Standard of the Sphere project advises a minimum of 15 litres per person per day as an average volume of water used for drinking and domestic hygiene. Yet, no literature was found on the means to quantify existing water resources, especially for ground water.

As for water access, consulting the community members and the relevant stakeholders can help to collect useful information about how water is used and can be accessed; and to be aware of any access limitations or seasonal variations. The present study could not get this insight. It is a task that must be done on the field.

For those two limitations, further verifications of the availability of the identified water resources must be planned on the field.

Thirdly, with regard to quality and suitability for human uses, it has been highlighted by the first Standard of the Sphere project on Water Supply, Sanitation and Hygiene Promotion (2018) that inadequate water quantity and quality is the underlying cause of most public health problems in crisis situations. Nevertheless, “in general, water quality is less of an issue during site selection than water quantity, since many effective treatment options are available to cope with sedimentation and purification. However, this is not the case with heavy metals contamination, which warrants specific testing” (IOM, NRC, UNHCR, 2015).

Water resources located with the model could not be assessed by remote sensing, so that it must be tested on the field.

Having regard to the considerations presented here-above, the results given in the present study on the location of water resources will have to be checked on the field, to establish access, quantity and quality of available water resources.

b) The two subcriteria taken into account in the model

- Quantity of precipitations

Precipitations are measured around the world, and the results are freely and publicly available. Therefore, the quantity of rainfall (mm/year) is part of the decision-making

relating to the location of a site, discussed in the present study. Precipitations are thus considered as a suitability criterion, but also as a constraint when precipitations are too scarce.
Niger is considered as a BWh hot deserts climate (arid) and BSh hot semi-arid (steppe) climate according to the Köppen climate classification map (Arnfield, 2019). In this classification, the first letter refers to the climate type. The letter "B", allocated to Niger, refers to a dry climate with annual evaporations above annual precipitations and with scarce waterways. The second letter refers to the rainfall climatology. In the case of Niger, W refers to an arid climate with precipitations below 250 mm per year. The letter S is for a steppe climate for which annual precipitations are between 250 and 350 mm. The third letter indicates the temperature; h refers to a mean annual temperature above 18 degrees Celsius (Doucet, 2018).

Therefore, an area with more rainfall will be considered as more suitable.

- Distance to underground and surface water

As previously explained, water is essential to sustain any type of life. The distance to water resources is used as part of the location of a site's decision-making in the present study. It is a suitability criterion, but also a constraint criterion when the distance to water resource is too long. An acceptable distance to this resource is also required due to the weight of it.

The supply of the survival level of safe drinking water is important. Safe drinking water is mostly found within boreholes. Nevertheless, in the case of a camp, water demands explode compared to what they are initially. It is thus not likely that a camp can draw all its water resources from an existing borehole already being used by the host population. But knowing the localization of wells and boreholes in an area can help determine where water could be accessible and available (M. Goffin, personal communication, May 15, 2019).

New infrastructures (boreholes) could then be built to produce and distribute drinkable water within the displacement camp. Nevertheless, the information must be verified on the field before taking a decision, since UNHCR (2015) recommends that "a site should not be selected on the assumption that water will be found by drilling".

As it has already been said, surface water also has a role to play since it can be used to meet the water resources requirements of the displaced population.

2. Slope

The slope must also be taken into consideration, because it is an important factor for construction purposes and it can cause excessive erosions. Nonetheless, in Niger, with a hilly landscape, the altitude and slope do not represent a big challenge (M. Goffin, personal communication, May 15, 2019).

In the present study, the slope is considered as a suitability criterion. Also, a slope too steep reflects a constraint criterion.

3. Above ground biomass production (AGP) - energy

Energy is an important factor to take into account, even if its access is often overlooked in emergency response (D'Annunzio, Gianvenuti, Henry, & Thulstrup, 2016). Indeed, crisis-affected populations - including refugees, internally displaced and the communities hosting them – need access to fuel and energy for cooking, heating and lighting and powering (FAO, 2018b). Firewood -the most widespread form of energy in camps (Tado, n.d.)- and biomass are usually used for the latter. Biomass can also be used for shelter construction (IOM, NRC, UNHCR, 2015).

Nevertheless, a lack of management for a safe and reliable access to energy for all can have severe consequences at several scales. The overuse of the biomass resource for firewood and services can lead to environmental degradation (Tado, n.d.), causing strong erosions and flooding, and having an important impact on biodiversity. Erosion is one of the most important concerns, which can lead to the pollution of neighbouring rivers, among others (N. Dominici, personal communication, May 21 2019). The degradation can occur rapidly around camps and may become irreversible, with significant implications for communities dependent on natural resources for their livelihoods and well-being (D'Annunzio et al., 2016).

Besides, letting displaced people fetch their own firewood can put people's safety at risk, especially women, who are expected to go every morning to look for that resource (Tado, n.d.).

Knowing the benefits of having a sufficient ground cover and vegetation (grass, bushes and trees) that provides shade, protects from the wind and reduces erosion and dust, UNHCR (2015) advises to take steps to ensure access to a supply of firewood, in collaboration with local forestry authorities and in negotiation with the host community. Indeed, "host communities should be involved in decisions relating to local management and extraction of natural resources. They should also benefit from some environmental support activities, such as tree planting, awareness raising, and have access to fuel-efficient stoves (IOM, NRC, UNHCR, 2015).

This communication and collaboration could avoid conflicts, enhance a more sustainable management of the resource and limit the constrained access to the resource that the displaced population can face today.

Tomorrow's selection of suitable sites should integrate a sustainable environmental dimension to assure the resilience and sustainability of the environment linked to the peace between host population and displaced people.

In the present study, the above-ground biomass production in kg per ha was used and considered as a suitability criterion.

4. Land cover

The land cover has to be taken into consideration, and the following areas should directly be excluded from a suitable site:

- Wetlands

For environmental and stability reasons, a camp cannot be installed on a wetland. Indeed, as explained by Ramsar (n.d.), the Convention on Wetlands, “wetlands are indispensable for the countless benefits or “ecosystem services” that they provide humanity, ranging from freshwater supply, food and building materials, and biodiversity, to flood control, groundwater recharge, and climate change mitigation.” And areas likely to become marshy or waterlogged during the rainy season should be avoided (UNHCR, 2015).

- Water bodies

A camp cannot be installed on water bodies for obvious reasons.

- Croplands

Croplands are not suitable to install a displacement camp for land tenure reasons.

Therefore, in this study, wetlands, water bodies and croplands are considered as constraints criteria and thus are masked. Moreover, it's advisable to foresee a buffer around wetlands in order to protect them. This question will be further developed later in the present study.

5. Boundaries

The location of displacement camps and settlements should be at a reasonable distance from the border of their country of origin, in a place where law and order can be secured. The location should be determined taking regard of the safety and the well-being of the displaced people as well as of the security needs of the receiving State (Nicholson, & Kumin, 2017).

Therefore, in the present study, a distance to boundaries is considered as a suitability criterion.

6. Altitude

Elevation at which the population has always lived is an important factor to consider. Indeed, people who used to live at high altitudes have less likely been exposed to malaria or other insect-linked diseases. Moving them near the sea level can have dramatic sickness or death consequences if they are not vaccinated (Michel B., personal communication, January 19, 2019). On the other hand, people used to live at or around sea level who are moved to higher elevations can also be affected.

To illustrate the first scenario, Prothero (2002) explained the consequences of a forced resettlement of an Ethiopian population by the government in the 1980s. People coming from altitudes above 2000 m and generally malaria-free areas (though with periodic malaria epidemics) lacked immunity. Therefore, when moved to lowlands where the disease is endemic, they were at risk to high morbidity and mortality from malaria, sleeping sickness, river blindness and yellow fever.
The second scenario is illustrated by West (2015). High altitude affects the human body because of oxygen deprivation. Other factors, such as severe cold, high winds, and intense

solar radiation, may be present but can be nullified by appropriate protection. Although acute mountain sickness can affect any human who ascend from near sea level to altitudes higher than 3000 m (or may also occur at altitudes as low as 2000 m), displaced people may be more sensitive and less capable of adaptation since they have been exposed to physical and psychological stresses. Therefore, the UNHCR (2015) recommends avoiding locating displaced people in places whose climate differs greatly from what they are accustomed.

Since this criterion is linked to the history of the population, it was left for the analysis of a human eye and knowledge once the results from the quantitative analysis are received.

7. Land use

As far as land use is concerned, two categories of site were considered: military bases and national parks.

- Military bases

As advised by UNHCR (2015), a site should be located a sufficient distance from […] conflict zones, and other potentially sensitive areas (such as military installations).

- National parks or nature reserves

Usually, to avoid problems with host communities, states decide to install displaced people in remote places. Therefore, it happens that areas surrounding nature reserves are targeted since the population density is smaller in those areas (N. Dominici, personal interview, May 21, 2019). If it is the case, site occupants should be educated about not damaging the protected areas (Kelly, 2005).

Therefore, in the present study, military sites and national parks or natural reserves are considered as constraints criteria and therefore masked.

3.2.2.3. Infrastructural category

1. Roads

People have a more positive outcome, a better resilience when they are closer to a road. Indeed, exchanges of goods and services can be done more easily, which enables the diversity of food and activities (F. Eveillé, personal communication, June 24 2019).

A road nearby helps the humanitarian aid to assist rapidly displaced people (N. Dominici, personal interview, May 21, 2019). Besides, to prevent the spread of water-borne diseases or vectors, such as diarrhea and measles, quick interventions need to be carried out. Prevention, through education, surveillance to detect epidemics, diagnosis as well as the management of a case of illness and finally an intervention if necessary represent essential steps (Sphere Association, 2018). These measures will only be possible if the facilities are accessible quickly and easily. It is therefore imperative that a camp is located near a road. Nevertheless, UNHCR could also build roads but the speed at which they could be able to assist the displaced would be reduced.

Paths and roadways are often the places where most of the population will communicate with each other and establish informal markets (UNHCR, 2015). The camp management toolkit recommends having a market place and accessing to roads well-lit and located in an easily accessible place for both camp residents and the local population, so as to encourage social and economic exchange (IOM, NRC, UNHCR, 2015). In fact, in a Rapid Woodfuel Assessment done in 2017 in Chad, three refugee camps were compared to one another. One of them, Amboko benefited from its position at the crossroad of different villages and the city of Goré. Therefore, it was shown that this refugee camp had more tools and more diversified cereals. Furthermore, refugees were employed as daily labor by the host community more easily than refugees from the other camps (FAO, 2018a).

Moreover, the UNHCR (2015) recommends having a reliable access to the site by ensuring that it has an adequate road infrastructure including during the rainy season.

For all these reasons, a site should be planned accordingly to the distance to existing features such as roads.
In the present study, the distance to roads is considered as a suitability criterion.

2. Electricity grids

From the energy point of view, to determine a potential site, UNHCR considers first of all the presence nearby of the national electricity grid. Indeed, rather than building an entire electrical system with thousands of generators that cost millions in gas and equipment, directly connecting to the national network and pay for it would ease the process (N. Dominici, personal communication, 21 May 2019).

Nevertheless, the tricky part is to have an electrical network nearby that works and is able to sustain a camp of a certain number of people (Michel B., personal communication, June 21, 2019). Therefore, it depends on the situations. Sometimes generators could be the best solution, sometimes national network is more suitable. It also depends on the contracts and negotiations that are made (N. Dominici, personal interview, May 21, 2019).

That's why, in the present study, the distance to electricity grids is considered as a suitability criterion.

3. Towns, health infrastructure and education infrastructure

UNHCR (2015) advises to assess the site's proximity to national services, including health facilities, markets and towns. Access to mainstream services is encouraged wherever possible and avoids the need to develop parallel services for the camp population. Enabling people to have access to different services is important since “movements resulting from political pressures or environmental catastrophes expose people to physical and psychological stresses (fatigue, undernutrition/malnutrition, problems of mental adjustment to new environments) which may reduce resistance to infection” (Prothero, 2002).
Therefore in this study, the distance to towns and infrastructure, such as health and education centers, is considered as a suitability criterion.

3.2.3. Available data for criteria expression

Finally, the conceptual criteria described in the above section can only be taken into consideration geographically if there is a way to map them or find a way around to take them into account.

Relating to the aims and objectives of the present study, the research of data was conducted keeping the elements below in mind:

- Preference for data available globally
- Preference for downloading data without registration requests
- Preference for automatic downloads to avoid manual steps

When worldwide data were available, they were checked and held in if considered pertinent. These data enable the analyst to have quickly access to the information of the country of interest. When no worldwide data was found available, national researches were made and used for Niger.

It is admitted that the weak point of this methodology is the dependency on the available data. It is obvious that worldwide datasets come with a compromise on the precision. Indeed, as the quality and scales of data available at national level may differ a lot, it's necessary to smoothen them to get a worldwide map. In this process, information is lost. Very general data may not be ideal for the camps settlements (M. Goffin, personal communication, May 16, 2019).

Being a pilot work, the present study aims mainly to make available an open source and flexible tool. However, to create it, data had to be found and used. The data presented in this thesis are not the most accurate. Nevertheless, the design of the tool enables national authorities, as well as national and international humanitarian actors who may have more accurate, reliable and relevant data in their hands to use them. Anyone can change and add the data to ensure a more effective and efficient humanitarian protection and assistance if considered pertinent.

Table 2 below summarizes the sources of data found and used for each criterion of the quantitative system. When it was found relevant, a description of the data was added.

Table 2. Overview of the data used and their characteristics.

Criteria	Data source	Description	Data type	Spatial resolution (m)
Precipitation	WaPOR, Precipipitation (Annual)	The source of this dataset is CHIRPS (Climate Hazards Group InfraRed Precipitation with Station) quasi-global rainfall dataset, starting from 1981 up to near present. The value of each pixel represents the total of daily precipitation in the year expressed in mm (1mm=1l/m² or 1mm=10m³/ha).	Raster	~5 000
Surface water	Geofabrik	Geofabrik GmbH is a free download server making available data extracted from the OpenStreetMap project which are usually updated every day.	Vector	
Underground water	Geofabrik	Geofabrik GmbH	Vector	
Slope	GIS blog	SRTM Data, Shuttle Radar Topography Mission	Raster	90
Above Ground Biomass Production	Action Against Hunger - Action contre la faim - BioHydroGenerator	The satellite data come from sensor acquisitions of VEGETATION embedded on SPOT-4 (1998-2013), SPOT-5 (2002-2014) and PROBA-V (since 2014) satellites. These satellite products are stored as periods of 10 days, and at a spatial resolution of 1 × 1 km.	Raster	1 000
Wetlands	Geofabrik	Geofabrik GmbH	Vector	
Water bodies (LC)	WaPOR: Land Cover Classification	This land cover dataset at continental scale is based on the Copernicus Global Land cover map. WaPOR data adds, on top of the Copernicus map, the distinction between irrigated and rainfed areas. It is published on a yearly basis.	Raster	250
Cropland (LC)	WaPOR : Land Cover Classification	Land Cover dataset based on Copernicus Global Land cover map	Raster	250
Borders	GADM - the Database of Global Administrative Areas	The 'getData' function of the raster package in R was used.	R data '.rds' format was generated	
Altitude	GIS blog	SRTM Data, Shuttle Radar Topography Mission	Raster	90
Military zone (LU)	Geofabrik	Geofabrik GmbH	Vector	
Nature reserve/national park (LU)	Geofabrik	Geofabrik GmbH	Vector	
Roads	Geofabrik	Geofabrik GmbH	Vector	
Electricity grid	Africa Electricity Grids Explorer	This dataset is linked to Niger - Electricity Access Expansion Project by the World Bank in 2015.	Vector	
Towns	Geofabrik	Geofabrik GmbH	Vector	
Health infrastructure	Geofabrik	Geofabrik GmbH	Vector	
Education infrastructure	Geofabrik	Geofabrik GmbH	Vector	

3.2.3.1. WaPOR, or the FAO Water Productivity Open-access Portal

(https://wapor.apps.fao.org/)
To download data from WaPOR, a registration is needed. Nevertheless, this source of information was chosen so far as, in the future, API could be used to ingest WaPOR data into SEPAL. Doing so would enable the user to directly get the data from SEPAL instead of downloading it manually.

It is possible to download the data for any area of interest (AOI) by uploading a shapefile of the AOI. Nevertheless, during the download, an error was generated linked to the topology and vertex complexity of the shapefile used for Niger. Therefore, a slightly simplified version of the country boundary was used and the download was then possible.

As far as precipitations are concerned, it was necessary to multiply the pixel values by 0.1 as mentioned in the layer's description in the catalogue on the website.

3.2.3.2. OpenStreetMap

(http://download.geofabrik.de/)
OpenStreetMap is a reliable and publicly available source of information. Of course, it is not the most precise since it relies on countries' accuracy of data. See Ramm (2019) for more information on the available layers.

3.2.3.3. GIS blog

(https://www.gis-blog.com/download-srtm-for-an-entire-country/)
A straightforward way to download SRTM at 90m resolution was found and used on a GIS blog. The author is named Martin currently working at GeoVille - an Earth Observation Company based in Austria, specialized in Land Monitoring.

3.2.3.4. Action Against Hunger – Action Contre la Faim

(http://geosahel.info/Viewer.aspx?map=Analyse-Biomasse-Finale#)
Action Against Hunger is a Non-Governmental Organization (NGO) that was created in 1979. Its mission is to save lives eradicating hunger through the prevention, detection, and treatment of malnutrition, in particular during and after emergency situations caused by conflicts and natural disasters (Action contre la faim, n.d.a).

Through the pastoral surveillance program, the NGO aims to strengthen the capacity of agro-pastoral and pastoral populations to respond to crises by focusing on the creation of tools and systems for real-time collection and extensive geographical coverage in the Sahel (Action contre la faim, n.d.b*)*. Therefore, interactive maps are available for reference and download.
With regard to these data, Fillol (2018) explained in details the way the above ground biomass production was calculated and the properties of the layers. Among other information, the following can be found: The products resulting from these satellite acquisitions are provided by VITO (Flemish Institute for Technological Research), through the European

project DevCoCast (GEONETCast for and by Developing Countries) led by the European Commission and the JRC (Joint Research Center). The products are available for download in real time, usually the day after the last day of the decade. There are three decades for each month: the first decade covers the period from the 1st to the 10th, the second decade 11th to 20th, the third of the 21st to the last day of the month. There are thus 36 decades per year.

Data can be downloaded through the "biomasse" folder under the « Maplayers » tab. Different years of interest for "production de la biomasse (kg/ha)" or biomass production are available. The download of the raster will directly start after selecting the "metadata" option (the "download" option is not activated).

3.2.3.5. GADM - the Database of Global Administrative Areas

(https://gadm.org/)
Through R Studio, many functions can be used. In the present study, the 'getData' function of the raster package was used to get the boundaries of Niger.

3.2.3.6. Africa Electricity Grids Explorer - an innovation of the World Bank

(https://energydata.info/)
"The World Bank has created the Africa Electricity Grids Explorer as a way to navigate the most up to date collection of open data on grid networks in Africa and the Middle East. This intends to support initiatives in grid and off-grid electricity access, grid infrastructure upgrading, renewable energy and sector planning. It is also part of a push to increase the openness and accessibility of energy data for Sustainable Development Goals, building on the energydata.info platform, along with platforms like World Bank Open Data" (The World Bank, n.d.b).

The World Bank cautions: "this data is based on a wide variety of sources, some already open, some open but hard to find, and many that have not been publicly available before. It is incomplete and the sources vary by country and region. It should not be used to make comparisons about the extent of grid coverage between countries or areas".

The dataset available for Niger is part of a project aiming at increasing access to electricity in Niger. One of the components of the project aims to support the expansion, reinforcement, densification, and rehabilitation of medium and low voltage (MV and LV) distribution systems so as to allow 60,000 new connections in seven major urban areas (Niamey, Dosso, Maradi, Zinder, Agadez, Tahaoua, and Tillabery) (The World Bank, 2015).
ECOWAS - Economic Community of West African States can help visualize the distribution grids of West African countries and the links between neighbouring countries. (http://www.ecowrex.org/mapView/?)

3.2.4. Criteria aggregation

3.2.4.1. Introduction

There are two types of criteria in the present study linked to the way they are taken into account in the spatial decision support system (SDSS): suitability and constraints criteria. They are presented in the figure 5.

	Suitability criteria	
Geographical	Precipitations	(mm/year)
	Distance to water ressources (surface and underwater)	(m)
	Slope	(%)
	Above ground biomass production	(kg/ha)
	Distance to boundaries	(km)
Infrastructural	Distance to roads	(km)
	Distance to electricity grids	(km)
	Distance to towns	(km)
	Distance to health infrastructures	(km)
	Distance to education infrastructures	(km)

	Constraints criteria	
Geographical	Precipitations	(mm/year)
	Distance to water ressources (surface and underground)	(m)
	Slope	(%)
	Above ground biomass production	(kg/ha)
	Distance to wetland	(m)
	Distance to nature reserve, national park	(m)
	Wetland	
	Water body	
	Cropland	
	Altitude	(m)
	Military base	
	Nature reserve, national park	
Social	Religion	(places of worship)
	Ethnicity	
	Conflict	
	Land Tenure	
	Population density	(number of people per grid-cell)

Figure 5. Organization of the criteria into three categories (geographical, infrastructural and social) on the basis of the way they are taken into account in the final model.

Some criteria were recognized right away as a limitation to install displacement settings. They are called constraints criteria. In their presence, the pixel value is 1 and the area is excluded, whereas the pixel value is 0 otherwise. As Hansens (2005) explains, constraints are thus expressed on a Boolean scale [true (1) / false (0)] and used to limit the next step of the analysis to some part of the study area where constraints are not met (as cited by Lejeune et al., 2010). Suitability criteria, on the other hand, reflect how appropriate a site is for the installation of a displacement setting regarding the feature looked at. In other words, they give a continuous measurement of suitability, related to certain aspects of the decision-making process.

In order to compare how suitable a site is regarding different criteria, all the suitability criteria needed to be standardized on the same scale. As it has been done by Zadeh and Chang et al., for aggregation purpose, suitability criteria are converted into suitability indexes and subsequently standardized on a continuous [0,100] scale through the use of membership functions (as cited by Lejeune et al., 2010) as the figures 6 and 7 show. Therefore, when a criterion is unsuitable, it will get a pixel value of 0 whereas, when criteria are suitable, the corresponding pixels will have a value of 100. In the middle, pixels will get a value in-between 0 and 100. This value is calculated using the equation 1.

As figure 6 shows, when higher values are considered more suitable than smaller values, a positive slope defines the suitability indexes of the corresponding criteria as it is the case for precipitations (figure 6), above ground biomass production and distance to borders.

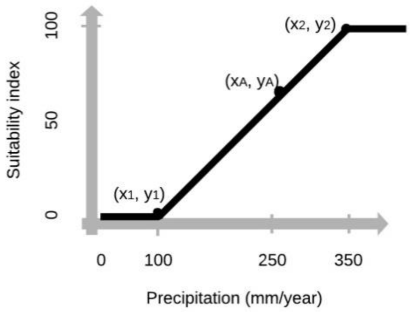

Figure 6. Membership functions are used to convert suitability criteria into suitability indexes. This figure shows an example of the precipitations given in mm per year. The points ($\mathbf{x_1}$,$\mathbf{y_1}$), ($\mathbf{x_A}$, $\mathbf{y_A}$), ($\mathbf{x_2}$, $\mathbf{y_2}$) added on the figure illustrate the equation 1; and unsuitable, middle and suitable sites respectively.

As figure 7 shows, when smaller values are considered more suitable than higher values, a negative slope defines the suitability indexes of the corresponding criteria: as it is the case for distance to water resources (figure 7), slope, distance to roads, distance to electricity, distance to towns, distance to health infrastructure and distance to education infrastructure.

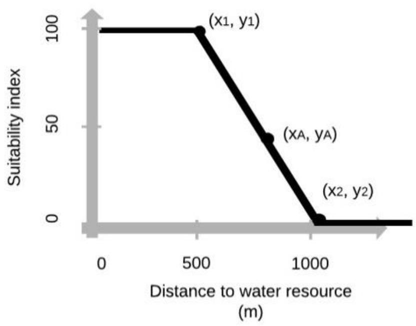

Figure 7. Membership functions are used to convert suitability criteria into suitability indexes. This figure shows an example of the distance to the nearest water resource given in meters. The points ($\mathbf{x_1}$,$\mathbf{y_1}$), ($\mathbf{x_A}$, $\mathbf{y_A}$), ($\mathbf{x_2}$, $\mathbf{y_2}$) added on the figure illustrate the equation 1; and suitable, middle and unsuitable sites respectively.

Equation 1. Transformation of A's suitability criterion value into its suitability index using a linear interpolation.

$$\frac{\Delta y_{1,2}}{\Delta x_{1,2}} = \frac{\Delta y_A}{\Delta x_A} \leftrightarrow y_A = y_1 + \frac{(y_2 - y_1) \times (x_A - x_1)}{(x_2 - x_1)}$$

3.2.4.2. Identification and definition of constraints criteria values

The values determined for each constraints criterion are summarized in table 3.

Social criteria (religion, ethnicity, conflicts and land tenure) as well as altitude were not included in the general SDSS. Indeed, because they depend on the life history of the displaced people and inasmuch as it is difficult to give them fixed values since they differ from one context to another, they will be used and discussed in the different scenarios presented in the chapter 4 of the present study. These criteria, especially, need to be analyzed taking into account the possible relation that they could have with the host population.

Table 3. **Summary of the constraints criteria and their values when defined.**

		Mask	
Constraints criteria	Units	1	0
Precipitations	(mm/year)	< 200	other
Distance to water ressources (surface and underwater)	(m)	> 2000	other
Slope	(%)	> 20	other
Above ground biomass production	(kg/ha)	< 1000	other
Distance to wetland	(m)	< 1000	other
Distance to nature reserve, national park	(m)	< 24000	other
Wetland		yes	no
Water body		yes	no
Cropland		yes	no
Altitude	Context dependent		
Military base		yes	no
Nature reserve, national park		yes	no
Religion	Context dependent		
Ethnicity	Context dependent		
Conflict	Context dependent		
Land tenure	Context dependent		
Population density	Context dependent		

1. Precipitations

Precipitations under 200mm/year, which means too little rainfall, are masked out.

2. Distance to water resources

The Sphere project (2018) and the Emergency handbook (UNHCR, n.d.a) recommend that any dwelling should only be a few minutes' walk from a water distribution point. Therefore, distances above 2 kilometers from any household to the resource are excluded.

3. Slope

As already mentioned, steep slopes should be avoided because of erosion problems and earthmoving operations for roads and building construction. Therefore, a constraint criterion was created to mask out the slopes superior to 20%.

4. Above ground biomass production

A constraint criterion was created to mask out the above ground biomass production under 1000 kg per ha (F. Eveillé, personal communication, June 24 2019).

5. (Distance to) wetlands

Due to their importance and the need to protect them, wetlands are masked out. Indeed, UNHCR (1996) warned that local people depend on wetlands as a source of fish, birds, medicinal herbs, etc. Therefore it is important not to degrade them and bear in mind that negative changes can have serious impacts in the long term.

Since the area adjacent to a wetland is essential to its survival and functionality (McElfish, Kihslinger, & Nichols, 2008), a buffer of 1 kilometer is also considered as a constraint criterion.

6. (Distance to) nature reserve and national park

UNHCR (2015) advises to avoid sites within one day's walk of an environmentally protected area such as a wild-life reserve. A normal walker can be expected to walk between 2.5 to 4 kilometers per hour. Therefore, an average speed of 3 km/h was used to calculate the distance that should separate a site from a nature reserve or national park. If the person walks eight (8) hours per day, the site should be at a distance of 24 km.

Therefore, in the present study, national parks and nature reserves were masked out, and a buffer around those areas was added as an additional constraint criterion.

7. Water bodies

For obvious reasons, water bodies were at once taken out and considered as a constraint criterion.

8. Croplands

Although UNHCR (2015) recommends selecting sites where the land is suitable for small-scale cultivation in the case the displaced could have access to it, it has been decided in the present study to consider croplands as a constraints criterion and mask it out, as conflicts may arise when natural resources are involved.

When considering this criterion in future studies, attention should be raised where there are irrigated croplands, as Prothero, (2002) cautions, because malaria risks may increase in those areas. In that case, it might be interesting to add a buffer around croplands when considered relevant.

9. Military bases

The Emergency Handbook (UNHCR, n.d.a) recommends the location of a site to be at a sufficient distance from military installations but does not give any more detail. Therefore, military bases are masked out, but no buffer around those areas was added in the present study.

If national authorities, national and international humanitarian actors want to take into account a distance to military bases, it can always be added in the equation.

3.2.4.3. Identification and definition of suitability criteria values

The values determined for each suitability criterion and their corresponding suitability indexes are summarized in table 4 below.

In line with the work done by Lejeune et al. (2010), the system component devoted to suitability criteria is adaptive and can be run without predefined criteria. All the functionalities have been included in order to create and manage a set of suitability criteria with a high degree of flexibility.

Table 4. Summary of the values of suitability criteria and their corresponding suitability indexes.

	Suitability index		
	100	]0,100[	0
Suitability criteria	**Values**		
Precipitations (mm/year)	≥ 350	250 ≤ p < 350	< 250
Distance to water ressources (surface and underwater) (m)	≤ 500	500 < d ≤ 1000	> 1000
Slope (%)	2 ≤ s ≤ 4	4 < s ≤ 10	s < 2 OR >10
Above ground biomass production (kg/ha)	≥ 3000	1500 ≤ b < 3000	< 1500
Distance to boundaries (km)	≥ 50	25 ≤ d < 50	< 25
Distance to roads (km)	≤ 1	1 < d ≤ 5	> 5
Distance to electric network (km)	≤ 5	5 < d ≤ 10	> 10
Distance to towns (km)	≤ 5	5 < d ≤ 10	> 10
Distance to health infrastructures (km)	≤ 5	5 < d ≤ 10	> 10
Distance to education infrastructures (km)	≤ 5	5 < d ≤ 10	> 10

An important part of the research was identifying and defining the values of suitability criteria. The decision behind their value is explained hereafter.

1. Precipitations

As already mentioned, precipitations can be part of the water resources solution. A desert type climate is characterized by less than 250 mm of rainfall per year, it is considered unsuitable. Middle values correspond to a steppe, with precipitations of 250 to 350 mm yearly. The most suitable values are defined as a minimum of 350 mm of rainfall per year.

2. Distance to water resources (surface and ground water)

The Sphere project (2018) indicates that any household should be at a distance of maximum 500 meters from the nearest water point, whereas the Emergency handbook (UNHCR, n.d.a) recommends a maximum distance of 200 meters from any household.

In the present study, households distant of 0 to 500 meters from a water source are considered as the most suitable. When a dwelling is 500 meters to 1 kilometer away from a water resource, it is considered as more or less suitable. Finally, when households are more than 1 kilometer away from a water source, the site is considered unsuitable.

3. Slope

"Ideally, a site should have a slope of 2% – 4% for good drainage, water distribution and agricultural opportunities. The slope should not be more than 10% to avoid erosion and the need for expensive earth-moving for roads and building construction" (UNHCR, 2015). Flat sites (0-2%) may have drainage problems and lead to the accumulation of standing water and thus become breeding grounds for disease-carrying vectors such as mosquitoes (IOM, NRC, UNHCR, 2015; Mong, Nelson, Oni, 2014).

Therefore, in the present study, slopes under 2 % and above 10 % are considered unsuitable; slopes in-between 2 and 4 % are considered the highest suitable. Finally, slopes in between 4 to 10% are considered more or less suitable.

4. Above ground biomass production

For the purpose of the present study, it was defined that a site with an above ground biomass production (AGBP) in Niger higher than 3000 kg per hectare yearly is considered as suitable. The suitability is less when the AGBP is in between 1500 and 3000 kg per hectare. Unsuitable sites have an AGBP under 1500 kg/ha (F. Eveillé, personal communication, June 24, 2019).

5. Distance to boundaries

The Emergency handbook (2015) recommends that a site should be located at a minimum distance of 50 kilometers from international borders. Therefore, the most suitable sites will be at 50 km or more from a border; more or less suitable sites are at a distance of 25 and 50km to boundaries. When a pixel is at a distance below 25 km from the country's borders, it is considered unsuitable.

6. Distance to roads

As already mentioned, being at a reasonable distance from roads can have many benefits for the displaced population. Therefore, a suitable distance to roads is considered to be from 0 to 1 km. An intermediate distance is between 1 and 5 km, whereas a distance above 5 km is deemed unsuitable.

7. Distance to electricity grids

A distance of 0 to 5 km to electricity grids is considered as suitable. A distance in-between 5 to 10 km is considered more or less suitable and further than 10 km is unsuitable (F. Eveillé, personal communication, June 24, 2019).

8. Distance to towns and health and education infrastructures

As the camp management toolkit recommends (IOM, NRC, UNHCR, 2015), the site location for a displacement camp should be selected with livelihoods opportunities and access to markets in mind.

Therefore a distance of 0 to 5 km to towns is considered suitable. Since health and education infrastructures are often linked to the presence of a town, the three criteria have the same suitability values. The values are calculated taking into account that an average person walks at a speed of 3 km per hour. Therefore, it would take that person up to two hours maximum to reach a town and/or infrastructures.
A distance in-between 5 to 10 km is considered more or less suitable and further than 10 km unsuitable.

These distances were also decided looking at another perspective. If UNHCR decides to build services and infrastructures, such as school buildings, community halls, roads, electricity cables or wells, it may benefit local communities after the displaced population has returned (IOM, NRC, UNHCR, 2015).

3.2.4.5. Attribution of weights to suitability criteria

Once the relevant criteria have been identified, as well as the way they should be taken into account to make a multi-criteria decision, it seems interesting to attribute weights to the suitability criteria.

The importance of each criterion in the final equation is determined using the Weighted Linear Combination method (WLC). The latter is based on the concept of weighted average (Lejeune, 2010). It is a popular method among complete aggregation techniques (Kangas, Kangas, & Kurttila, 2008).

This step is subjective. Indeed, since all the criteria are acknowledged as important, the weight given to each differs when various experts give their point of view. The weight attributed to each criterion is summarized in table 4 below.

Table 5. Summary of the suitability criteria divided into 3 groups according to the weight attributed.

	Weight
Group 1	0.5
Distance to water ressources (surface and underwater) (m)	0.5÷3
Slope (%)	0.5÷3
Distance to roads (km)	0.5÷3
Group 2	0.3
Above ground biomass production (kg/ha)	0.3÷3
Distance to boundaries (km)	0.3÷3
Precipitations (mm/year)	0.3÷3
Group 3	0.2
Distance to electric network (km)	0.2÷4
Distance to towns (km)	0.2÷4
Distance to health infrastructures (km)	0.2÷4
Distance to education infrastructures (km)	0.2÷4
Sum	1

The first group includes three criteria that are considered as the most important when planning a site location. Firstly, the distance to water resources is considered as one of the most important criterion. Indeed, it is needed to sustain life. Therefore, if the distance to this resource is high and, in consequence, its availability is too scarce, it is unsuitable to build a displacement camp nearby. Secondly, gentle slopes enable mobility facility, limit erosion risks and reduce construction problems. Finally, roads are very important for early transportation. They also facilitate social contacts and relations; they enable to diversify goods and diets.

The second group gathers three criteria considered as less critical for a site selection, even though their importance is acknowledged. A sufficient biomass production for energy needs, soil stability and sometimes construction of shelter; distance to boundaries for security; and enough precipitations as another source of water and to support biomass production.

The third group brings together four criteria that are less crucial for taking the final decision. The reason why they are less important is due to the possible financing of infrastructure by UNHCR or other sources: electricity network powered by other sources of electricity that might be more sustainable, schools and health centers. Towns are also part of this group since the above-mentioned criteria are usually around cities.

3.2.4.5. Model

The final map will be constituted of pixels with values corresponding to their final suitability indexes.

Pixels with a value of 0 mean that some criteria were masked out or that the suitability indexes of the criteria were equal to 0. When a pixel value is 100, it means that all the suitability criteria are the most suitable and that no constraints criteria are present. When a pixel is in between 0 and 100, it means that there are no constraints criteria excluding them and that part of the suitability criteria vary between 100 (suitable site) and 0 (unsuitable site).

To get those results, the equation below is used to combine the criteria together, slightly modified from Lejeune et al. (2010).

Equation 2. Aggregation of suitability and constraints criteria by combining suitability indexes using weighted linear combination and masking the suitability map by excluding constraint criteria.

$$S_p = \left(\sum_{c=1}^{n} (x_{c,p} \times w_c)\right) \times (1 - C_p)$$

Where:

S_p is the suitability index for the pixel p;
n is the number of suitability criteria;
$x_{c,p}$ is the value of the suitability index of the criterion c in the pixel p;
w_c is the weight attributed to the suitability criterion c;
C_p is the global value (0 or 1) of the constraints criteria for the pixel p

The first part of the equation shows that the aggregation of suitability indexes uses weighted linear combination. And the second part translates the option to mask out the suitability map by excluding sites with the constraints criteria.

The global constraints criterion for a pixel p (C_p) is calculated with an equation using gdal calc. Whenever constraints criteria meet, in a pixel, the excluding value determined in table 3 above, the latter gets a value of 1. Whenever the excluding value is not met, the pixel gets a value of 0, as figure 11 shows in the results.

Therefore, in equation 2 above, whenever there is a constraints criterion that must exclude an area in the final map, since the pixel value is 1, the first part of the equation will be multiplied by 0, resulting in masking the area. Whereas whenever there are no constraints criteria, pixel values are equal to 0, which results in multiplying the first part of the equation by 1. The corresponding area is thus not masked.

3.3. Development of the model

This section explains in concrete terms the implementation of the concept presented in the previous section.

3.3.1. Tools used

3.3.1.1. R

The aim of this thesis is to enable national authorities, as well as national and international humanitarian actors to make a thorough but rapid decision regarding the selection of optimal displacement sites in a country.

Coding is found to be an efficient way of proceeding. Indeed, once a script is written in a way that it is flexible and repeatable, it can be edited easily and ran again.

The R computer language was chosen in the present study for three reasons:
- the author had used and studied it at university;
- SEPAL, the platform hereafter presented has RStudio in its available applications;
- there are many forums available on the Internet that are of great help when trying to work out errors. As explained furthermore by Wickham (2015), "as of January 2015, there were over 6,000 packages available on the **C**omprehensive **R** **A**rchive **N**etwork, or CRAN, the public clearing house for R packages. This huge variety of packages is one of the reasons that R is so successful: the chances are that someone has already solved a problem that you're working on, and you can benefit from his work by downloading their package."

The strength of this methodology is the way the scripts have been written, as explained furthermore in the next section.

3.3.1.2. SEPAL

System for Earth observation, data access, Processing, Analysis for Land monitoring is a cloud computing platform for geographical data processing. It enables users to quickly process large amount of data without high network bandwidth requirements or need to invest in high-performance computing infrastructure. SEPAL is also a set of free and open-source software tools that facilitates flexible and efficient data collection, analysis and reporting for the environment and more specifically for forests (Openforis, n.d.).

On SEPAL, the user can choose a machine to work on depending on the task to be done. "Super computers" enable to run heavy processing data.

3.3.1.3. QGIS

Finally, QGIS previously known as Quantum GIS is used in the present study as the desktop application of GIS because it is open-source and free, enabling everyone to replicate the methodology developed. It was used to check some created features and to create the maps presented throughout this study.

3.3.2. Structure of the scripts

As mentioned above, the strength of this methodology is the way the code is written to be flexible. Criteria can be added or deleted; their classification and importance can also be changed.

All the steps are divided into 10 scripts, going from s0 to s9. The order in which the criteria are presented follows table 1, reading it from top to bottom. The scripts can be found on a github page, linked to the FAO SAFE project (Safe Access to Fuel and Energy): https://github.com/openforis/safe_sepal.

3.3.2.1. "s0_setworking.R"

The first script installs the necessary packages to use the underlying functions called in the following scripts. As explained by Wickham (2015), "the fundamental unit of shareable code is the package in R. A package bundles together code, data, documentation, and tests, and is easy to share with others".

After the packages are installed, a few lines are dedicated to setting the R working environment, or workspace. It is where all of the user-defined objects (vectors, matrices, data frame, lists and functions) will be stored. (Kabacoff, 2017).

To organize the data that the user will work with, it is handy to create subfolders. The latter are R objects at this point. To be able to see the folders once R is shut down, the "dir.create" function is used to create them physically on the machine.

3.3.2.2. "s1_def_output.R"

The second script is dedicated to assigning names to the paths of the layers that will be created in all the following steps. Therefore, through this script, the user can visualize all of layers that are created later on.

This script is divided into eight parts:

- path linked to the creation of the country's mask
- path linked to the reading of shapefiles
- path linked to the rasterization of shapefiles
- path linked to the adjustment of rasters on the country's mask
- path linked to the creation of the distances to features
- path linked to definition of the suitability criteria's scores
- path linked to the creation of the constraints criteria's mask
- path linked to the suitability map

The different folders created correspond to:

- data 0: outputs
- data in: inputs
- grid: creation of the country mask
- scripts: where all the scripts are saved and where the python function for the rasterization is “oft-rasterize_attr.py”.
- tmp: where all the temporary files, especially the initial OSM data, are stored.

3.3.2.3. “s2_parameters.R”

The third script should catch the user’s attention since the adaptations to the AOI must be made in this script. It is divided into four parts.

- The definition of the country of interest. See the code of the country of interest on http://kirste.userpage.fu-berlin.de/diverse/doc/ISO_3166.html
- The definition of the Coordinate Reference System (CRS). The latter is defined by its EPSG code. The ESPG code for a country can be found on https://epsg.io/

As the figure 8 shows, Niger is on three different UTM zones. Therefore, the Africa Albers Equal Area Conic projection was chosen for its equal-area representation for large countries.

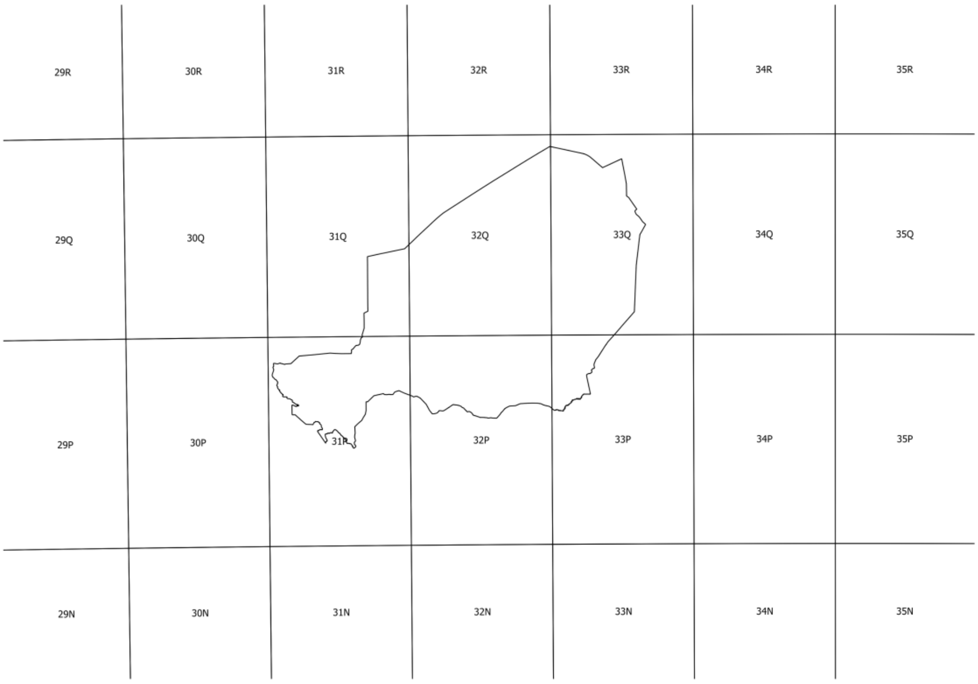

Figure 8. Niger is a large country, on three different UTM zones.

- The definition of the wanted resolution
- The definition of where to find and download the data.

In the present study, the following data were used and are thus present in the script “s2_parameters.R”.

- Boundaries of the country of interest

The boundaries of the country of interest will work for any country. Indeed, the URL doesn't need to be changed since it is linked to the country code, and it has been determined already.

- OpenStreetMap

As table 2 shows, many criteria found their translation into geographic data on OpenStreetMap. To get OSM data for the country of interest, the following link can be used http://download.geofabrik.de/. Through the link, the continent is chosen, followed by the country. A right click on the corresponding ".shp.zip" will show different options. The "copy the link address" must be selected and pasted in the script, as done for Niger: "url_osm ⇐ http://download.geofabrik.de/africa/niger-latest-free.shp.zip". These steps will enable the automatic download of the latest layers available on OSM for the country of interest selected.

- Electricity grid data

Electricity grid data was found for Niger. The same procedure as the previous point can be followed for the url link to directly download the data from the website of choice.

- SRTM data

SRTM data will work for any country as the boundaries are linked to the country code that has already been determined.

Unfortunately, the four criteria mentioned here below have not found their geographic translation into layers that can be downloaded automatically at this point. Therefore, they need to be downloaded manually if the user does not have other relevant source of data where a URL could be copied as done above.

- Precipitation
- Above Ground Biomass Production
- Water bodies
- Cropland

3.3.2.4. "s3_mask.R"

The fourth script is used to create a layer of the country of interest with the wanted resolution, the extent -with integer lines and columns- and with the chosen coordinate reference system.

First, a shapefile of the country is created adding a new column with numbers, which will enable the rasterization later on. Then, a raster layer box is created where the resolution, the extent and the projection are defined.

For the extent, the raster layer box is rounded to the pixel size using the function "floor". The latter rounds a numeric input down to the next lower integer (Statistics Globe, n.d.). As table 6 below shows, this function gave closer results to the real extent than other available functions.

Table 6. Comparison of rounding functions to define the extent of the raster layer box.

	x_{min}	x_{max}	y_{min}	y_{max}
Real extent	- 2 592 228	- 942 425.2	1 365 526	2 698 776
Rounded extent (‘floor’)	- 2 592 180	- 942 390	1 365 570	2 698 830
Rounded extent (‘round’)	- 2 592 090	- 942 300	1 365 660	2 698 920
Rounded extent (‘ceiling’, ‘trunk’)	- 2 592 090	- 942 300	1 365 660	2 698 920

The raster created is a polygon of the country of interest where, inside the polygon, pixel values are equal to 1 and, outside, pixel values are equal to 0. The extent defines the box having for maximal values the extremities of the country’s boundaries.

3.3.2.5. “s4_shp_in.R”

The fifth script is where the shapefiles are first extracted from their source, i.e. where the data are downloaded and unzipped. Then, data are prepared as follows for the rasterization:
-interesting features of the initial shapefile are selected. This selection is made on the basis of the infrastructure, religions, etc. that are present in the country of interest using the function ‘level(as.factors())’;
-a column is added with numeric values;
-the result of the two first steps are re-projected into the target coordinate system; and
-a new shapefile is created.

For each new created shapefile, the selected features for the OSM data are summarized in the table joined in the appendix 1. See the section “more information” of the table to know more about the OSM data.

For the religion criterion, even if Niger has only two major religious groups: Muslims and Christians, all the possibilities of OSM data have been added. This was done for that part of the script to be applied to any AOI. Indeed, if OSM data on religion are present in the AOI, they will be taken into account and added in the new shapefile. If they are not present, they won’t be taken into consideration. Therefore, in the case of Niger, online places of worship of Muslims and Christians were taken into consideration.

The order in which the features are presented in the OSM explaining document was kept the same for the selection of the features in the script.

3.3.2.6. “s5_rasters.R”

The sixth script rasterizes shapefiles in the first part and aligns rasters with the country mask in the second part. These steps are essential to enable the combination of all the criteria in the final equation.

For the first part, all of the shapefiles had been prepared in the previous script ("s4_shp_in.R"), with the exception of the boundaries that need to be transformed from a polygon into a line. Indeed, for the 'distance to boundaries' criterion, the interest is to see where there are suitable sites that are at a minimum distance of 50 km from the country's borders (i.e. inside the borders). Nevertheless, when the distance is calculated with 'gdal_proximity' if the country of interest is a polygon, the function only calculates the distance from the borders to the features outside of the borders. Whereas, when the Niger's boundary is a line, the function calculates both, the distances from the boundaries to the features inside and outside the country.

The rasterization of the shapefiles has been done using a python function called into RStudio, created by Rémi D'annunzio from the Forestry Department of the FAO. In the column created, all the objects that have an attributed number different from 0 are rasterized, keeping their attributed number as a pixel value. So having the information in the shapefiles is interesting, because it enables to know what pixel number corresponds to what in reality.

```
system(sprintf("python %s/oft-rasterize_attr.py -v %s -i %s -o %s -a %s",
        path of directory where the python function is,
        path of the input or shapefile to rasterize,
        path of the country mask used for the rasterization,
        path of the output raster,
        "column name where numerical values will be used for the rasterization"
))
```

For the second part, a code enabling the user to download SRTM 90m data for any country was used, as mentioned above in the data sources. The slope was then computed.

Finally, the above ground biomass production, precipitations and landcover initial rasters were aligned on the country mask created in the fourth script ("s3_mask.R"). Pixel values of the precipitation layer had to be multiplied by 0.1, as mentioned in the WaPOR layer's catalogue.

3.3.2.7. "s6_distance.R"

The seventh script is where the distances to the corresponding criteria are computed using a python function called into R 'gdal_proximity.py'. In this step, it is essential to know the type of data that needs to be generated (8 bits, 16 bits or 32 bits) according to the size of the country of interest. For Niger, it was necessary to generate an output with Int32 as the data type. Otherwise, the upper limit is reached and the computed distances are wrong and lead to errors later on.

```
system(sprintf("gdal_proximity.py -co COMPRESS=LZW -ot Int32 -distunits GEO %s %s -co BIGTIFF=YES",
            input,
            output
))
```

This function compresses the result (-co COMPRESS=LZW) and generates distances as integers of 32 bits (-ot Int32), i.e. the values have minimum and maximum values between ($\pm 2^{32}$);
values are computed in georeferenced coordinates (-distunits GEO). A particular attention must be raised on the 'overwrite' function, that does not exist in gdal_promity.

As explained in the previous part, the distance to water resources corresponds to one criterion and not two, since surface and underground water have been combined. The decision to combine has been taken because, in the different handbooks recommending a distance to water resources, no distinction is made between surface and underground water. Nevertheless, the distances to surface and underground water are computed separately, and a new layer combining both initial layers is created, taking the minimum value of either one as the distance value in the final layer.

Figure 9 shows the summary of the data process for water resources, and figure 10 presents an example of data processing for a simpler layer, such as the distance to electricity grids.

For all the layers except for the distance to boundaries, 'gdal_calc' was first used to focus on the country of interest in order to avoid computing distances of features that are not within the boundaries of interest. Since the layer of the country's boundaries is 0 everywhere else than on the country's limits, the distances were first computed and then the result was multiplied by the country mask.

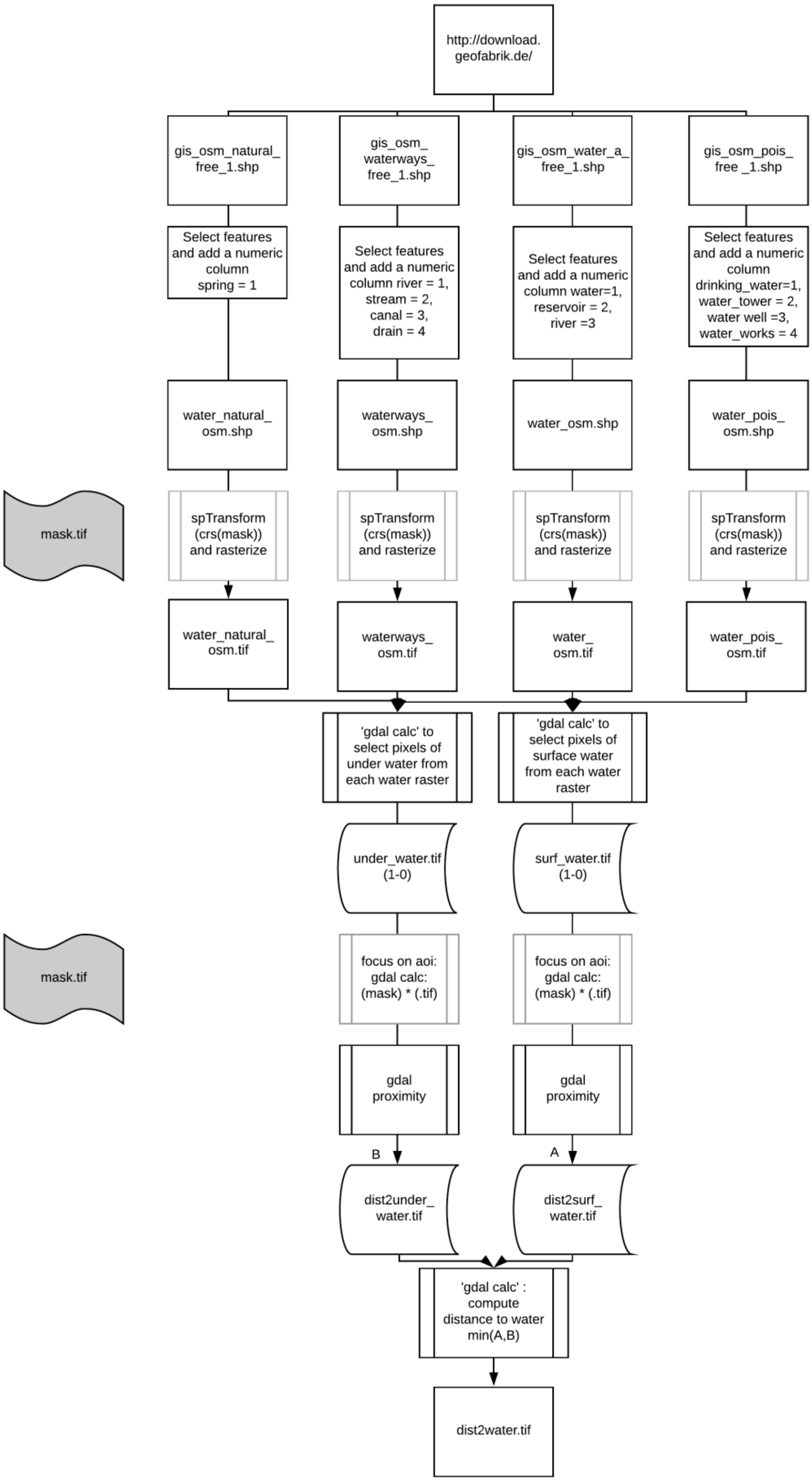

Figure 9. Data processing summary for the distance to water resources.

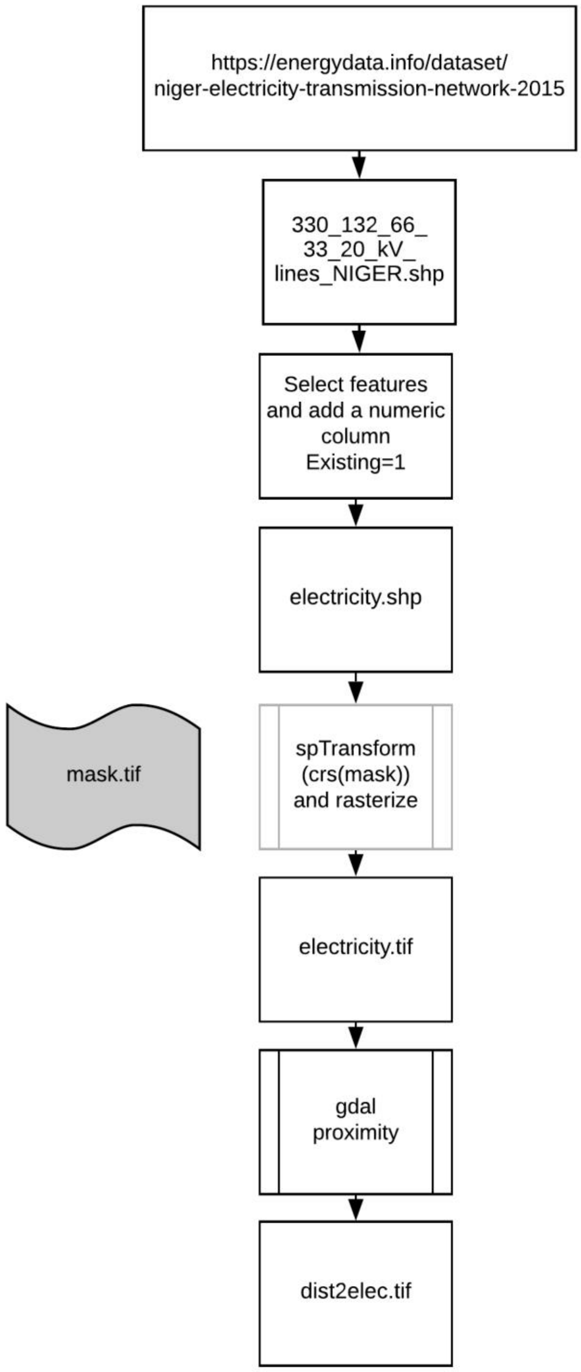

Figure 10. Data processing summary for the distance to electricity grids.

3.3.2.8. "s7_ constraints_criteria.R"

The eighth script defines the constraints criteria. See table 3 to get the summary of the constraints criteria.

The gdalcalc formula is the concrete translation into R of what was explained above on how to manage constraints criteria. The different layers presented in table 3 are called by letters in R, i.e. precipitations' layer is A, distance to water resources is B, and so on.

The type 'Byte' was chosen since the function will generate scores from 0 to 100. Therefore, the min and max will be within $\pm 2^8$. The layers are compressed (--co=\"COMPRESS=LZW\"), the list of layers 'preci_factmult', 'tmp_dist2water' […] to 'lc_tif' are the inputs and 'tmp_mask_exclusion' is the output.

```
system(sprintf("gdal_calc.py -A %s -B %s -C %s -D %s -E %s -F %s -G %s -H %s -I %s -J %s --co=\"COMPRESS=LZW\" --type=Byte --outfile=%s --calc=\"%s\" --overwrite",
          preci_factmult,
          tmp_dist2water,
          tmp_slope_path,
          tmp_mask_biomass,
          tmp_dist2_unsuit_wetland,
          tmp_dist2_unsuit_land_reserves,
          unsuit_land_military_tif,
          unsuit_land_reserves_tif,
          unsuit_wetland_tif,
          lc_tif,

          tmp_mask_exclusion,

"((A<200)+(B>2000)+(C>20)+(D<1000)+(E<1000)+(F<24000)+(G==1)+(H==1)+(I==1)+(J==41)+(J==42)+(J==80))>0"
))
```

The equation here above is the translation into code language of the table 3. In other words, if A (precipitations) is below 200 mm/year, a number 1 is given to the corresponding pixels. It is the same for the other layers except for the four last ones (military bases; nature reserves and national parks; wetlands; and land cover).
The layer G, corresponding to military bases, already has pixels with the value of 1 when military bases are present, and 0 otherwise. This was defined in the fifth script ("s4_shp_in.R"), when a shapefile only for military bases was created and later on rasterized. The same thing is also true for layers H (nature reserves and national parks) and J (wetlands).

As for the Land Cover layer (J), as presented by WaPOR in the layer's catalogue, pixels with 41 and 42 values correspond to 'cropland, rainfed or fallow' and 'cropland, irrigated or under water management' respectively. Also, 80 value pixels correspond to water bodies.

3.3.2.9. "s8 _suitability_criteria.R"

The ninth script attributes suitability indexes to the suitability criteria. It is the concrete step of table 4 presented previously. As pointed out at the beginning of this section, the SI are computed in the same order as in table 1, reading it from top to bottom for the user to keep track more easily.

The equation below using gdal-calc was used to create the suitability indexes of the precipitations.

```
system(sprintf("gdal_calc.py -A %s --co=\"COMPRESS=LZW\" --type=Byte --outfile=%s --calc=\"%s\" --overwrite",
        preci_factmult,
        score_preci_factmult,
        " (A>=350)*100+(A<250)*0+(A>=250)*(A<350)*(100*(A-250)/(350-250))"
))
```

Here again, the ‘byte’ type is enough, since we are dealing with results within the interval of $\pm 2^8$. The output layer is ‘score_preci_factmult’ is the output.

The formula asks the system to attribute values of 100 when the pixel values of the precipitations layer (A) is above or equal to 350 mm/year of rainfall. When the rainfall is under 250 mm yearly, the corresponding pixels will get a value of 0. And when precipitations are between 250 mm/year and 350 mm/year, the system attributes a suitability index relating to the linear combination. In the case of precipitations, it corresponds to figure 6.

3.3.2.10. “s9_decision.R”

The tenth or last script combines all the suitability and constraints criteria together.
It is the concrete translation of Equation 2 into R langage.

3.3.2.11. “master.R”

The script called “master.R” can be used to automatically run one script after the other. Indeed, as explained in the R Documentation, the function “source” causes R to accept its input from the named file or URL or connection or expressions directly. Input is read and parsed from that file until the end of the file is reached, then the parsed expressions are evaluated sequentially in the chosen environment (Becker, Chambers, & Wilks, 1988).

In other words, the function loads the scripts mentioned, executes them and make the results immediately available.

Nevertheless, before that, the user should use the script “s2_parameters.R” to change the parameters for his area of interest, as well as parameters corresponding to his needs.

Chapter four: Results and discussion

4.1. Introduction

The present study was results-driven, starting from the dissection of its aims and objectives to the results through the development of a model following a developed methodology.

This chapter begins with reminding the reader what are the aims and objectives of this master thesis and summarizes how they have been achieved. Then, the model's intermediate results are presented with two maps: the constraints criteria map and the suitability criteria map. Later on, those two maps are combined giving the reader a first idea of the sites in Niger that are suitable to host displaced people. This output is further developed taking into account the context dependent constraints criteria, which narrows the study down to each region. The results are then visually compared with today's displacement sites.

Further on, the results are discussed so as to try to understand the difference of results when constraints criteria are applied to the suitability map. Then, the final results encompassing all the criteria are discussed; this leads up to highlighting some regions as better host than others. Finally, a comparison between the final results of this study on Niger and today's displacement sites is made. The similarities and differences are presented and discussed.

4.2. Reminder of the present study's aims and objectives

The aims and objectives that have guided this author through the present work are as follows.

1. Is it possible to map the basic features highlighted by the humanitarian recommendations that should be taken into account when installing a displacement setting (link between humanitarian living criteria and geographical data)?
2. Are there global data enabling the user to work for any area of interest (AOI)?
3. Is it possible to have a systematic methodology where parameters only have to be changed to be applicable to another AOI?
4. Is it possible to make available a practical, adjustable and flexible tool enabling UNHCR to help decision-makers take a suitability-linked decision based on landscape/physical features?
5. Does the tool give realistic results when Niger is taken as an example?

The first step was to put together the humanitarian recommendations regarding displacement settings and see if there was a way to translate them into geographic data. The conclusion was that many criteria considered relevant have found a geographic translation. However, other criteria, social for most, were harder to consider generally. While it's necessary to ensure the physical survival of the populations, it is also essential to care about their mental and social well-being. To cope with that observation, the results gotten with the "general criteria" inserted in the model were analyzed furthermore depending on the situation in the highlighted sites and the relation that displaced populations could have with the host population.

The second step was to see if some global data could be used to quickly get an idea of general geographic features stepping in when thinking of displacement camps settlement. OpenStreetMap (OSM) data was found to be useful for that purpose. Nevertheless, OSM data rely on countries' accuracy of data. Moreover OSM is a collaborative project, in which anyone can add data after a registration. Other data that users of this tool could have in their hands can always be added to the model.

The third step was to see if a systematic methodology encompassing changeable parameters applicable to another AOI could be created. The answer and solution were found by writing the R scripts in a way that makes them flexible and easy to understand. Indeed, writing different scripts enables the user to follow the steps taken to get to the final results and to monitor step by step what was created.

The fourth step was to have an open-source, practical, adjustable and flexible tool to help UNHCR and decision-makers take a suitability-linked decision, based on landscape features. The solution was to select open-source softwares and data accessible to the public. Moreover, all the scripts written are available on a github page, linked to the FAO SAFE project (Safe Access to Fuel and Energy): https://github.com/openforis/safe_sepal.
Since this master thesis is done in close collaboration with the Forestry Department of the FAO, its impact can be expanded and shared more easily with national authorities, as well as national and international humanitarian actors.

The fifth step was to test the tool developed on a chosen AOI, which is Niger, and to discuss its results comparing them with today's displacement settings locations. To do that, the web service of UNHCR (https://gis.unhcr.org/arcgis/rest/services/core/wrl_ppl_poc_p_unhcr/FeatureServer) was added into QGIS via the ArcGIS REST API Connector extension. As it was possible to display them on the same software, the model's results and today's sites could easily be compared.

4.3. Presentation of the results

A resolution of 90 meters was selected and used in line with the resolution of the SRTM data, since the slope is considered as one of the most important criteria, although in the case of Niger, the slope does not represent a big challenge.

Different layers [precipitations (~5km), AGBP (~1km), LC water bodies and croplands (~250 m) to 90m] were oversampled or aggregated to make resolutions compatible so as to enable the stacking of rasters. This increases the number of pixels of the input rasters to meet the number of pixels of the target raster, by assigning the same information as in the initial raster.

4.3.1. Constraints criteria map

Figure 9 below features the constraints map, integrating all the constraints criteria into one map. Those constraints criteria have been presented above in the present study, in table 4. The different maps of each of the constraints criterion are presented in the appendix to help the reader put an image on the areas excluded and understand why it has been excluded. This helps understand step by step what was masked and explain better the following results.

The constraints map shows that about 98% of the territory of Niger are excluded (in white on figure 11). This percentage is calculated using the function below, 'system("gdalinfo -hist /home/swertz/safe_sepal/data0/tmp_mask_exclusion.tif")' concluding that there are 142 293 254 pixels that are masked on a total of 145 410 808 pixels covering Niger with a resolution of 90m.

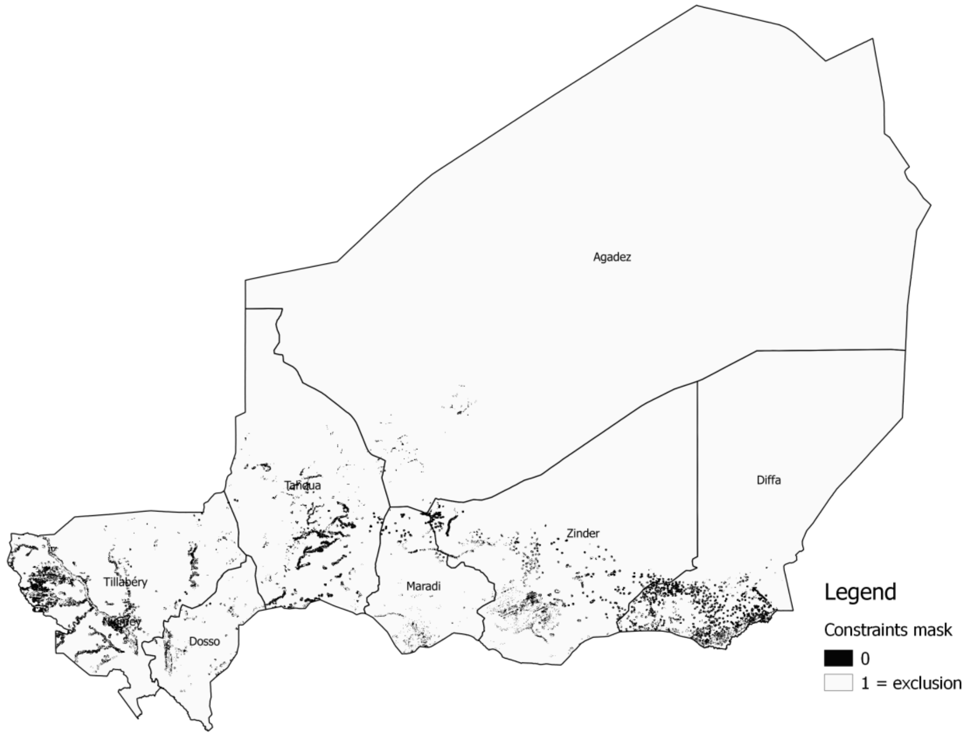

Figure 11. Constraints mask where pixels equal to 1 correspond to the constraints criteria; and pixels with a value of 0 correspond to the areas where pixels are not excluded. The list of the constraints criteria taken into account are in table 4 hereabove: precipitations (>200mm/year), distance to water resources (>2000m), slope (>20%), AGBP (<1000 kg/ha), distance to wetland (<1000m), distance to nature reserve or national park (<24000m), wetland, water body, cropland, military base, nature reserve or national park. Altitude, religion, ethnicity, conflict, land tenure and population density are context dependent and are discussed below.

Conclusion: constraints criteria per region:

- Agadez and Diffa, followed by Zinder, are much affected by the constraints criteria. In the region of Agadez, precipitations, distance to water, above ground biomass production, croplands and military bases are the constraints criteria. In the region of Diffa, precipitations, above ground biomass production, distance to wetlands, wetlands, water bodies and croplands are the constraints criteria. And in the region of Zinder, precipitations, distance to water, above ground biomass production and croplands are the constraints criteria

- In the region of **Dosso**, the distance to water, the distance to nature reserve or national park, croplands and nature reserve or national park are the constraints criteria.

- In the region of **Maradi**, the distance to water and croplands are the constraints criteria.

- In the region of **Tahoua**, the distance to water, distance to wetlands, wetlands and croplands are the constraints criteria.

- In the region of **Tillaberi**, the distance to water, above ground biomass production, distance to wetlands, distance to nature reserve or national park, wetlands, water bodies, croplands and nature reserve or national park are the constraints criteria.

4.3.2. Suitability criteria map

Figure 10 below represents the suitability map, integrating all the suitability criteria into one map when their importance is weighted. The different suitability criteria and their corresponding suitability indexes used to create this map have been presented above in table 3.

Weighting the criteria brings some areas to light and fades others, as it can be seen when comparing figure 12 below with figure 42 of the appendix (or comparing figures 42 and 43 of the appendix). Pixels with a suitability index between 0 and 50 are considered as unsuitable; in consequence, they are not taken further in the analysis, as the map below shows: only pixels that have a suitability index of 50 and above appear on the map.

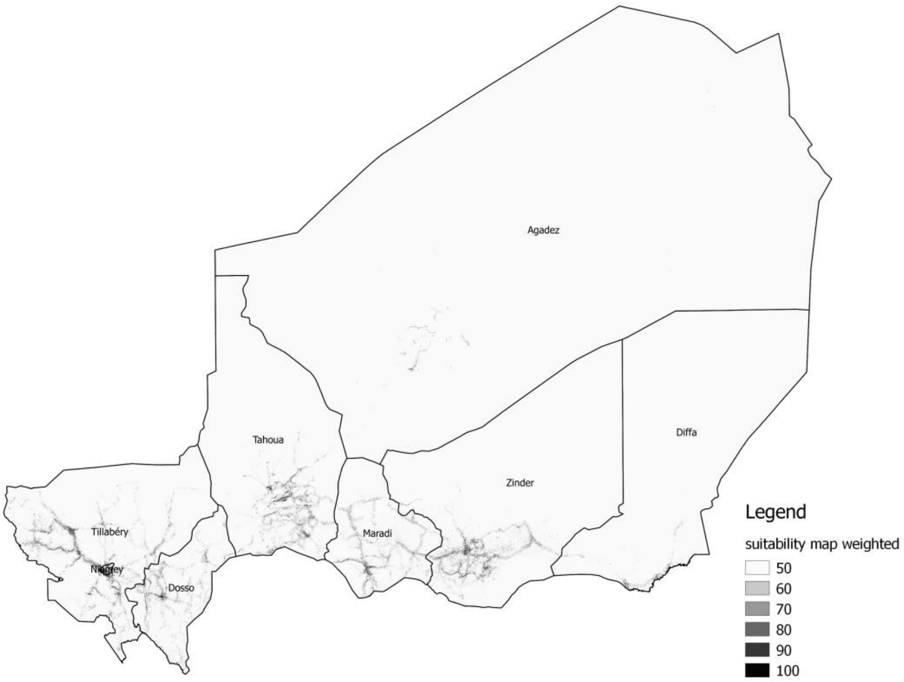

Figure 12. Suitability map where pixels equal to 100 correspond to the most suitable sites, whereas pixels with a value of 50 correspond to less suitable sites. Here, criteria presented in table 3 are weighted with the values of table 5. The list of the suitability criteria and the importance given to each are the following: Distance to water resources (0.5÷3), slope (0.5÷3), distance to roads (0.5÷3), AGBP (0.3÷3), distance to boundaries (0.3÷3), precipitations (0.3÷3), distance to electric network (0.2÷4), distance to towns (0.2÷4), distance to health infrastructure (0.2÷4), distance to education infrastructure (0.2÷4).

Conclusion: Suitability criteria per region:

At this stage, only with the suitability criteria taken into account, it can be observed that **Maradi** is the most suitable (S.I. 50-100) hosting region with a percentage of about 19% the region territory; **Dosso** is the second most suitable hosting region with a little bit less than 19% of its territory that is suitable at 50 to 100. Then, **Tillaberi** (about 12%), **Tahoua** (about 8%), **Zinder** (7%), **Diffa** (about 1%) and finally **Agadez** with less than 1%.

4.3.3. Suitability and constraints criteria map

The two maps presented above are combined into one, and the result is shown in figure 13. There is a notable difference between this map and the suitability only map presented in figure 12.

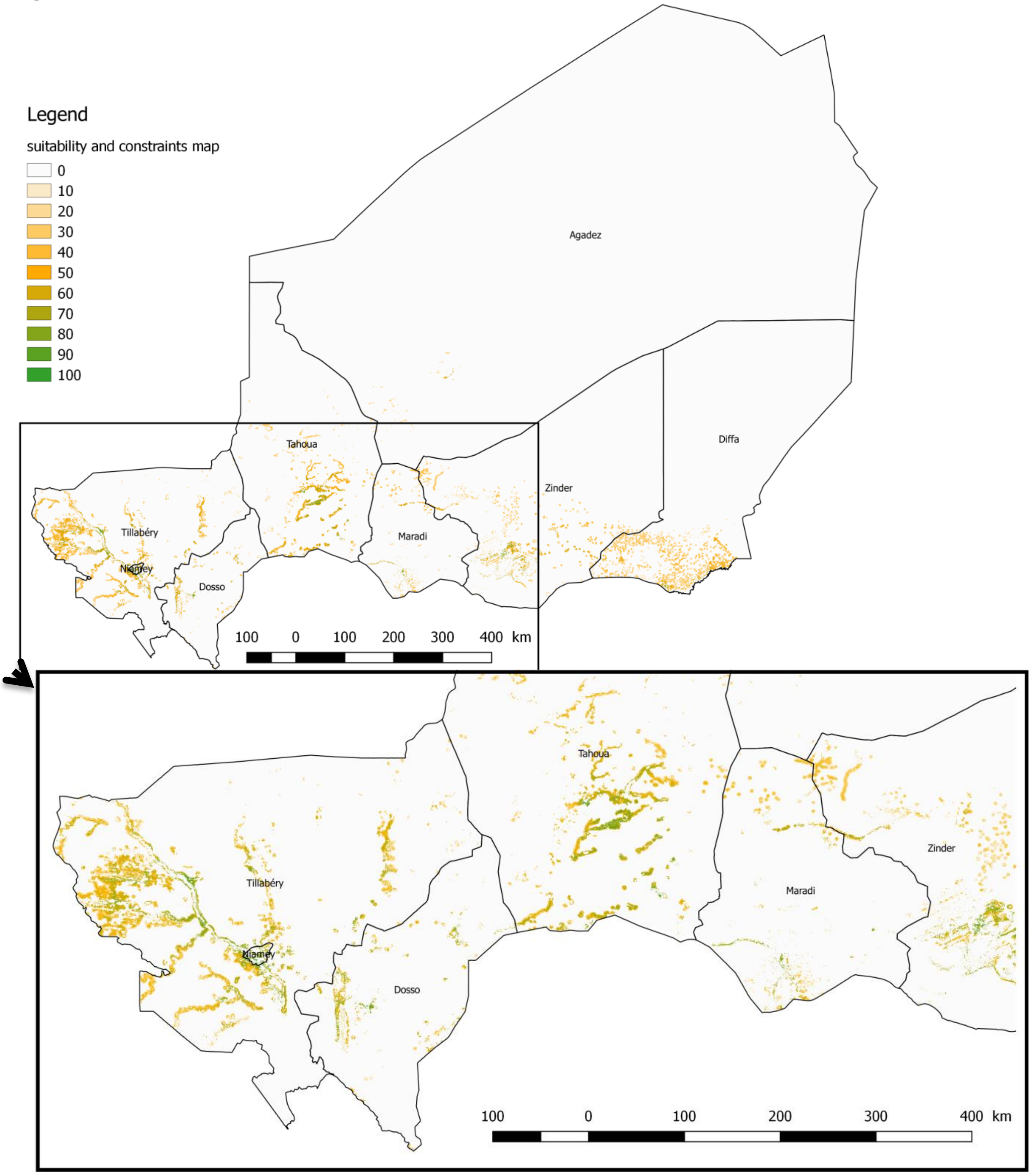

Figure 13. Suitability and constraints criteria map. The list of the suitability criteria has been presented above in table 3: precipitations (mm/year), distance to water resources (m), slope (%), AGBP (kg/ha), distance to boundaries (km), distance to roads (km), distance to electric network (km), distance to towns (km), distance to health infrastructure (km) and education infrastructure (km). And the list of the constraints criteria taken into account are in table 4 presented above: precipitations (>200mm/year), distance to water resources (>2000m), slope (>20%) AGBP (<1000 kg/ha), distance to wetland (<1000m), distance to nature reserve or national park (<24000m), wetland, water body, cropland, military base, nature reserve or national park. Altitude, religion, ethnicity, conflict, land tenure and population density are context dependent and are taken into account below.

Table 7 below compares, on one hand, how suitable Niger is to host displacement settings without taking into account constraints criteria (suitability map, figure 12) and, on the other hand, how suitable it is if these criteria are taken into account (suitability and constraints map, figure 13). Figure 14 gives a more visual approach of the difference mentioned above. As mentioned above, suitability indexes between 0 and 50 are considered unsuitable, and, in consequence, will not be discussed.
This comparison is interesting since it shows that there is a noticeable difference of final suitability when constraints criteria are added, which translates the importance and influence of these criteria on the final results. These differences are further developed in the next section (discussion of the results) by narrowing the analysis down to Niger's regions. Different scenarios are discussed when taking some of the constraints criteria out.

The weighted suitability map without constraints criteria (figure 12) shows that about 4% of Niger's territory have a suitability index between 50 and 100; about 1% of Niger's territory has a suitability index between 60 and 100; and less than 1 % of Niger's territory has a suitability index between 70 and above. When constraints criteria are added, those numbers decrease, with a fall of 3.19 % of Niger's territory to be suitable for suitability indexes from 50 to 100; a fall of 0.96 % for suitability indexes from 60 to 100; a fall of 0.25 % for suitability indexes from 70 to 100; a fall of 0.05 % for suitability indexes from 80 to 100 and a fall of 0.01 % for suitability indexes from 90 to 100.

Table 7. Comparison of the percentage of Niger that is suitable to host displacement settings without and with constraints criteria linked to the suitability indexes of suitability criteria.

	% of Niger territory	
Suitability index	without constraints	with constraints
50-100	3.81%	0.62%
60-100	1.27%	0.31%
70-100	0.37%	0.12%
80-100	0.09%	0.04%
90-100	0.02%	0.01%
100	0.001%	0.001%

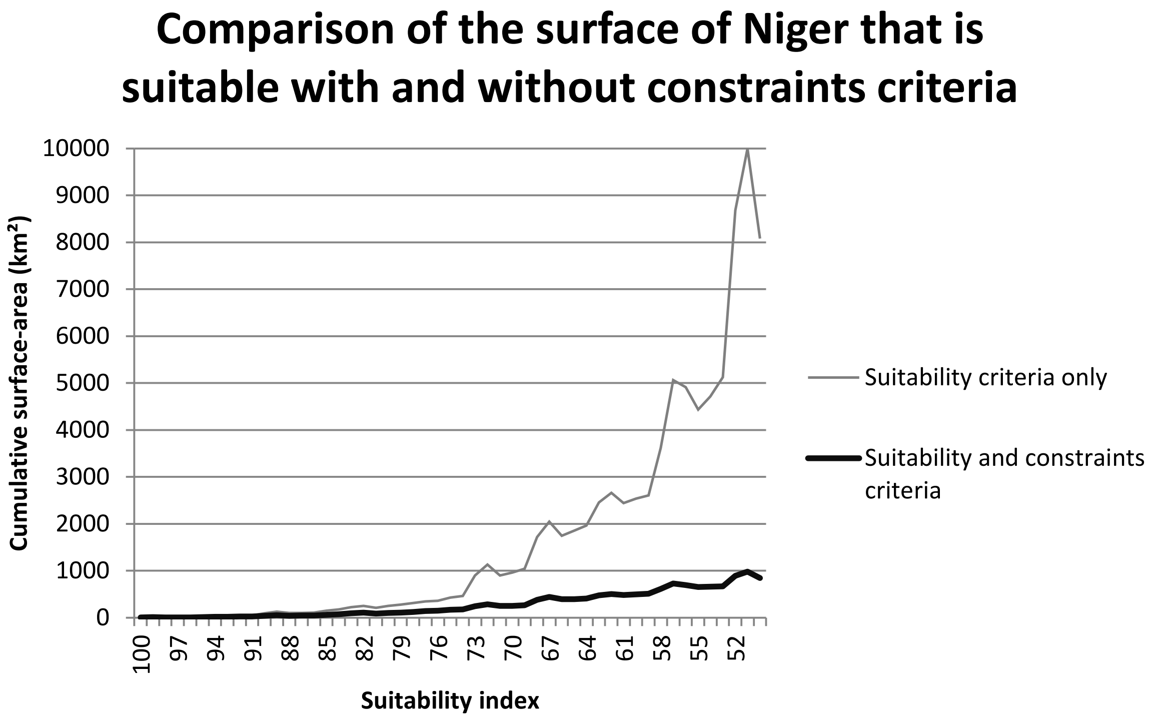

Figure 14. Comparison of the surface of Niger that is suitable for the installation of displacement settings with and without constraints criteria.

4.3.4. Context dependent criteria

These results (table 7 and figure 13) have to be developed further taking into account the context dependent criteria (altitude, religion, ethnicity, conflict, land tenure and population density). These criteria are not less important than the criteria (suitability and constraints) inserted into the model. Indeed, they can be even more important than some of them in certain situations.

In order to give a final result taking into account all the criteria highlighted as important in the present study and to show a way of analyzing furthermore the results that the model gives, the context dependent criteria are presented in two steps. First, population density, religion, ethnicity and conflicts are taken into account. Then, more difficult criteria to take into account remotely are presented, i.e. altitude and land tenure.

4.3.4.1. Population density, religion, ethnicity and conflicts

1. Population density

Taking into account the people who already live in the highlighted sites seems evident. Table 8 below gives the population density per region.

Table 8. The population density in Niger. The population numbers are from the National Institute of Statistics, made available by OCHA Niger, the humanitarian data exchange (UN Office for the Coordination of Humanitarian Affairs country office in Niger, 2018). The surface area of each region is available on the INS Niger site (Institut national de la statistique, 2016). The population density is calculated using the population and the surface of each region. The regions are ordered from the highest population density to the lowest population density.

Region	Population (inhabitants)	Surface (km²)	Population density (inhabitants/km²)
Maradi	4 340 983	41796	104
Dosso	2 554 376	31000	82
Tahoua	4 131 385	113371	36
Tillaberi	3 409 673	97251	35
Zinder	4 487 009	155778	29
Diffa	714 244	156906	5
Agadez	585 738	667799	1

Conclusion: population density per region:
Agadez has the lowest population density, followed by **Diffa** and **Zinder**. This is explained by climatic conditions in those regions: in the north of Diffa and Zinder, and for the most part in Agadez.
Tillaberi and **Tahoua** have about the same population density, while **Dosso** doubles the population density of the two latter. **Maradi** is the region that has the highest population density, whose value is notable compared to the other regions.

Nevertheless, those numbers are not so high compared to the 214.4 inhabitants per km² in Wallonia, Belgium, at the beginning of 2018, (Institut wallon de l'évaluation, de la prospective et de la statistique, 2019). However, the two countries do not have the same carrying capacity of the land, the same climate restrictions and the same quantity of available resources.

2. Religion

According to the Constitution, the Republic of Niger is a laic country. Therefore, everyone is equal regarding the law. According to the Statistic National Institute of Niger (2013), there are 99% of Muslims and 1% of other religions (Institut national de la statistique Niger, 2013). Therefore, Muslims represent the vast majority of the population, while animists and Christians account for the rest (Observatoire de la liberté religieuse, n.d.).
A community of Catholics is concentrated in Niamey and the region of Maradi. Relations between Muslims and other religious communities in the country are traditionally good. Nevertheless, violence towards Christians has increased in some regions and faded in others.

In Diffa and Tahoua, violence has intensified due to control of some zones by radical islamists. In Zinder, cases of violence towards Christians have also been reported. On the contrary, in Maradi, Tahoua, Dosso, Tillaberi and Niamey, the government has pushed towards a pacific cohabitation between Muslims and Christians, which has eased the situation (Observatoire de la liberté religieuse, n.d.).

In Niger, as OSM data show, there are 453 places of worship for Muslims and 43 for Christians; making a total of 487 georeferenced places of worship (POW) in Niger. The table 9 below presents the distribution of the places of worship in the different regions.

Table 9. Distribution of the places of worship in Niger between the different regions of the country.

Regions	POW for Muslims	POW for Christians
Agadez	22	2
Diffa	6	0
Dosso	37	2
Maradi	43	7
Tahoua	90	7
Tillaberi	29	3
Zinder	21	4
Niamey	196	18

Figure 15 below shows a map of the places of worship in Niger. No color or shape difference is highlighted between Muslim and Christian POWs in the figure. Indeed, the points representing the areas are very close to each other, so that any differentiation would not give an idea of the reality at the country level anyways.

Nevertheless, the fact that places of worship of both religions are so close to each other shows that both religions cohabit.

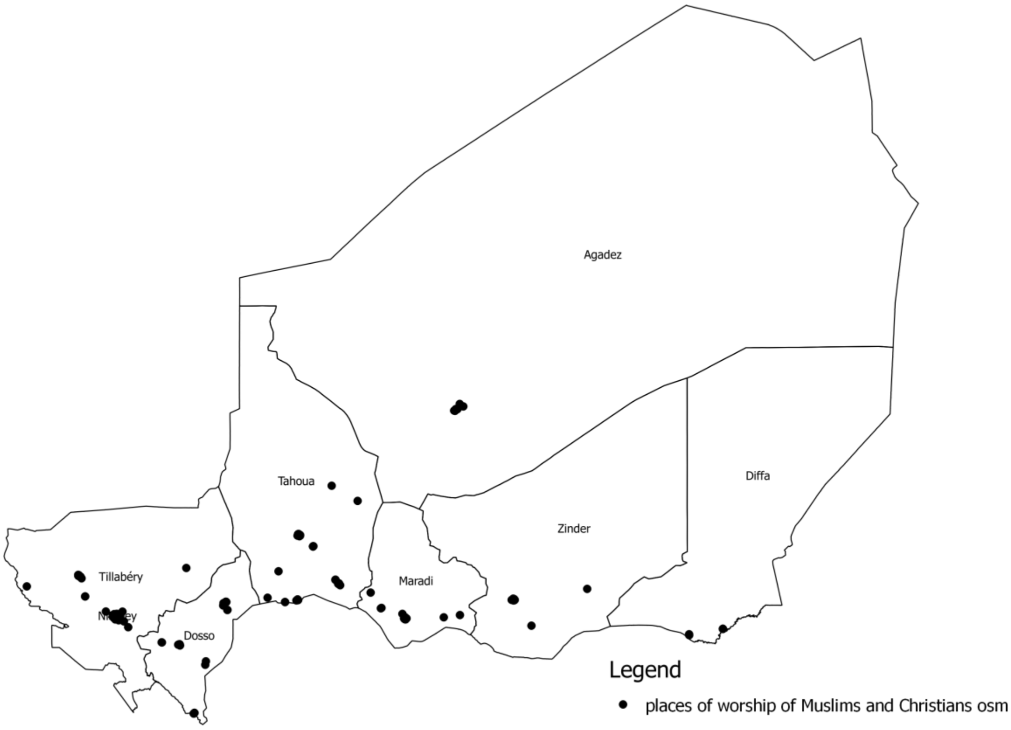

Figure 15. Places of worship in Niger.

Conclusion: religion per region:

- In the region of **Agadez**, the places of worship are mostly located in the city of Agadez. Two mosques are also located at a place north-east of the city of Agadez.
- In the region of **Diffa**, the places of worship are concentrated in the south, close to the Nigerian border (< 5km). There are no Christian places of worship georeferenced in that region.
- In **Dosso**, there are only two churches located in the south of the region, whereas mosques are in the north, in the center and in the south of Dosso.
- In the **Maradi** region, georeferenced places of worship are located in the south, mostly in the city of Maradi, where there are mosques and churches.

- In the region of **Tahoua**, places of worship are present from the center of the region to the south, with many POWs located in the city of Tahoua.
- In the region of **Tillaberi**, churches are only present in Tillaberi city. Mosques are also present in the city as well as in other parts of the region.
- In the region of **Zinder**, there are churches with mosques in Zinder city. There is also a church present in Gouré, east of Zinder city, but with no mosque georeferenced in that area. Moreover, in Wacha, south of Zinder city, there is a mosque but no georeferenced church. In the capital city, Niamey, churches and mosques are present.

Apart from the region of Zinder where there was a church with no mosque in Gouré, and a mosque with no church in Wacha, the other regions translate a cohabitation between the two religions. It seems that both religions exist together when there is no extremist pressure.

3. Ethnicity

The major ethnic groups in Niger include Hausa (54%), Zarma (21%), Tuareg (10%), Fulani (9%), Beri Beri or Kanuri (5%) and Tubu, Arab, Gurma with less than 0.5% (Geesing and Djibo 2001; Hobbs 1998; USDOS 2009 as cited in LandLinks, 2010; Sousa, 2018). Table 10 below summarizes the major ethnic groups in Niger, with their share of the population of Niger.

Conclusion: ethnicity:
Hausa people represent the majority of the Nigerien population. They mostly live in the center of the country. They are farmers, artisans and shopkeepers. Zarma people live around Dosso. Both Hausa and Zarma people can be considered as sedentary farmers who live in the southern portion of the country. The other ethnic groups are nomadic or semi-nomadic pastoralists. Tuaregs are nomads living in the arid zones of the country. Fulani (Peul) people are breeders. The Sahelian zone is occupied by Peuls Bororo, who is a sub-ethnic group of Peul. Kanuri people are found in the South East part of Niger all the way to the Lake Chad (Geesing and Djibo 2001; Hobbs 1998; USDOS 2009 as cited in LandLinks, 2010).

Table 10. Summary of the major ethnic groups in Niger, information taken from S. Gregory, 2018.

Ethnic group	% Niger's popu-lation	Origin and other countries	Activity and localisation in Niger	Major language(s)	Main religion	Conflicts
Hausa	54.1%	One of the largest ethnic groups in all of Africa	Small towns, raise livestock, farmers, conduct trade	Hausa, French, English, Arabic	Islam	
Zarma	21.1%	Mostly found in Niger (95%), the rest in Nigeria, Benin, Ghana, Burkina Faso	Mostly around the Niver River Valley in the arid Sahel lands	Zarma, part of the Songhay language group	Sunni Islam	
Tuareg	9.9%	About 2/3 of them live in Niger. Found in 7 different countries	Mostly in the Sahara desert, nomadic herders, control trade routes (Saharan region), manage conflicts in the area	5 languages in the Tuareg group making up the Afro-Asiatic group	Islam	
Fulani	9.2%	Found in 21 countries from Gambia to the east of Ethiopia	Mostly nomadic trading people. Herd various animals: cattle, sheep. The largest nomadic ethnic group on Earth.	Fula, part of the Niger-Congo language group, Arabic, English, French	Islam	Conflicts with the settled farmers for land use and crops
Kanuri	4.6%	Majority found in Nigeria, the rest found in Chad, Niger and a small number in Cameroon	Mostly southeastern area of Niger, making up the majority of the area's sedentary population	Kanuri, part of the Nilo-Saharan language family	Sunni Islam	
Tubu	0.4%	More than half lives in Chad and a significant population is in Niger. Divided by the language into 2 groups: the Teda (found in the Sahara region of northeast Niger, northwest Chad and southeast Libya); and Daza (found in the Sahel region, north-central area of Chad).	Mostly herders, nomads or oases farmers. In some place, they live as slat or natron miners. They have a clan-based society. Most are nomadic but some have settled in mud, palm-thatched house.	Dazaga and Tedaga, part of the Tebu languages of the Saharan language family	Sunni Islam	
Arab	0.4%	Came to Niger from Sudan and Chad at some point during the 19th century	In Niger, the Arab nomadic tribes are located in the eastern part of the country, mostly in the Diffa region.	Arabic	Islam	Conflict with other ethnic groups the Hausa, Tuareg, and Kanuri
Gurma	0.3%	Most live in Burkina Faso, the rest in southwestern Niger and northern parts of Benin and Togo.	Live in wooded savanna area, flat land with rare, isolated hills. Mostly farmers.	Gourmanchéma, part of the Gur languages of the Niger-Congo group	Islam	

4. Conflicts

Zones and regions bordering Mali, Libya and Nigeria near the Lake Chad are instable and face insecurities (Observatoire de la liberté religieuse, n.d.). Therefore, the inhabitants of these regions are forced to flee their homes, resulting in great internal displacements. Moreover, over the last couple of weeks, there has been a significant influx of Nigerian refugees in Maradi region, fleeing insecurity and violence in the North of Nigeria. Therefore, the pressure on local population who are hosting refugees is now extreme, where in many places refugees are more than host population. It results that infrastructures and services are at their limit, with overcrowded water points (European Commission's Directorate-General for European Civil Protection and Humanitarian Aid Operations, 2019).

As the Armed Conflict Location & Event Data Project (ACLED, 2018) explains, Niger has low levels of political violence and low levels of protests and riots compared to the African continent at large. In recent years, the main perpetrators of political violence were Boko Haram, various state forces as well as mutinous soldiers, and Al-Qaeda in the Islamic Maghreb (AQIM) as well as other Islamist groups. Niger's other areas of instability include Northern Agadez and Niamey, where most demonstrations take place. The risk to civilians living in Niger is low, with the exception of the Diffa region where most civilian deaths have been recorded over the past five years due to Boko Haram activity. Tillaberi is also considered a risky area for civilians, as there are periodic incursions by Malian groups. Tahoua mostly host internally displaced people.

Conclusion: conflicts:
The South of Diffa, the north of Tillaberi and Tahoua, the South of Maradi and the north of Agadez are insecure places in Niger.

4.3.4.2. Altitude and land tenure criteria

1. Altitude

The elevation in Niger varies from about 150m to 2000m (SRTM). The high altitudes are met only in the center and North of Agadez, where areas are considered as unsuitable anyways as the results of the model show.
Therefore, altitude could represent a constraint for people who are used to living at high altitudes and do not have antibodies. This criterion has to be analyzed further with the displaced population and its specificities.

2. Land tenure

Land tenure is a difficult parameter to take into account remotely.

Niger's Rural Code (founding text "Principes d'Orientation du Code Rural, Ordinance 93-015 of 2 March 1993") can be used as an informative and decision tool (The Rural Hub, n.d.). Also, FAO's guidelines can help orientate the decision-making (FAO, 2016b).

One of the most important actions is to go on the field and check with the government and the village chiefs or local community whose land it is; if it is accessible; if settling displaced people could cause any conflicts with the nomad population. Indeed, it is notable that important corridors for livestock movements exist between Niger and Nigeria and between Niger and Benin (World Bank 2009a; Geesing and Djibo 2001; Gnoumou and Bloch 2003; AUC et al. 2008 as cited in LandLinks, 2010).

4.3.5. Final map created by the model

To create the final map (figure 16) with the model and the population/context dependent criteria, different steps were taken:

- select the areas with a suitability index (SI) above or equal to 50 in the suitability and constraints criteria map (figure 13);
- zoom in the corresponding areas and display the towns near those areas;
- check the location on Google Earth to see how each area looks like;
- exclude areas in which the context dependent criteria are not met.

For the purpose of clarity of the map, all the areas that had a SI above 50 are not displayed. The idea is to give the reader a big picture of the areas that are considered suitable. Thus, during the selection, groups of suitable pixels were preferred than isolated pixels. A more profound analysis can be done in the future on the field. Indeed, figure 16 can be taken as a start to highlight remotely groups of suitable sites that will be verified on the field to see the amount of free space available.

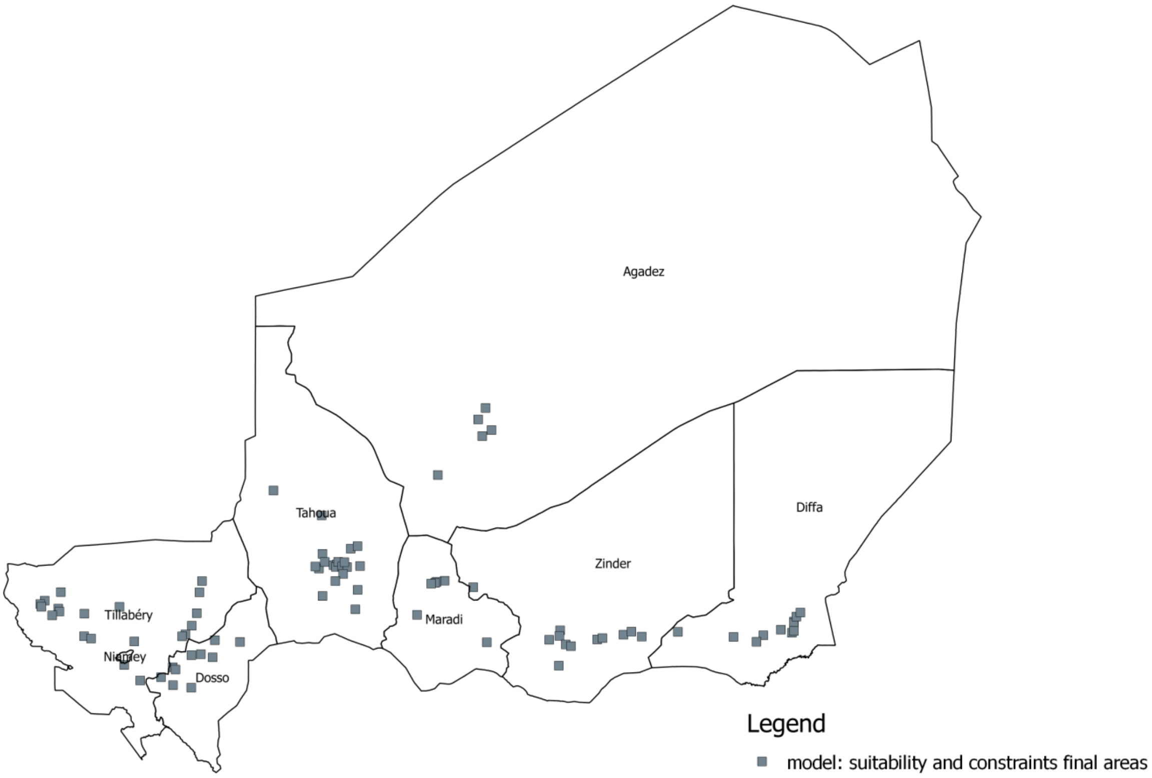

Figure 16. Final map delivered by the model, displaying the suitable sites with a SI index of 50 and above.

Conclusion:
In the region of **Diffa**, considering the conflicts around Lake Chad, even if areas had a SI above 50, they were not taken into account for security reasons if they were at a distance below 50 km to the boundaries. On the other side, even if areas had a SI of just 50 but were at a distance above 50 km away from the boundaries, they were taken into account since the Diffa region needs hosting areas for internally displaced people and refugees.

In the region of **Dosso**, some areas that had a high SI, were taken into account even if the distance to boundaries was less than 50 km because the security near the borders is less of an issue today compared to other regions of the country. The city of Dosso was not taken into consideration even with its high SI (93), since the region of Dosso was the second most populated region with a high population density in the city of Dosso.

In the region of **Maradi**, southern sites near the border were not taken into account in spite of their high SI, because the high influx of Nigerian refugees in July and early August 2019 already put pressure on the resources and the host population. Only sites above 45 km away from the border were taken into account. The city of Maradi has a good SI (80), but is not taken into account since it already has a high population density.

In the region of **Tillaberi**, suitable areas highlighted by the model at a distance below 50 km away from the border were not taken into account for security reasons. An exception was made in the North West, due to the need to host people fleeing the conflicts in Mali. Nevertheless, sites at a minimum distance of 40 km away from the border were selected.

For each of the areas highlighted as suitable in the final map (figure 16), the following verifications have to be on the field:
- check the compatibility of the displaced people and the host population regarding the ethnicity and the religion, using the information presented in the previous section;
- check land tenure rights with the government and the host communities around the area;
- calculate how much space is needed considering the number of people to be hosted, while each person has to have 3.5m² and 4.5m² in cold climates (Sphere Association, 2018); and compare with the surface of the area highlighted.

4.3.6. Today's displacement sites

Today, there are three major areas where displacement settings are concentrated in consequence of neighbouring conflicts: in the south of Diffa and in the North of Tillabéry and Tahoua, as shows the map in figure 17.

The map also shows that most of today's displacement sites correspond to Internally Displaced Locations. There are 4 refugee camps; three of them are located in the Tillaberi region and one in Diffa.

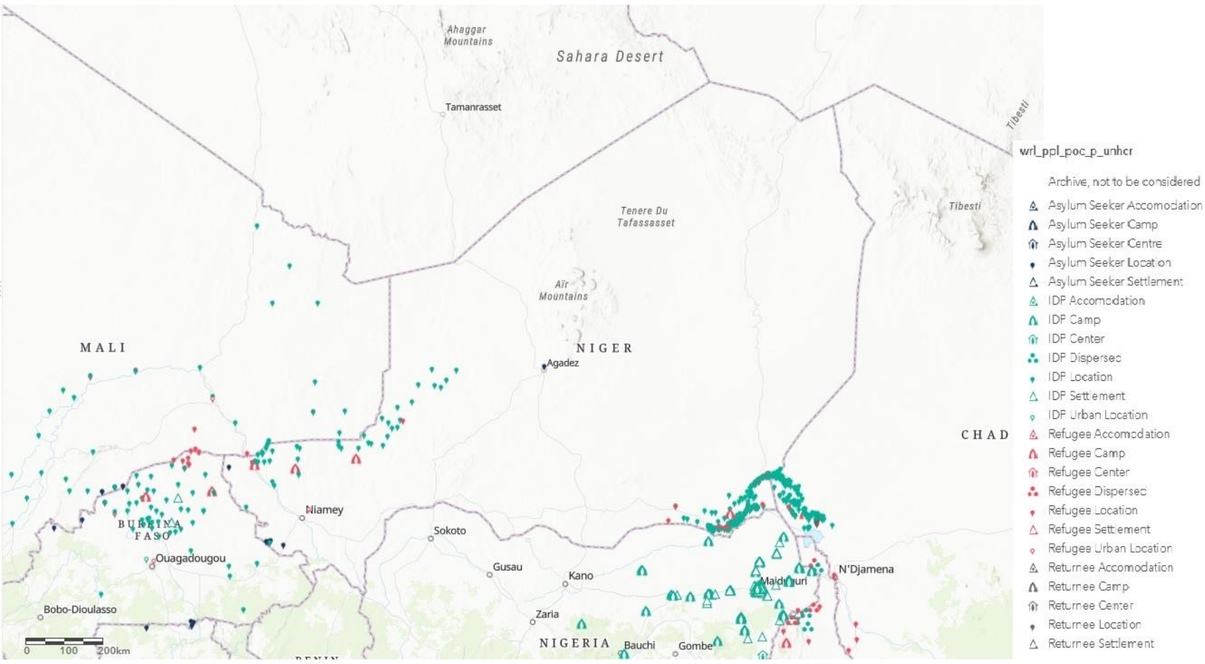

Figure 17. Displacement sites in Niger updated frequently from the ArcGIS Online map viewer of the UNHCR of the world people of concern (poc), refugees, internally displaced and returnees.

4.4. Discussion of the results

This section discusses furthermore the results delivered by the model, as well as the location of today's sites. A comparison is done between both.

4.4.1. Interpretation of the constraints and suitability map

This section aims at understanding and discussing the differences between the results delivered by the suitability map alone and the results from the suitability and constraints map.

As already mentioned above, it is interesting to see the impact of excluding criteria because it stresses the importance of the choice and selection of constraints criteria.

To understand better the country-level results presented in table 7, Niger is narrowed down to its seven regions. Indeed, as presented in the study area in chapter three, Niger's regions are very different. It is clear that Agadez, which represents more than 50 % of the country, will be for the most part unsuitable and thus lowers the global percentage of suitable areas in Niger.

Table 11 and 12 present the percentages of Niger's regions that are suitable to host displacement settings without and with constraints criteria linked to the suitability indexes of suitability criteria.

Excluding constraints criteria, table 11 and 12 show that Maradi is the region that has the best capacity to host displaced people. The second region is Dosso, then Tillaberi, followed by

Tahoua, then Zinder. Finally, Diffa and Agadez are the least two regions suitable to host displaced people.
When constraints criteria are taken into account, these results change, with Tillaberi being the best suitable region to host displaced people. It is followed by Tahoua, Dosso, Zinder and Maradi. Diffa and Agadez are still the last ones.

It is interesting to note that Maradi was considered as the best region to host displaced people when no constraints criteria were taken into account and that, after excluding areas, it is almost the last. The next section on constraints criteria aims at understanding those differences.

Table 11. Comparison of the percentage of Niger suitable to host displacement settings without and with constraints criteria linked to the suitability indexes of suitability criteria for the regions of Agadez, Diffa and Dosso.

	Regions (% of Niger's territory)					
	Agadez		Diffa		Dosso	
	53 %		12 %		3 %	
	% of the region					
Suitability indexes	without constraints	with constraints	without constraints	with constraints	without constraints	with constraints
50-100	0.1292 %	0.0063 %	0.993 %	0.396 %	18.64 %	1.41 %
60-100	0.0447 %	0.0031 %	0.335 %	0.133 %	5.62 %	0.74 %
70-100	0.0061 %	0.0011 %	0.081 %	0.031 %	1.33 %	0.26 %
80-100	0.0004 %	0.0001 %	0.015 %	0.007 %	0.28 %	0.09 %
90-100	0.00001 %	0.00001 %	0.001 %	0.001 %	0.05 %	0.02 %
100	0 %	0 %	0 %	0 %	0.01 %	0.01 %

Table 12. Comparison of the percentage of Niger that is suitable to host displacement settings without and with constraints criteria linked to the suitability indexes of suitability criteria for the regions of Maradi, Tahoua, Tillaberi and Zinder.

	Regions (% of Niger's territory)							
	Maradi		Tahoua		Tillaberi		Zinder	
	3 %		9 %		8 %		12 %	
	% of the region							
Suitability indexes	without constraints	with constraints	without constraints	with constraints	without constraints	with constraints	without constraints	with constraints
50-100	18.99%	0.79%	7.81%	1.59 %	11.56 %	3.17 %	7.00%	0.87 %
60-100	5.28%	0.42%	2.80%	0.86 %	4.31 %	1.54 %	2.18%	0.42 %
70-100	1.23%	0.13%	0.74%	0.38 %	1.39 %	0.60 %	0.68%	0.16 %
80-100	0.23%	0.04%	0.15%	0.11 %	0.42 %	0.20 %	0.16%	0.05 %
90-100	0.04%	0.01%	0.04%	0.03%	0.07 %	0.04 %	0.03%	0.01 %
100	0 %	0 %	0.0002%	0.0002%	0.003%	0.002 %	0.002%	0.001%

4.4.1.1. Interpretation of the constraints criteria

The three major excluding criteria are the quantity of **precipitation** per year; the **distance to water resources** and the above ground biomass production (see figures 20, 21 and 23 in the appendix). It would be against the recommendations discussed above to take them out of the equation at once.

Nevertheless, populations who are used to living in arid conditions may have developed strategies to cope with scarce water. Therefore, in that case it is conceivable to take out the precipitation constraint criterion, which is more excluding than the distance to water. Moreover, the distance to water constraints criterion can also be modified if considered relevant. More sites are thus made available in the Center of Niger when the precipitations are taken out (figure 31 in the appendix).

Nevertheless, the question of accessibility to those "new" sites in the Center of Niger is an important facet to discuss. At the end of May 2019 there were 175 577 refugees hosted by Niger (UNHCR, 2019c) when they were 175 418 at the end of 2018, with 156 136 IDPs and 24 727 returnees (UNHCR, n.d.b). The majority of those refugees come from three neighbouring countries: Nigeria, Mali and Chad, with 118 868, 56 306 and 165 persons respectively (UNHCR, 2019c). The starting point of the refugees in their countries will determine if the sites highlighted in Niger are reasonable to take into account or not; in other words, if those distances and climate conditions with arid zones are possible to be crossed.

Concerning the **AGBP** criterion, other vegetation indices could be used in the future to ease the strict exclusion of the AGBP as figure 14 in the appendix shows. Nevertheless, it seemed that AGBP is a good criterion, since it is linked to the capacity of a land to produce biomass (kg/ha) and to the humidity in one place. As already mentioned in the previous chapter, energy is an important factor to take into account, and its access has been often overlooked in emergency response. Therefore, in the future, this criterion should be further more analyzed, even more when we know that firewood is the most widespread form of energy in camps. Nevertheless, the development of innovative technologies and approaches in Niger like fuel-efficient cookers and solar-powered lighting could lower the pressure on natural resources in the future while still addressing the energy needs of the displaced. In that case, the amount of biomass needed would be lowered.

Croplands are also a big excluding criterion. If not considered, areas in the south and south west of Niger are not excluded. Nevertheless, it is difficult to imagine settling displacement camps in cultivated zones, where the greater part of the population is concentrated even if it is close to the boundary with Nigeria, from which the majority of refugees come from. Settling displacement locations there would add a risk of creating competition for the resource and, in consequence, of causing conflicts. Nevertheless, depending on the government policy, people in those areas could be in need of workforce and, thereby, be favorable towards the host of refugees. That scenario could be possible if the density of population is not too high, if the ethnicity and religion of displaced people are compatible with these of the host people and if the government accepts and supports mixing populations.

Today, the Government of Niger and UNHCR seek to accelerate the socio-economic integration of Malian refugees in Tillaberi and Tahoua regions. They also work on the closure of the camps through urbanization by the end of 2020, with the support at local integration and development of an EU Trust Fund supported regional project as well as a GIZ supported project. Therefore, this tool could help them identify new places where displacement people could be moved to, considering the above mentioned population dependent criteria.

Moreover, despite a complex security context in the Diffa region linked to Boko Haram, the Government of Niger, UNHCR and the World Bank agreed in 2018 on the need to engage strongly in development oriented interventions. Additionally, an EU Trust Fund supported project is ongoing in the region, aimed at supporting economic recovery and long term solutions through urbanization and the construction of durable housing (UNHCR, 2019b).

Therefore, it seems that the Government of Niger is prone to having an integration of the displaced people in the host community. Nevertheless, the map of the actual displacement locations of UNHCR (figure 17) does not show signs of displaced population in the South West of the Zinder region, in the Maradi and the Dosso region. Once again, the tool developed in the present study can help decision makers to find suitable areas to host displaced people in the near future.

To conclude, the most important constraints are linked to the arid climate of Niger, resulting in poor quantities of precipitation, low AGBP, distances to water, the presence of croplands in the south of Niger. Agadez and Diffa are mostly constrained by low precipitation and low AGBP. Zinder and Maradi are mostly constrained by the presence of croplands. Tahoua is mostly constrained by precipitations and a bit by AGBP. Dosso is mostly constrained by the presence of croplands and finally Tillaberi is mostly constrained by the presence of a nature reserve in the south and by the presence of croplands.

4.4.2. Checking the reliability of the results

Criteria to take into account when planning the installation of displacement settings have been compiled and translated into geographic information previously in this study. In the present section, the author wanted to check that humanitarian criteria were well represented in the suitability and constraints final map.
For this verification, three sites were randomly selected and analyzed. For each site, the suitability indexes of each suitability criterion were checked. They are presented in table 13 below. Also, Google Earth was used as a visual verification of the three selected sites.

For the random selection of the three sites, the total number of sites (79) highlighted by the model, presented in figure 15, is divided by 3. Then, one point every 26 points (79 points divided by 3) is selected. The id of the 26th, 53rd and 79th sites are then selected and analyzed.

The following explanations should be read in parallel to table 13 since they follow the latter from top to bottom.

Table 13. Verification of the reliability of the results delivered by with the model developed for three randomly selected points.

	site 1	site 2	site 3
id	27	53	79
global SI	67	63	67
SI of precipitations	100	100	100
SI of distance to water resources	100	100	100
SI of slope	0	0	0
SI of AGBP	82	100	100
SI of distance to boundaries	100	100	100
SI of distance to roads	100	69	91
SI of distance to electric network	0	0	0
SI of distance to towns	100	100	100
SI of distance to health infrastructure	0	0	0
SI of distance to education infrastructure	0	0	0

The first point, id 27 corresponds to an area in the region of Maradi, at about 140 km north-north east of the city of Maradi and South of Dan Boka, about 1km away. This area benefits from about 447 mm of rainfall annually, which verifies the suitability index of 100 attributed in the final map. Also, it has a suitability index of 100 for the distance to water resources, translating a distance of 0 to 500 meters away from that resource. Indeed when the water resources layer is checked, it can be observed that the site is near a water-well. Moreover, it has a slope of 1%, resulting in a suitability index of 0. It has an annual biomass production of about 2700 kg/ha, explaining the SI of 82 in the table above. As a reminder, a SI of 100 would have been attributed if the AGBP was above or equal to 3000 kg/ha. It is about 170 km away from the borders. It is also 500 m away from a secondary road. Moreover, it is 65 km away from a transmission line with a voltage of 33 kV; and 71 km away from a 20 kV transmission line, resulting in a suitability index of 0. It is 500 m away from a village (no name georeferenced in OSM). It is 73 km away from a hospital called ‘Bermo’ (OSM). It is too far away from any school or college (140 km minimum).

The second point, id 53 corresponds to an area in the region of Tahoua, south-south east of Tahoua city about 93km away. It has 380 mm of rainfall annually. As the table 13 above shows, like the id 27, it is 0 to 500 meters away from a water resource. Moreover, it has a slope of 1% resulting in a suitability index of 0. It has an annual biomass production of about 5700 kg/ha. It is about 54 km away from the borders. It is also 2 km away from a secondary road. Furthermore, it is 15 and 28 km away from two transmission lines with a voltage of 33 kV. It is 540 m away from a village named “Désa” (OSM). It is 25 km away from the ‘hospital of the Madaoua district’ (OSM). Finally, it is 16 km away from a primary school ‘école primaire Arzerori sedentaire’ and from a franco-arab school ‘école franco-arabe de Azérori’.

The third point, id 79 corresponds to an area in the region of Zinder. It is 170 km east of Zinder city. It has 424 mm of annual rainfall. As the table 13 above shows, like the two previous points, it is near a water resource; which is a water-well. It has a slope of 1%. It has an annual biomass production of about 4000 kg/ha. Moreover, it is about 60 km away from the borders. It is also near a primary road. It is 32 km away from a transmission line with a voltage of 20 kV. It is 400 m away from a village named "I-n-Gikilanba" (OSM). It is 60 km away from a first hospital called 'CSI Kirbitoa'(OSM), 65 km away from a second hospital called 'CSI Karagou' (OSM) and 70 km away from a third hospital called 'CSI Kouloumfardou' (OSM). Finally, it is at 65 km away from the primary school of Karagou 'école primaire de Karagou' (OSM).

Conclusion:
The verification done above is positive. The humanitarian standards have been translated into geographic information and they represent the targets to reach for the location of displacement settings.

4.4.3. Comparison between the model and the reality

Figure 18 below compares the suitable sites highlighted by the model and the location of today's displacements locations.

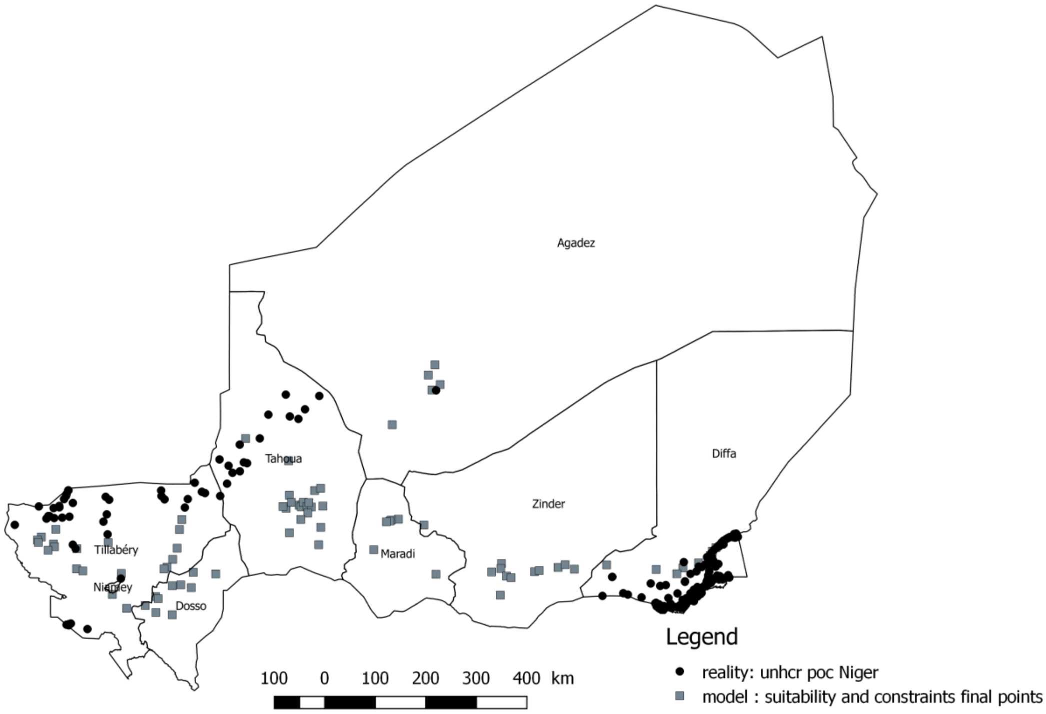

Figure 18. Comparison between the suitable sites highlighted by the model and today's actual locations of displacements settings. The location of today's displacement sites are from the web service of UNHCR (https://gis.unhcr.org/arcgis/rest/services/core/wrl_ppl_poc_p_unhcr/FeatureServer) which was added into QGIS via the ArcGIS REST API Connector extension.

The analysis of figure 18 shows that there are differences between the locations of displacement settings recommended by the humanitarian standards and the actual displacement situation in Niger today.

Observation 1: today's locations of displacement settings (IDP location and refugee location) are closer than 50 km away to the borders of the countries in conflict.

This observation raises the question of feasibility on the field of the humanitarian recommendations regarding the distance to borders. It is assumed that this distance to boundaries translates the urgency of people at risk fleeing their home or their country to find a new place to settle. Nevertheless, they could benefit from more suitable sites if the tool developed in the present study was used in the future. This map (figure 18) could help visualize the targets to reach (humanitarian standards written in the handbooks) compared with the reality; this information could thus orientate the work to be done.

To show the utility of the tool and explain why the areas located by it are a good alternative to consider, a comparison between one area considered suitable by the model (id 33) and two locations of actual displacement sites (id 27682 and id 27687) located closely to each other are compared. The three points are located in the north of the region of Tahoua, about 160 km north east of the city of Tahoua, as it can be seen on figure 19.

Table 14. Comparison of a displacement setting highlighted as suitable by the model and two locations of actual displacement settings in the Tahoua region.

	site 1 model	site 2 actual	site 3 actual
id	33	27682	27687
global SI	50	0	0
SI of precipitations	68	15	25
SI of distance to water resources	100	0	0
SI of slope	100	0	0
SI of AGBP	0	0	0
SI of distance to boundaries	100	100	77
SI of distance to roads	0	0	0
SI of distance to electric network	0	0	0
SI of distance to towns	0	100	0
SI of distance to health infrastructure	0	0	0
SI of distance to education infrastructure	0	0	0

The area highlighted as suitable by the model has the advantage to have a Suitability Index of 100 for the distance to water resources, translating a distance under 500 m to this vital resource compared to a SI of 0 for today's sites. Moreover, the SI of the precipitations is higher in the area found by the model than in the actual displacement sites. The slope criterion is also filled, while it is not the case in the actual sites. The area highlighted by the model is only 15 km and 28 km away from the actual displacement sites, id 27687 and 27682 respectively.

This observation could be verified on the field, making sure that this model can be trusted. A field study could also highlight the reasons of the locations of today's sites. This would be a good way to confront the reality with the results of the model developed, thus with the humanitarian recommendations.

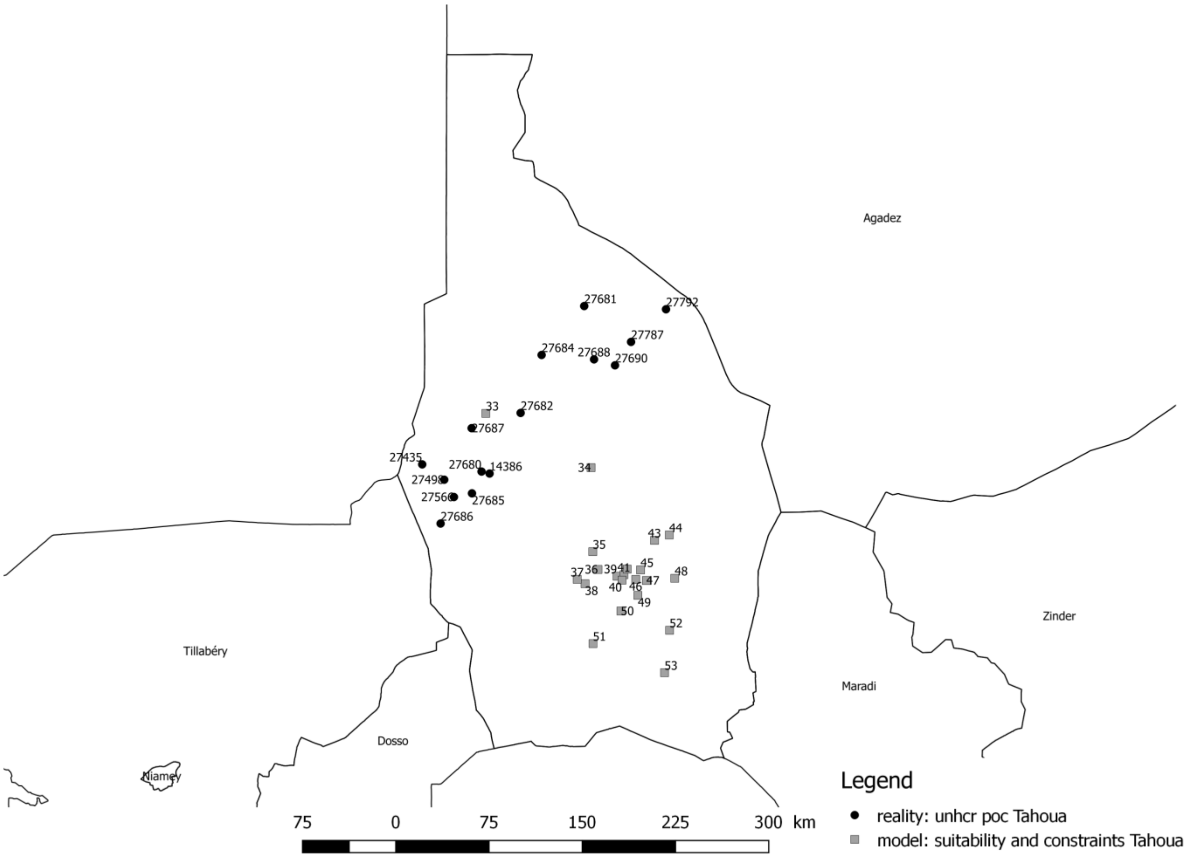

Figure 19. Focus on the Tahoua region to compare theorical setting and real displacement settings. The comparison is made on one displacement setting highlighted as suitable by the model, id 33, and two locations of actual displacement settings, id 27682 and 27687, in the Tahoua region.

If a field verification shows that this model can be trusted and followed to orientate the decision of the implementation of a displacement site, it could be a huge step towards a better management for the humanitarian work and planning. However, the question of logistics to move displacements further away from the zones or countries of conflicts would have to be taken into account, as well as the budget allocated to it. Nevertheless, on the other hand, money could be saved by having a first idea of the suitable areas providing the necessary services for the displaced.

Observation 2: today's sites are only located near the countries under conflict.

Observation 3: actual sites are gathered into few places.

Observations 2 and 3 are discussed together. Gathering many people in a place where resources are already scarce can be problematic. Also, gathering displaced people in one place make them easy targets.

On the other hand, the sites highlighted by the model have different advantages, in so far as it is possible, from a logistics and management point of view, to settle many camps in many different places. Indeed, as they are distant to one another, they could:
-lower the pressure on the local population hosting the refugees or the IDPs;
-avoid having places where the number of refugees is higher than the host population;
-avoid having a saturation of existing services and infrastructures (food stocks, health services, overcrowded water points, hindered education);
-avoid having bad perceptions of refugees by the host population. It is an additional source of stress for the displaced people. This has been the case in the Lake Chad Basin, in the region of Diffa in 2018, where regional authorities expressed plans to relocate all refugees from the villages along the border with Nigeria to a camp, due to increasing perceptions that refugees were being used by insurgents to infiltrate communities (UNHCR, 2019a).

Observation 4: some of today's displacement sites correspond to a suitable location as the result of the model highlights (suitability and constraints map).

Observation 5: there are actual sites that are a few kilometers away from sites highlighted as suitable by the model.

Observations 4 and 5 are discussed together.

On the one hand, several displacement sites today are located in suitable areas, where the SI is higher than 50. Therefore, it could be interesting to understand how those decisions, in line with the humanitarian recommendations, are taken today and to use the tool developed here to continue in that positive direction when deciding the locations of future sites. To illustrate this point, the displacement site with the id 27516 in the region of Diffa was chosen to be analyzed, as it has a global suitability index of 71. Nevertheless, it is only 23 km away from the border of Nigeria. The results are given in table 14 below.

On the other hand, some of today's sites are located in areas that have a SI of 0 according to the suitability and constraints map developed by the model. To illustrate this point, the displacement site with the id 27548 in the region of Diffa is analyzed. The results are given in table 14 below.

The analysis of point 2 (id 27548) shows that the suitability index for the criterion 'distance to towns' is equal to 100 indicating that there is a town at a distance inferior to 5 km away from the point. Therefore, the nearest town was searched for and found to be Kakarma 5km away and North-North East of Toumour. The situation of Kakarwa was then analyzed, to check how populations live. As the global SI of Kakarma shows, the situation is not ideal when recommendations are taken into account. It means that it happens that host populations have less than what the humanitarian handbooks recommend. Therefore, an attention should be raised not to create distortions between host communities and displaced population in the resources that are accessible for the displaced, or services made available.

Table 15. Comparison of a displacement setting highlighted as suitable by the model and two locations of actual displacement settings in the Diffa region taking into account each of the suitability criteria and their corresponding suitability indexes.

	site 1 actual	site 2 actual	Kakarwa
id	27516	27548	/
global SI	71	0	19
SI of precipitations	81	51	51
SI of distance to water resources	100	0	0
SI of slope	100	0	0
SI of AGBP	3	30	39
SI of distance to boundaries	3	0	0
SI of distance to roads	100	0	0
SI of distance to electric network	0	0	0
SI of distance to towns	100	100	100
SI of distance to health infrastructure	100	67	93
SI of distance to education infrastructure	38	0	0

This methodology also gives an idea of the services nearby the area and what there is not, enabling a better planning of the needs and the budget that will have to be allocated. Indeed, in the case of site 1 and 2 in table 15, there is no transmission line nearby; therefore, part of the planning will have to consider the installation of generators.

4.4.4. Study limitations and recommendations

Some limitations and recommendations for further research are developed here after.

Firstly, the criteria taken into account are not exhaustive. Other relevant criteria could be considered in the future:

- seasons: from the variation of annual precipitations to monsoons;
- weather extremes: cyclones, hurricanes, floods and droughts;
- other social criteria, like the community acceptance;
- carrying capacity of the land. It has been mentioned in the present study but should be studied deeper linking it to the density of the host population. This would give an idea of the number of people who can be hosted.
- duration of the settlements: the infrastructures, the needs and the design of displacement sites may change when a site is temporary or long term;
- economic point of view: access to markets -as food and charcoal- and the rate of unemployment in the area.

Secondly, even if the scripts have been written to be flexible and customizable, they need to be improved regarding the last steps of the methodology. Indeed, in the eight script “s7_ constraints_criteria.R", the excluding thresholds are inserted manually as well as the values of the suitability criteria and their corresponding suitability indexes in the ninth script.

In the future, the user should be able to only make changes in the third script "s2_parameters.R", which can be considered as a 'control tour', where all the parameters are defined and their corresponding values assigned. Once it is done, the script "master.r" could be used for all the following scripts to run by themselves. This would be interesting for quick comparisons of different scenarios.

Thirdly, detection of the presence and the quantity available of water resources would be interesting to study deeper. Indeed, as explained by Riazanoff S. (personal interview, April 17, 2019) : "satellite imagery can locate groundwater discharge and recharge areas using thermal infrared, NDWI surface moisture index or more indirectly by calculating the surface vegetation index. Microwave radar imaging is also interesting for characterizing moisture and surface biomass."

Moreover, more studies could be conducted on innovative technologies that would ease the pressure on natural resources of the country.

Fourthly, an API link to insert WAPOR data into SEPAL could be added. This would enable the user to automatically download the wanted data.

Furthermore, different scenarios could be generated changing the constraints and suitability criteria and analyzing the results. If possible, those results should be verified on the field.

Finally, a graphical user interface would be a great tool to develop in the future. The scripts presented in the present study could be the back-end scripts and serve as a basis of the server-side or web design. And they would run according to the requests made by the user using the interface, the front-end or client-side.

Chapter five: Conclusion

Today, conflicts and natural disasters are causing the displacement of millions of people. In view of helping the assistance of the displaced, a methodology using GIS and remote sensing was developed in the present study to support decision making on the selection of locations for the installation of new displacement settings in case of a sudden crisis.

To complete this ambitious task, the methodology was created following different steps. The major one are briefly presented here after.

First, the selected humanitarian recommendations regarding displacement settings were organized into three categories -social, geographical and infrastructural- and were translated into geographic information. Two types of criteria were then highlighted: constraints criteria, which exclude areas at once; and suitability criteria, which give an idea of how suitable a site is in the light of the considered criterion. The processing of criteria and their combination were realized by coding in R language using SEPAL.

The final map, taking into account suitable and constraints criteria as well as context and population dependent criteria was created. All of the suitable sites are not represented on the final map for the purpose of clarity.

This map was then compared with today's displacement sites (refugee, IDP and returnee locations). It results that there are differences between the results of the model corresponding to the selected humanitarian recommendations and today's locations of displacement sites.

Different observations were made during the comparison and were discussed. One of them raises the question of feasibility on the field of the humanitarian recommendations. Another one questions the presence of big camps that gather many people in few places, pressuring natural resources and isolating the displaced.

A third one concerns the difference between the humanitarian standards and the livelihoods of the host populations.

The recommendations presented in this study should not be the focus of the displaced people alone. Indeed, considering the fact that many displaced people are hosted by the least developed countries, humanitarian recommendations are likely to be above the host community living practices. Humanitarian aid should be deployed to benefit both the displaced and the host communities.

The results delivered by the model are not sufficient for the selection of sites since there are realities that cannot be assessed remotely but, those results, thus the model developed, can help in many other ways.

Notably, the methodology developed has at least four positive outcomes:
- it enables to take stock of the actual situation visually vs. what the humanitarian standards reach for. Also, it demonstrates that some of today's sites are not in suitable locations, while others are. Moreover, the different layers corresponding to the suitability criteria help better identify the reasons why sites are considered unsuitable through their suitability indexes. A comparison of the actual sites with the criteria considered in the model is done in chapter four of the present study but could be studied furthermore on the field;
-it enables the targeting of sites considered suitable when compiling the different humanitarian standards;
-it enables to present alternatives and make a first selection of sites that could host displaced people, i.e. areas that meet the different humanitarian criteria; more suitable sites can be thus selected.
-it enables a global view of the available services or infrastructures nearby.

Therefore, the methodology developed first enables the translation of the humanitarian standards into geographic information. Second, it can be used as a monitoring and evaluation tool because it is polyvalent, flexible and customizable.

The present study has shown great potential for the future. Nevertheless, improvements can always be done. The results presented should be verified on the field.

The humanitarian action is complex. Hopefully, this methodology will ease the steps to be taken and will help national authorities, national and international humanitarian actors ensure a more effective humanitarian protection and assistance while preserving and strengthening the resilience of host communities.

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Appendix

1. Summary of the features taken into account for each of the criteria that found their geographic translation in OSM data.

Criteria	Initial layer	Selected features	Given number	Meaning	Final layer	More information
Religion	gis_osm_pofw_free_1.shp	christian _ *	1	A christian place of worship (usually a church) without one of the denominations below	religion_osm.shp	MORE INFO page 11 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
		christian_anglican	1	A christian place of worship where the denomination is known. (Note to German users: “protestant” is “evangelisch” in German; “evangelical” is “evangelikal” in German.)		
		christian_catholic	1			
		christian_evangelical	1			
		christian_lutheran	1			
		christian_methodist	1			
		christian_orthodox	1			
		christian_protestant	1			
		christian_baptist	1			
		christian_mormon	1			
		jewish	2	A jewish place of worship (usually a synagogue).		
		muslim_*	3	A muslim place of worhsip, (usually a mosque) without one of the denominations below		
		muslim_sunni	3	A Sunni muslim place of worship.		
		muslim_shia	3	A Shia muslim place or worship.		
		buddhist	4	A Buddhist place of worship.		
		hindu	5	A Hindu place of worship.		
		taoist	6	A Taoist place of worship.		
		shintoist	7	A Shintoist place of worship.		
		sikh	8	A Sikh place of worship.		
water_pois (points of interest)	gis_osm_pois_free_1.shp	drinking_water	1	A tap or other source of drinking water.	water_pois_osm.shp	MORE INFO page 10-11 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
		water_tower	2	A water tower		
		water_well	3	A facility to access underground aquifers.		
		water_works	4	A place where drinking water is processed		
water_osmcode	gis_osm_water_a_free_1.shp	water	1	Unspecified bodies of water. Typically lakes, but can also be larger rivers, harbours, etc.	water_osm.shp	MORE INFO page 17 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
		reservoir	2	Artificial lakes, typically above a dam.		
		river	3	Polygons for larger rivers.		

waterways_osm_code	gis_osm_waterways_free_1.shp	river	1	A large river	waterways_osm.shp	MORE INFO page 16 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
		stream	2	A smaller river or stream.		
		canal	3	An artificial waterway		
		drain	4	A small drainage ditch or similar structure		
water_naturalcode	gis_osm_natural_free_1.shp	spring	1	A spring, possibly source of a stream.	water_natural_osm.shp	MORE INFO page 11 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
Wetland (unsuitable_water)	gis_osm_water_a_free_1.shp	wetland	1	Swamp, bog, or marsh land	unsuit_wetland_osm.shp	MORE INFO page 17 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
Military bases (unsuitable_land)	gis_osm_landuse_a_free_1.shp	military	1	Military landuse, usually no access for civilians.	unsuit_land_military_osm.shp	MORE INFO page 17 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
Nature reserve and national park (unsuitable_reserve)	gis_osm_landuse_a_free_1.shp	nature_reserve	1	A nature reserve.	unsuit_land_reserves_osm.shp	MORE INFO page 17 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
		national_park	2	A national park.		
roads_code	gis_osm_roads_free_1.shp	motorway	1	Motorway/freeway	roads_osm.shp	MORE INFO page 14 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
		trunk	2	Important roads, typically divided		
		primary	3	Primary roads, typically national		
		secondary	4	Secondary roads, typically regional.		
		tertiary	5	Tertiary roads, typically local.		
		motorway_link	1	Roads that connect from one road to another of the same of lower category		
		trunk_link	2	""		
		primary_link	3	""		
		secondary_link	4	""		
		tertiary_link	5	""		

towns	gis_osm_places_free_1.shp	city	1	As defined by national/state/provincial government. Often over 100,000 people	towns_osm.shp	MORE INFO page 5 and 6 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
		town	2	As defined by national/state/provincial government. Generally smaller than a city, between 10,000 and 100,000 people		
		village	3	As defined by national/state/provincial government. Generally smaller than a town, below 10,000 people		
		hamlet	4	As defined by national/state/provincial government. Generally smaller than a village, just a few houses		
		national_capital	5	A national capital		
		suburb	6	Named area of town or city		
Health infrastructure	gis_osm_pois_free_1.shp	pharmacy	1	A pharmacy.	health_osm.shp	MORE INFO page 6-7 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
		hospital	2	A hospital.		
		doctors	3	A medical practice.		
		dentist	4	A dentist's practice.		
Education infrastructure	gis_osm_pois_free_1.shp	university	1	A university.	education_osm.shp	MORE INFO page 6-7 : http://download.geofabrik.de/osm-data-in-gis-formats-free.pdf
		school	2	A school.		
		kindergarten	3	A kindergarten (nursery).		
		college	4	A college.		

2. List of experts

Experts contacted	Institution
Andrea Dekrout	UNHCR
Baudouin Michel	Gembloux Agro-Bio Tech (ULiège)
Camille Touzé	FAO
Florent Eveillé	FAO
Marie-Julie Lambert	Action Contre la Faim
Michel Goffin	SHER Ingénieurs-Conseils, Société pour l'Hydraulique, l'Environnement et la Réhabilitation
Nathanael Dominici	UNHCR
Serge Riazanoff	VisioTerra

3. Intermediate maps

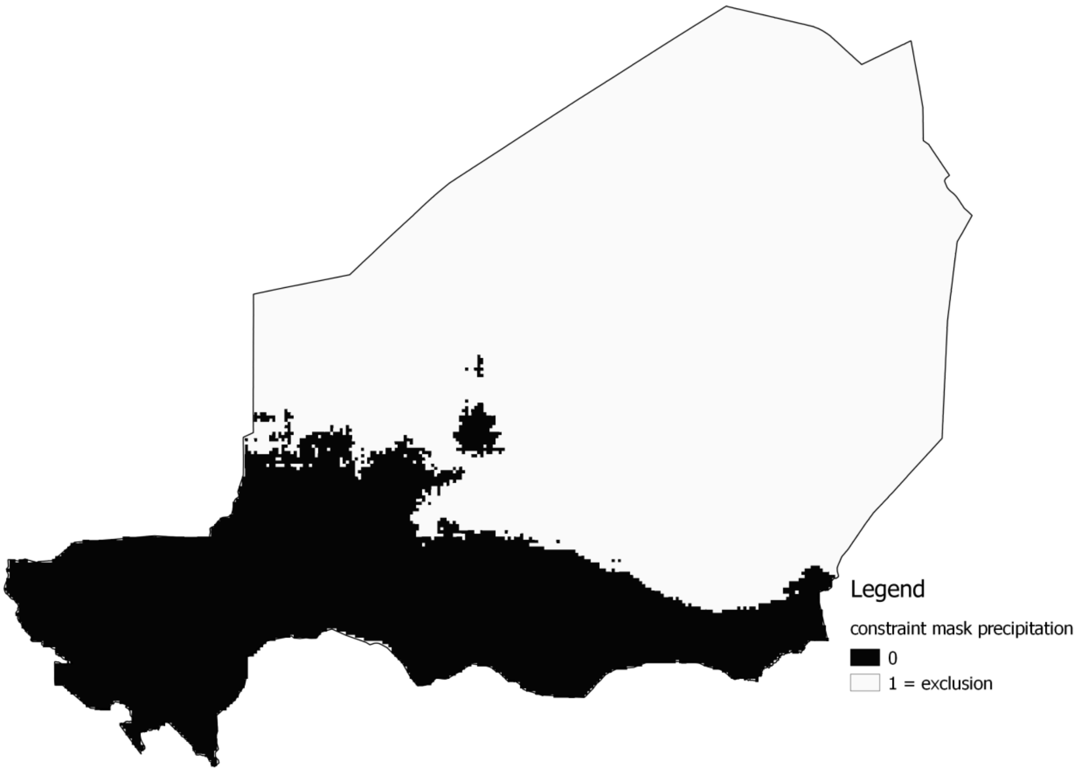

Figure 20. Constraints map of the precipitation in Niger; where pixels with a value of 1 are excluded, corresponding to annual rainfall below 200 mm.

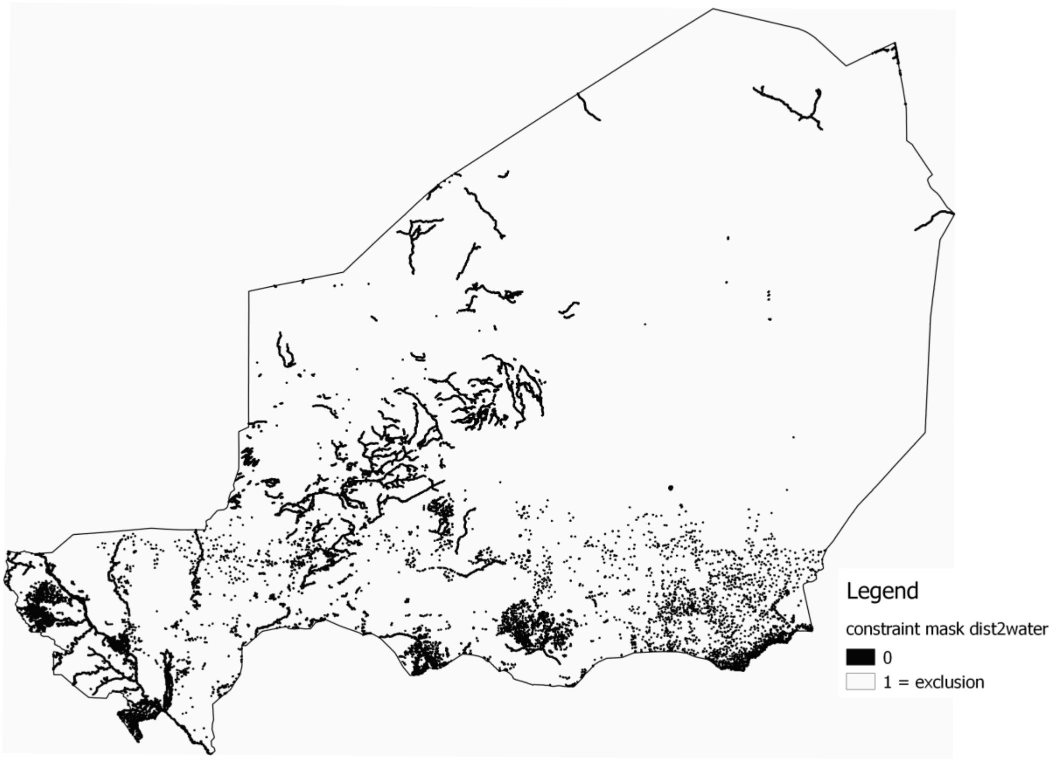

Figure 21. Constraints map of the distance to water resources (surface and underground) in Niger; where pixels with a value of 1 are excluded, corresponding to a distance to water resources above 2000 m.

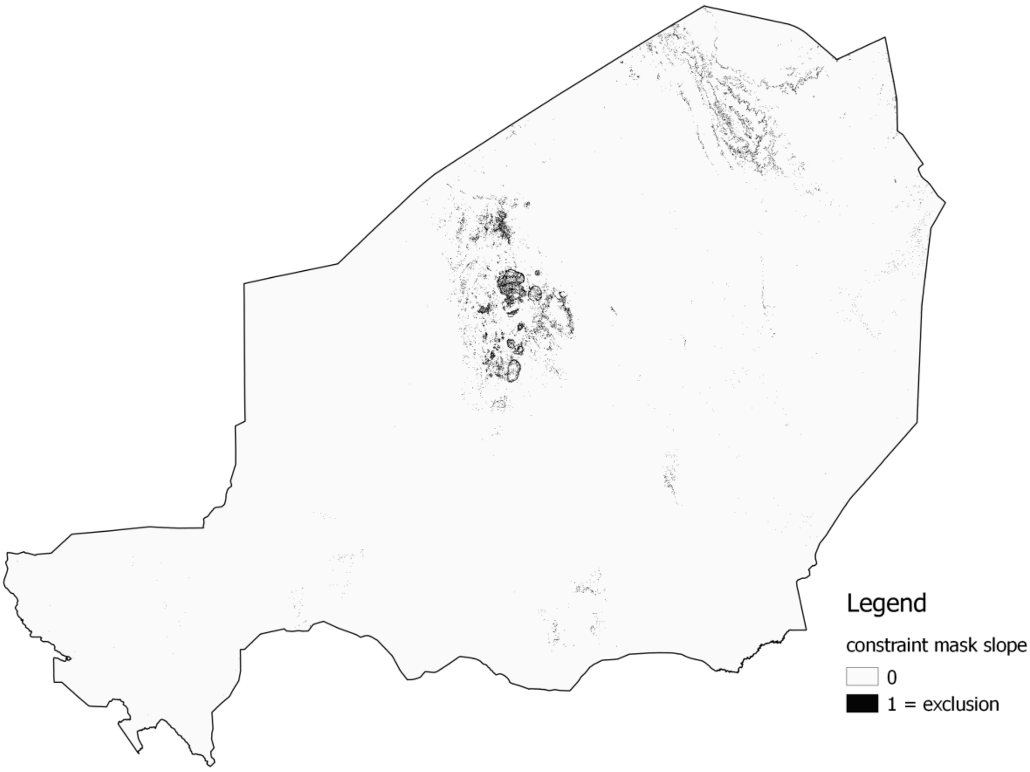

Figure 22. Constraints map of the slope values in Niger; where pixels with a value of 1 are excluded, corresponding to steep slopes above 20%.

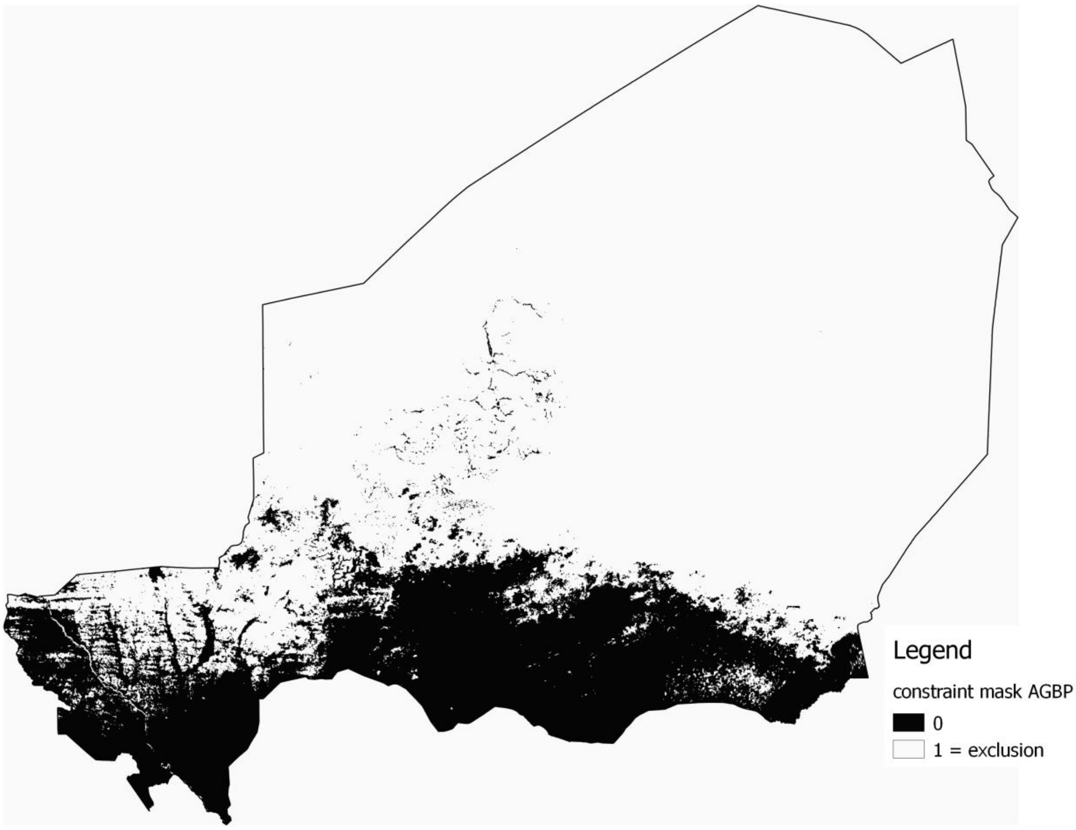

Figure 23. Constraints map of the above ground biomass production in Niger; where pixels with a value of 1 are excluded, corresponding to an annual AGBP below 1000 kg/ha.

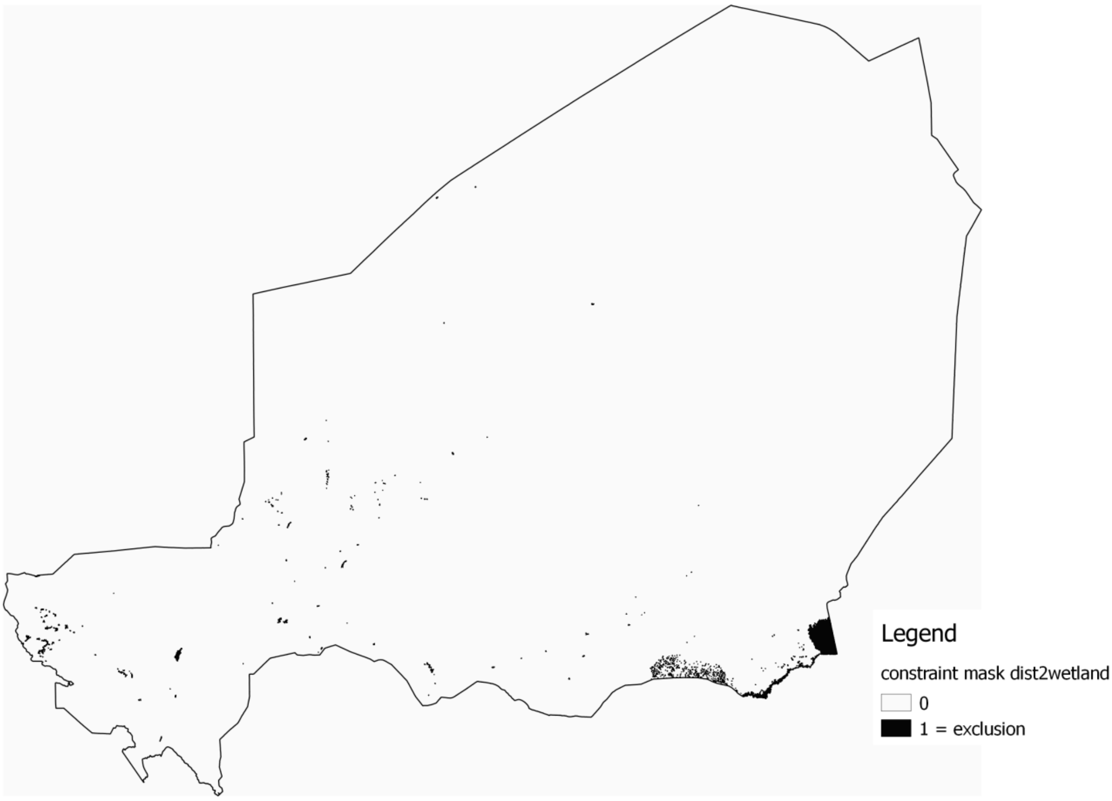

Figure 24. Constraints map of the distance to wetland in Niger; where pixels with a value of 1 are excluded, corresponding to distances to wetland below 1000 m.

Figure 25. Constraints map of the distance to nature reserves or national parks in Niger; where pixels with a value of 1 are excluded, corresponding to distances to nature reserves or national parks below 24 km.

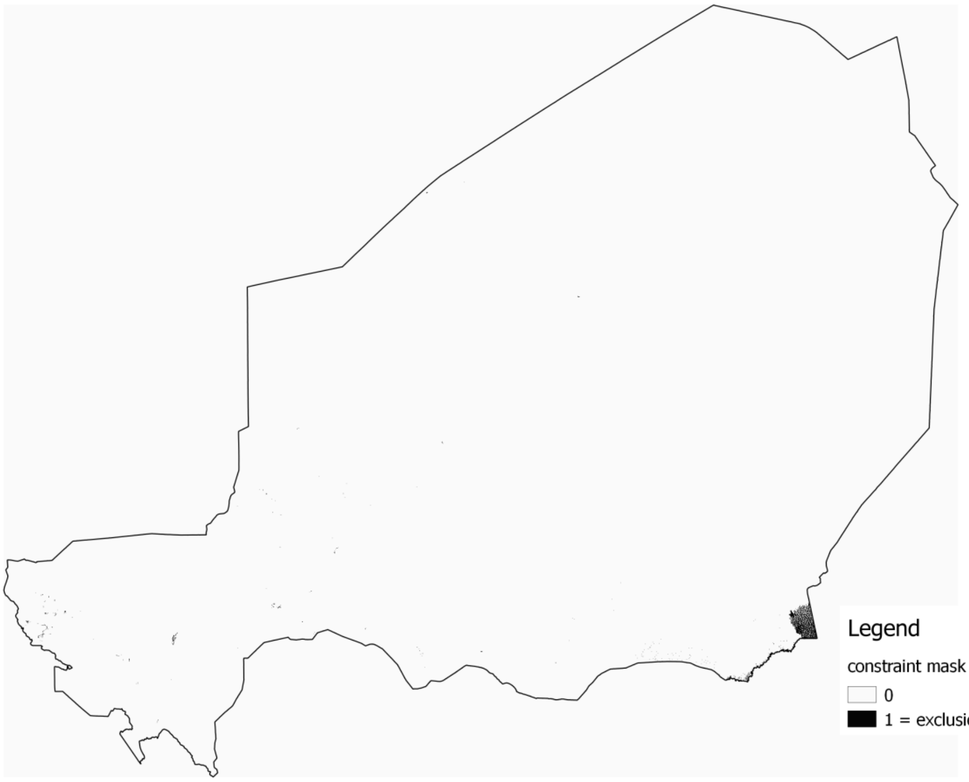

Figure 26. Constraints map of the presence of wetlands in Niger; where pixels with a value of 1 are excluded, corresponding to the presence of wetlands.

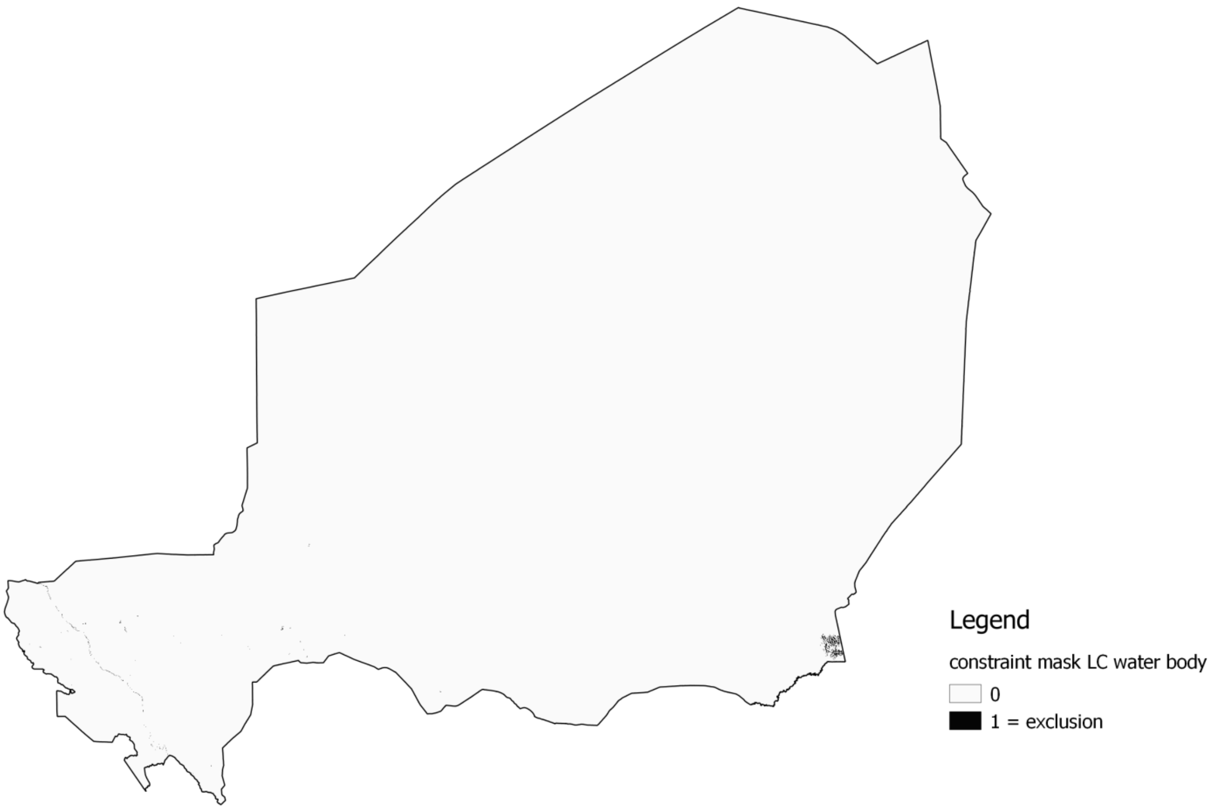

Figure 27. Constraints map of the presence of water bodies in Niger; where pixels with a value of 1 are excluded, corresponding to the presence of water bodies.

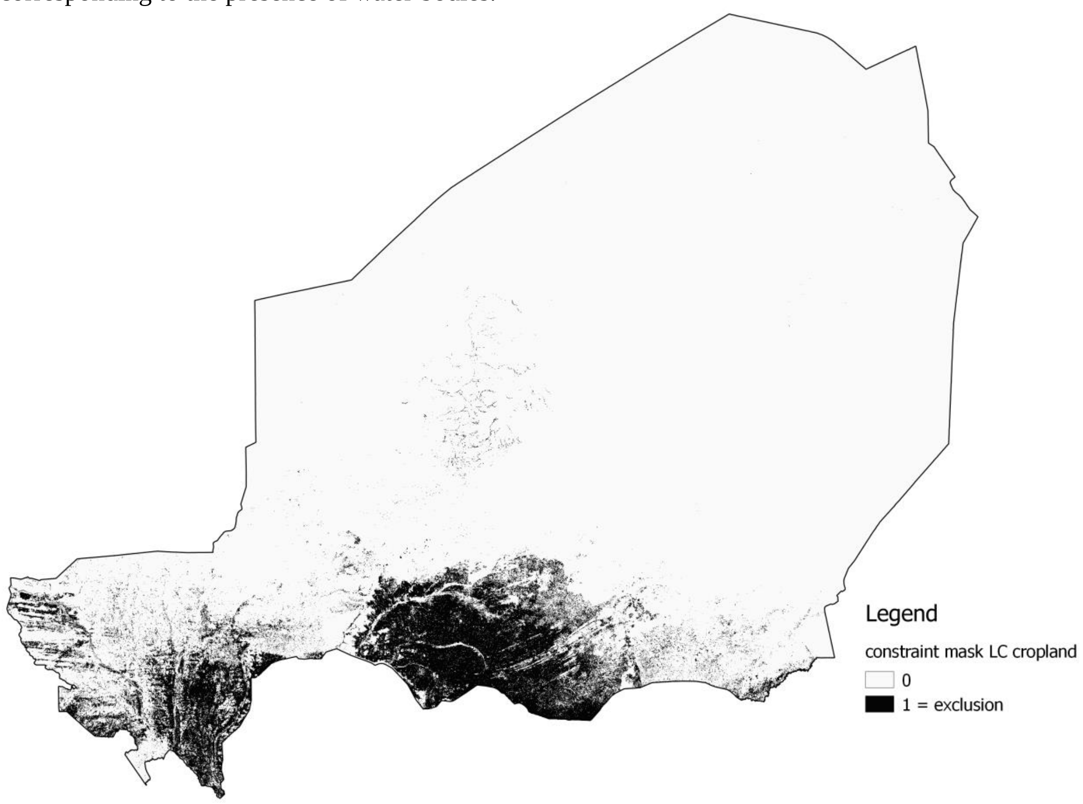

Figure 28. Constraints map of the presence of croplands in Niger; where pixels with a value of 1 are excluded, corresponding to croplands.

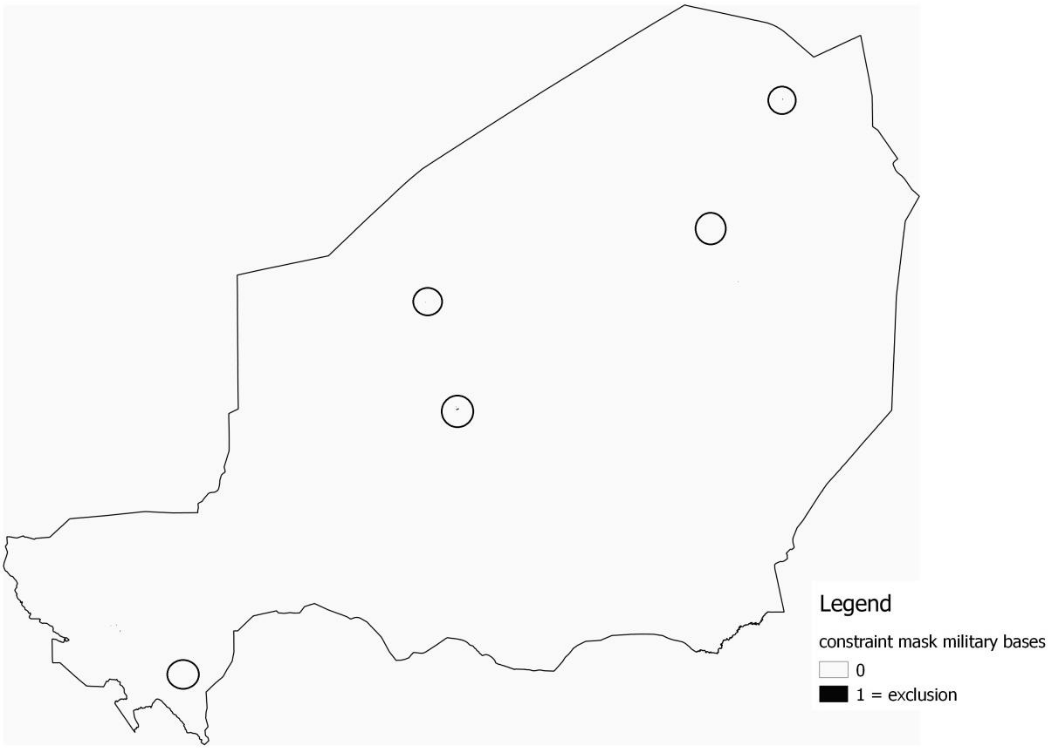

Figure 29. Constraints map of the presence of military bases in Niger highlighted by circles; where pixels with a value of 1 are excluded, corresponding to military bases.

Figure 30. Constraints map of the presence of nature reserves or national parks in Niger; where pixels with a value of 1 are excluded, corresponding to nature reserves.

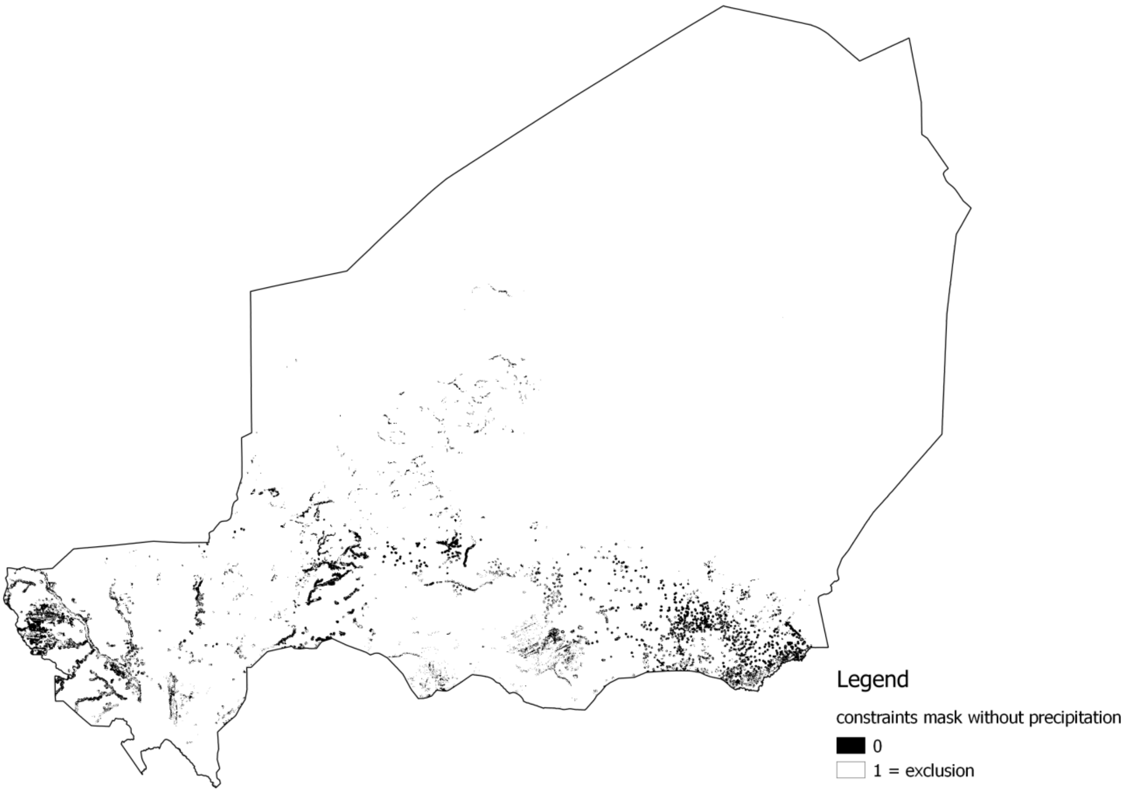

Figure 31. Constraints mask of the precipitations where pixels equal to 1 correspond to the constraints criteria without precipitation; and pixels with a value of 0 correspond to the areas where the constraints criteria are not present. The list of the constraints criteria taken into account are in the table 3 presented above taking the precipitation criterion out.

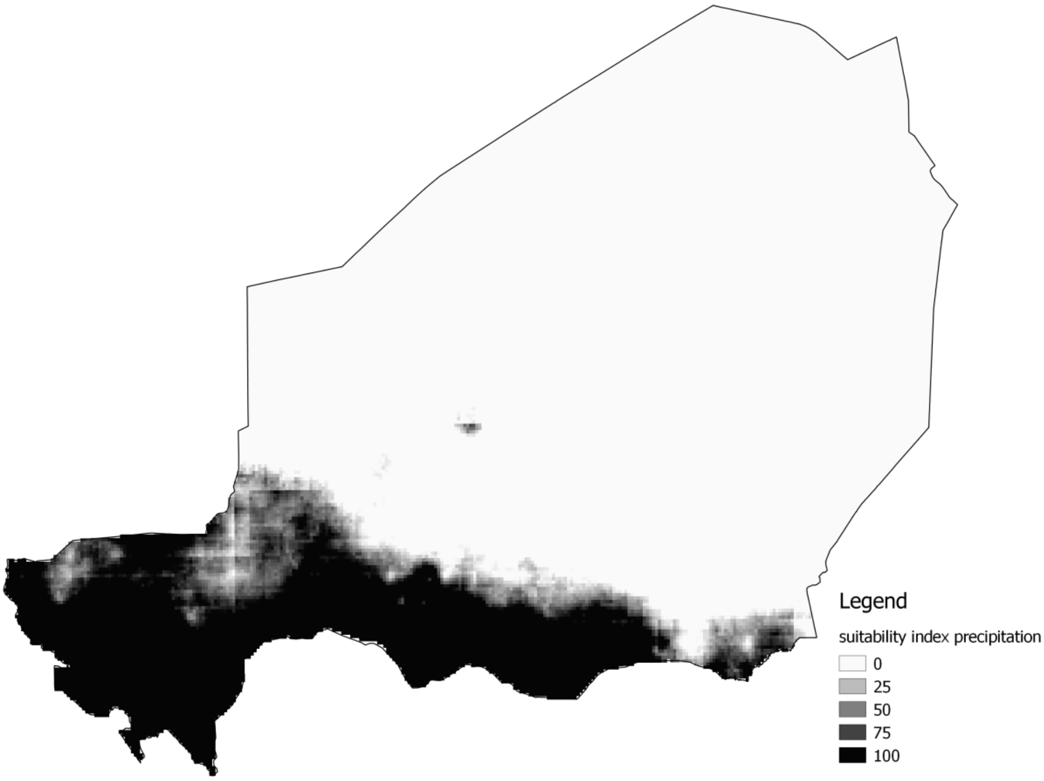

Figure 32. Suitability map of the precipitation in Niger; where a suitability index of 100 is attributed to annual rainfall above or equal to 350mm; where a suitability index of 0 is given to precipitation below 250 mm; and where suitability indexes in-between 0 and 100 are given to annual rainfall between 250 and 350 mm.

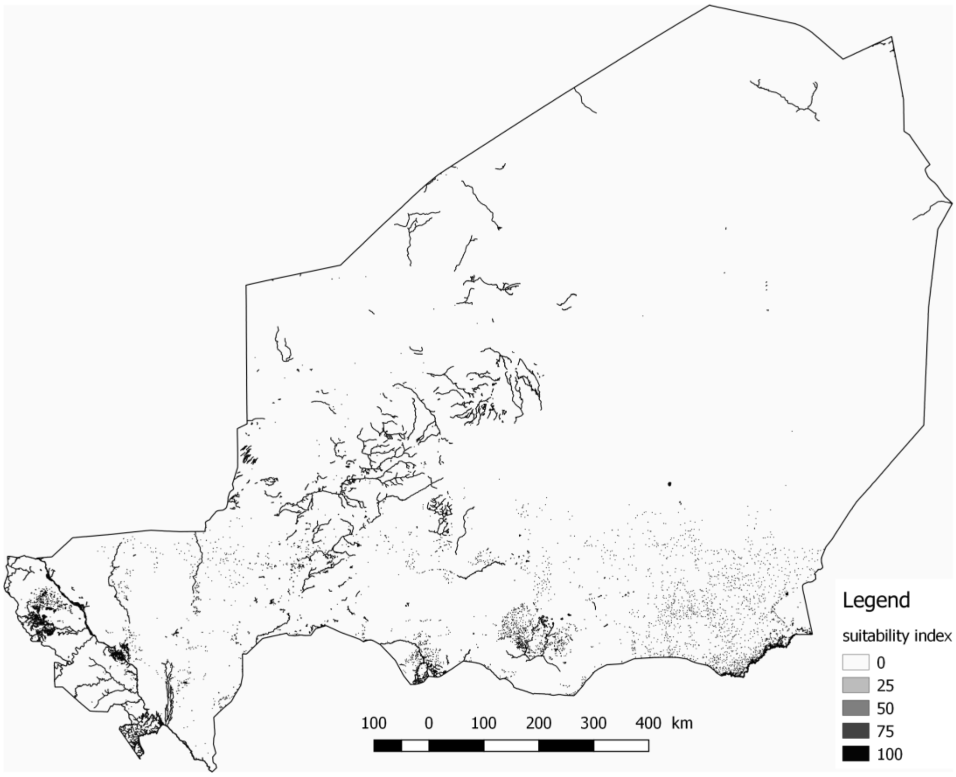

Figure 33. Suitability map of the distance to water in Niger; where a suitability index of 100 is attributed to a distance of 0 to 500 m away from the resource; where a suitability index of 0 is given distances above 1 km away from the resource; and where suitability indexes in-between 0 and 100 are given to distances between 500 and 1000 meters.

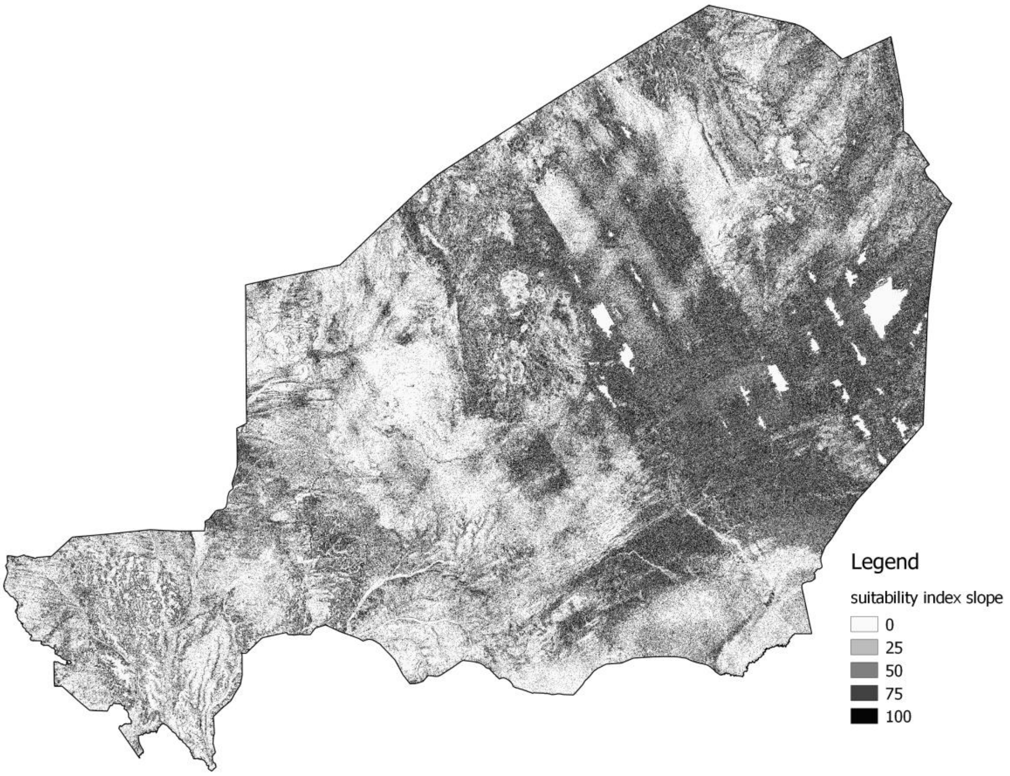

Figure 34. Suitability map of the slope values (in %) in Niger; where a suitability index of 100 is attributed to gentle slopes in-between 2 and 4 %; where a suitability index of 0 is given to steep slopes, above 10% or slopes that are too gentle, under 2%; and where suitability indexes in-between 0 and 100 are given to slopes with values between 4 and 10%.

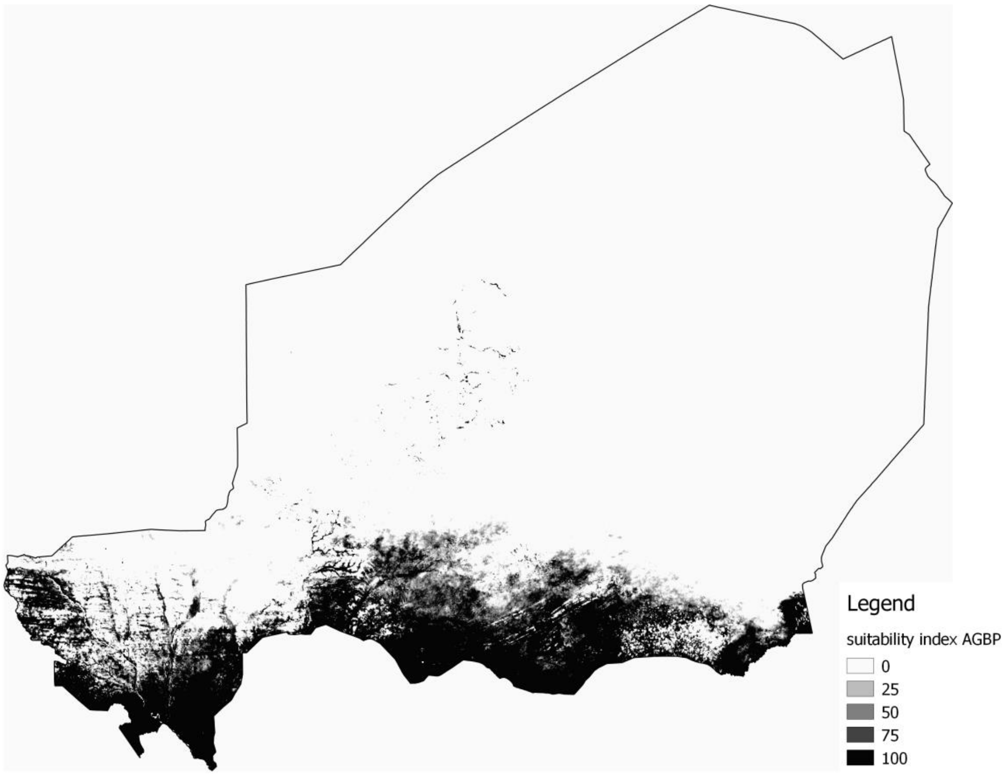

Figure 35. Suitability map of the above ground biomass production in Niger; where a suitability index of 100 is attributed to an annual AGBP above or equal to 3000 kg/ha; where a suitability index of 0 is given to an annual AGBP below 1500 mm; and where suitability indexes in-between 0 and 100 are given to an annual AGBP between 1500 and 3000 kg/ha.

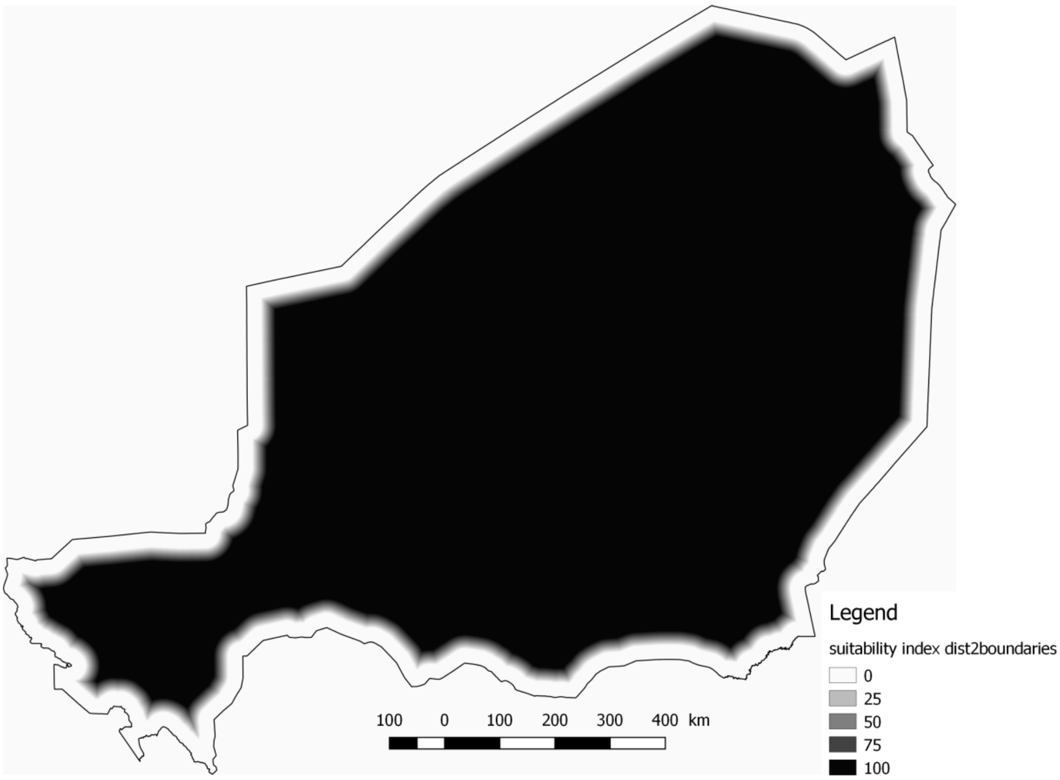

Figure 36. Suitability map of the distance to boundaries in Niger; where a suitability index of 100 is attributed to distances to boundaries above or equal to 50 km; where a suitability index of 0 is given to distances to boundaries below 25 km; and where suitability indexes in-between 0 and 100 are given to distances to boundaries between 25 and 50 km.

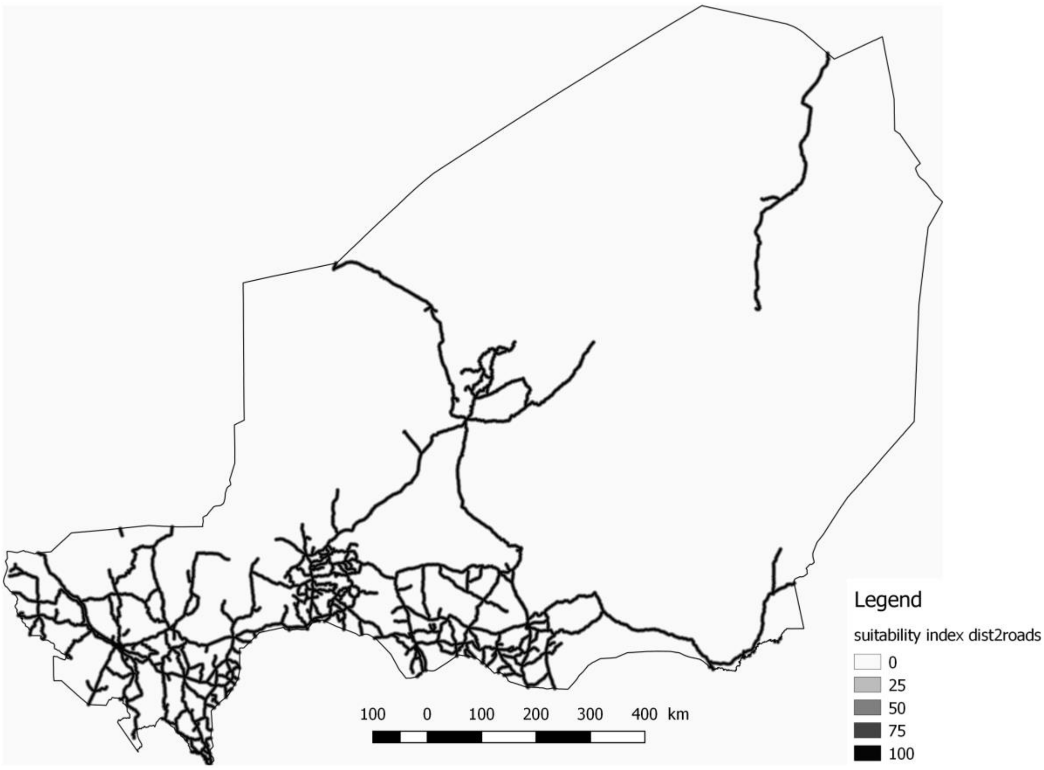

Figure 37. Suitability map of the distance to roads in Niger; where a suitability index of 100 is attributed to distances to roads below or equal to 1 km; where a suitability index of 0 is given to distances to roads above 5 km; and where suitability indexes in-between 0 and 100 are given to distances to roads between 1 and 5 km.

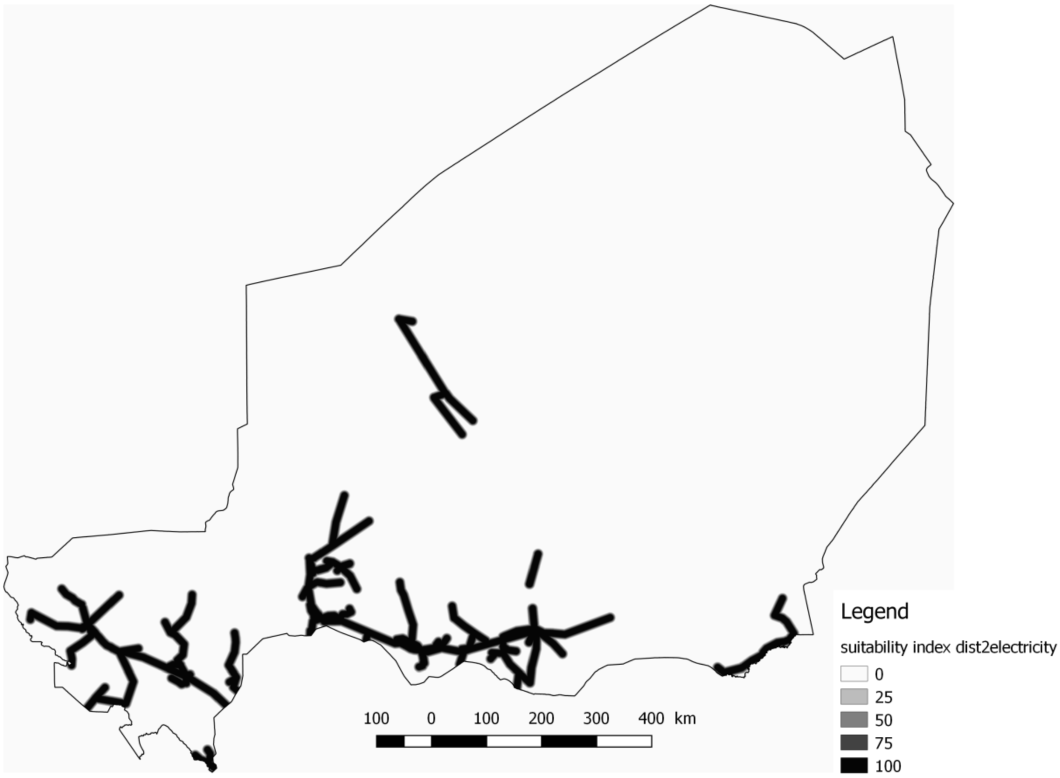

Figure 38. Suitability map of the distance to electricity grids in Niger; where a suitability index of 100 is attributed to distances to an electric network below or equal to 5 km; where a suitability index of 0 is given to distances to an electric network above 10 km; and where suitability indexes in-between 0 and 100 are given to distances to an electric network between 5 and 10 km.

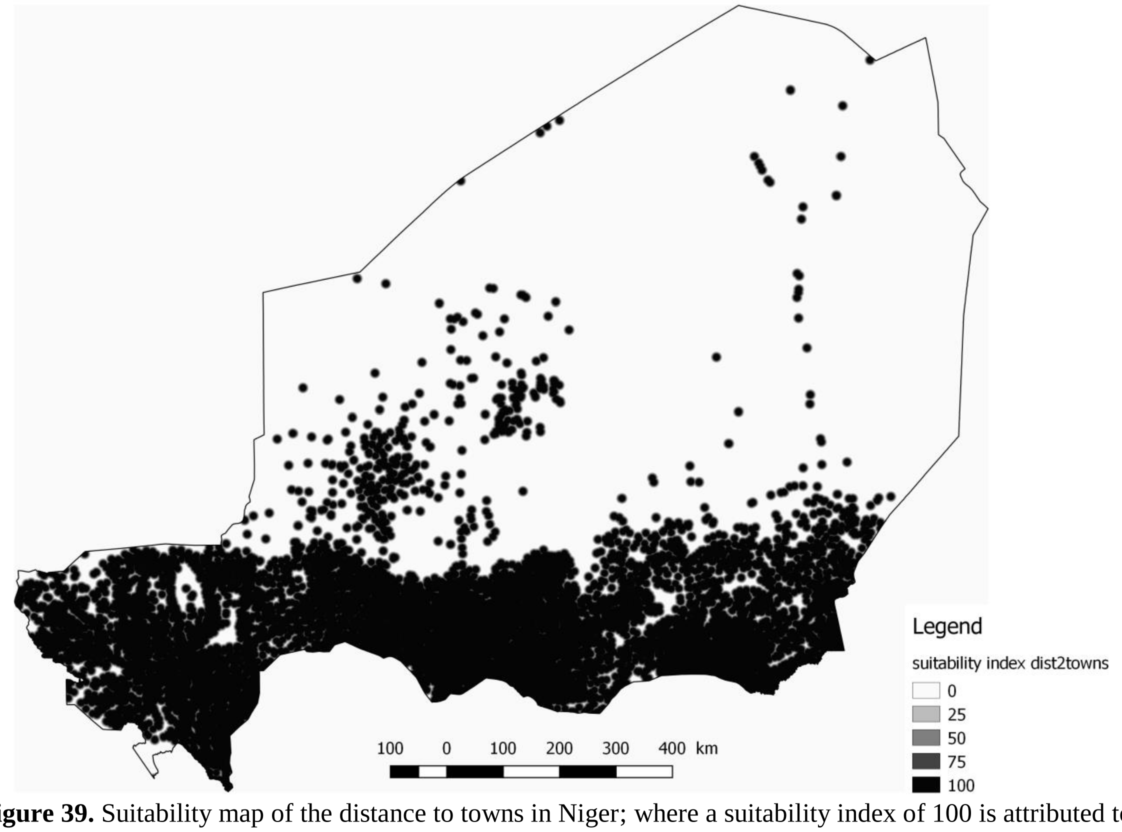

Figure 39. Suitability map of the distance to towns in Niger; where a suitability index of 100 is attributed to distances to towns below or equal to 5 km; where a suitability index of 0 is given to distances to towns above 10 km; and where suitability indexes in-between 0 and 100 are given to distances to towns between 5 and 10 km.

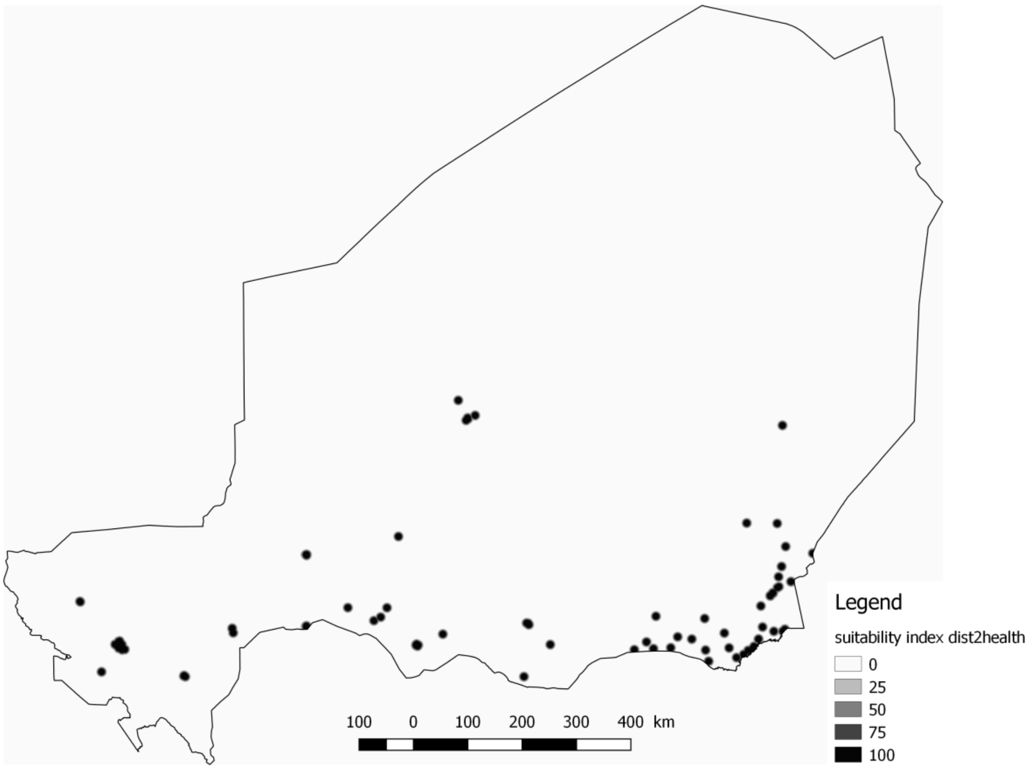

Figure 40. Suitability map of the distance to health infrastructures in Niger; where a suitability index of 100 is attributed to distances to health facilities below or equal to 5 km; where a suitability index of 0 is given to distances to health facilities above 10 km; and where suitability indexes in-between 0 and 100 are given to distances to health facilities between 5 and 10 km.

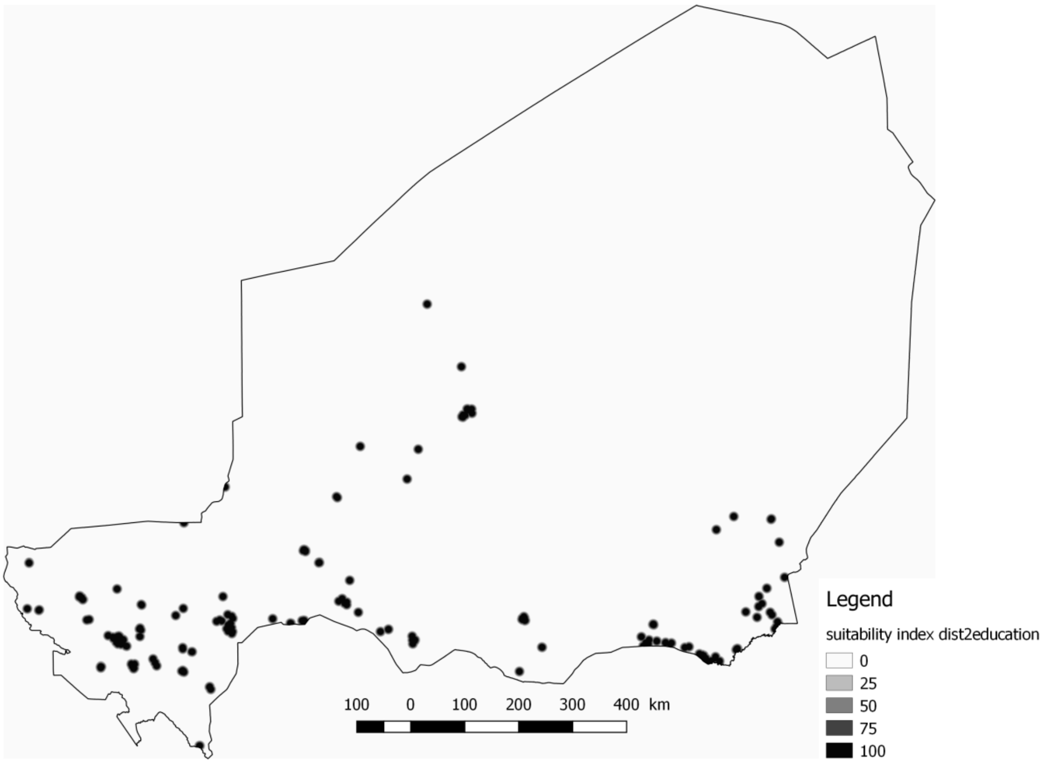

Figure 41. Suitability map of the distance to education infrastructures in Niger; where a suitability index of 100 is attributed to distances to education facilities below or equal to 5 km; where a suitability index of 0 is given to distances to education facilities above 10 km; and where suitability indexes in-between 0 and 100 are given to distances to health facilities between 5 and 10 km.

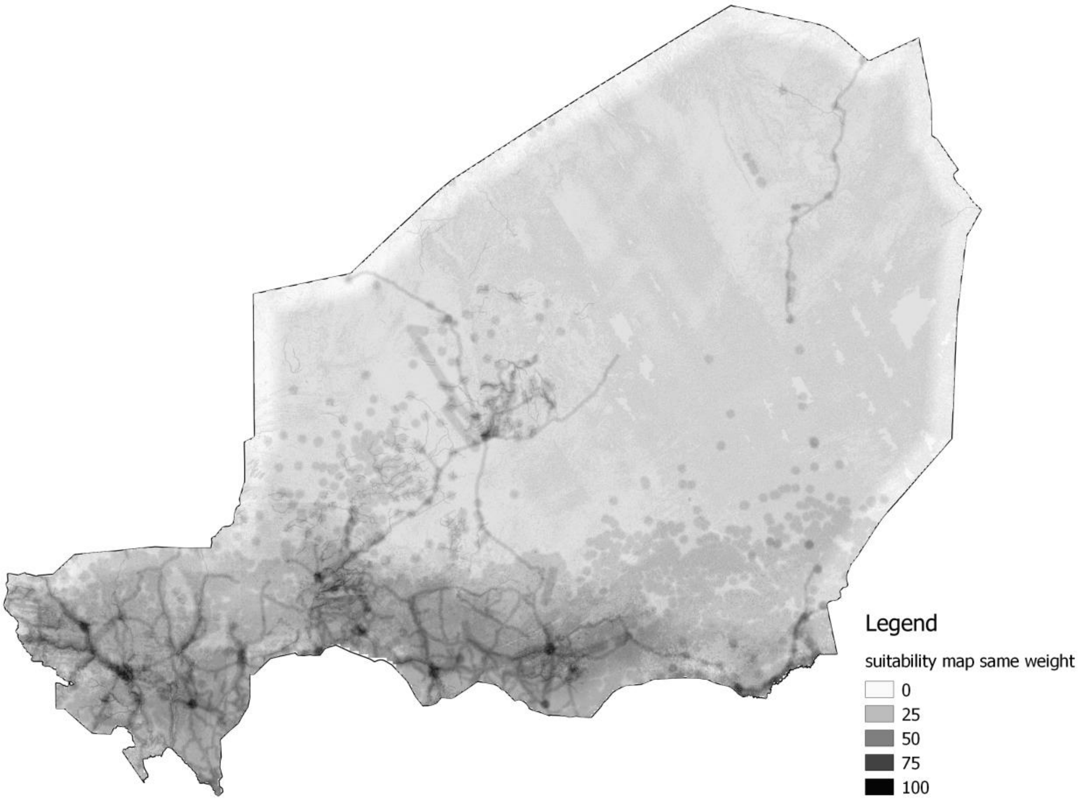

Figure 42. Suitability map where pixels equal to 100 correspond to the most suitable sites whereas pixels with a value of 0 correspond to unsuitable sites and pixels with a suitability index between 0 and 100 translate a more or less suitable site. Here, all the criteria have the same weight. The list of the suitability criteria taken into account are in the table 3 presented above: precipitations (mm/year), distance to water resources (m), slope (%), AGBP (kg/ha), distance to boundaries (km), distance to roads (km), distance to electric network (km), distance to towns (km), distance to health infrastructure (km) and education infrastructure (km).

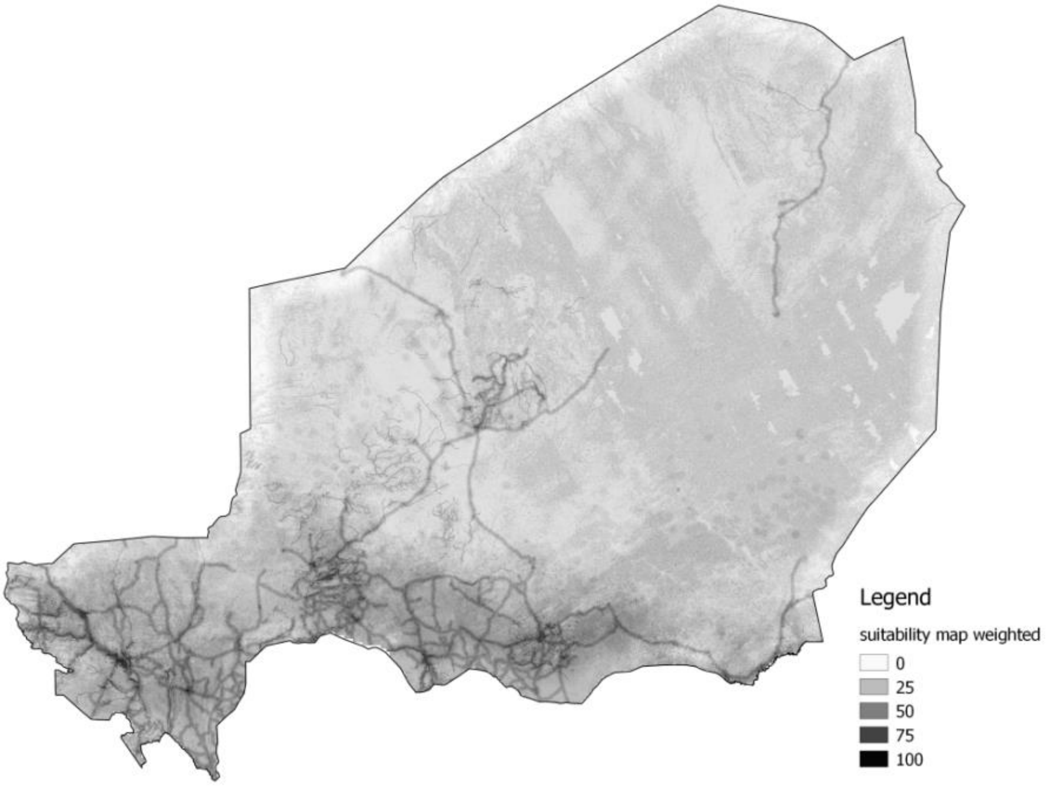

Figure 43. Suitability map where pixels equal to 100 correspond to the most suitable sites whereas pixels with a value of 0 correspond to unsuitable sites and pixels with a suitability index between 0 and 100 translate a more or less suitable site. Here, weights are attributed to all the criteria, as the table 5 shows. The list of the suitability criteria taken into account are in the table 3 presented above: precipitations (mm/year), distance to water resources (m), slope (%), AGBP (kg/ha), distance to boundaries (km), distance to roads (km), distance to electric network (km), distance to towns (km), distance to health infrastructure (km) and education infrastructure (km).