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Contribution of Remote sensing to water management via WAPlugin and the WaPOR database

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ملخـــــص في ظل التحديات المتزايدة المرتبطة بندرة الموارد الطبيعية، ولا سيما الأراضي والمياه، ووسط تنامي الطلب العالمي على الغذاء نتيجة النمو السكاني المتسارع، تبرز الحاجة الملحّة إلى تبني أدوات وتقنيات مبتكرة تعزز من كفاءة إدارة الموارد المائية وتحسين إنتاجية نظم الري. في هذا السياق، تتيح قاعدة بياناتWaPOR ، التابعة لمنظمة الأغذية والزراعة للأمم المتحدة(FAO) ، والمبنية على بيانات الاستشعار عن بعُد المفتوحة المصدر، إمكانات واعدة لرصد أداء الري وتحديد مجالات التدخل لتحسينه. تهدف هذه الدراسة إلى تقييم أداء أنظمة الري وتحليل إنتاجية المياه والأراضي في سهل متيجة بالجزائر، بالاعتماد على بيانات الإصدار الثالث (V3) من قاعدة WaPOR بدقة 02 متزًا، خلال الفترة الممتدة من 0202 إلى 0202. تم تنفيذ التحليل باستخدام المكون الإضافي WAPlugin ضمن بيئة برنامجQGIS ، مع التركيز على مؤشرات رئيسية تشمل كفاءة استخدام المياه وإنتاجية المحاصيل.

أظهرت النتائج الأولية تباينًا واضحًا في توزيع المياه عبر السنوات، إلى جانب تفاوت في مؤشرات الأداء الزراعي، مما يعكس ضعفًا نسبيًا في إدارة الموارد المائية ضمن منطقة الدراسة. وتؤكد هذه النتائج الحاجة إلى تطوير استراتيجيات تكاملية ومستدامة لتحسين كفاءة استخدام المياه وتعزيز الإنتاج الزراعي في ظل الظروف المناخية والبيئية الحالية.

الكلمات المفتاحية : الكلمات المفتاحية: إدارة الموارد المائية ،WaPOR، الاستشعار عن بعُد، إنتاجية المياه، أنظمة الري.

ABSTRACT

In light of the growing challenges associated with the scarcity of natural resources particularly land and water and amid the increasing global demand for food driven by rapid population growth, there is an urgent need to adopt innovative tools and techniques that enhance the efficiency of water resource management and improve the productivity of irrigation systems. In this context, the WaPOR database, developed by the Food and Agriculture Organization of the United Nations (FAO) and based on open-access remote sensing data, offers promising potential for monitoring irrigation performance and identifying areas for improvement. This study aims to assess the performance of irrigation systems and analyze water and land productivity in the Mitidja Plain, Algeria, using the third version of the WaPOR database at a spatial resolution of 20 meters, covering the period from 2018 to 2024. The analysis was carried out using the WAPlugin within the QGIS environment, with a focus on key indicators related to water use efficiency and crop productivity. Preliminary results revealed significant variations in water distribution across the years, along with disparities in agricultural performance indicators. These findings indicate a relative weakness in water resource management within the study area and highlight the need for integrated and sustainable strategies to enhance water use efficiency and boost agricultural production under current climatic and environmental conditions.

Keywords: Water resource management, WaPOR, remote sensing, water productivity, irrigation systems.

RÉSUMÉ

Face à la raréfaction croissante des ressources naturelles, notamment terres et eau, et à la hausse de la demande alimentaire due à la croissance démographique, il devient urgent d'adopter des outils innovants pour optimiser la gestion de l'eau et la productivité des systèmes d'irrigation.

Dans ce contexte, la base de données WaPOR, développée par la FAO et fondée sur des données de télédétection en libre accès, offre un potentiel intéressant pour le suivi des performances de l'irrigation et l'identification des axes d'amélioration. Cette étude évalue la performance des systèmes d'irrigation et la productivité de l'eau et des terres dans la plaine de la Mitidja (Algérie), en utilisant la version 3 de WaPOR, avec une résolution spatiale de 20 m, sur la période 2018–2024.

L'analyse, menée via le module WAPlugin dans QGIS, porte sur des indicateurs clés liés à l'efficacité de l'eau et à la productivité des cultures. Les résultats préliminaires révèlent des variations annuelles marquées dans la distribution de l'eau et des disparités dans les performances agricoles, indiquant une gestion perfectible de l'eau dans la zone. Cela souligne la nécessité de stratégies durables et intégrées pour améliorer l'efficacité hydrique et la production agricole dans le contexte climatique actuel.

Mots-clés : Gestion des ressources en eau, WaPOR, télédétection, productivité de l'eau, systèmes d'irrigation.

Keywords Cloud

Acknowledgements

Dedication

إلى أرواح الشهداء الخالدين الذين جاهدوا بأرواحهم في سبيل فلسطين...
إلى كل مقاوم تحت الأرض وفوقها نهدي كل إنجاز صغير أو كبير قمنا أو
إلى أمثالكم ترفع القبعة وإنا على دربكم لسائرين... سنقوم به

أريد أن أهدي هذا الجهد إلى والدي الذي كان يشجعني بحماس في كل مرة كنت
على وشك الاستسلام، لذلك كنتُ أخشى أن أفقد حماسه أكثر مما كنت أخشى
فشلي , ولأنني أعلم أنه نتاج الخطوات التي اتخذتها لنا يا أبي.
نتاج العمر الذي قدمته لكي ترانا الأفضل دائما, نتاج كل طريق صعب مشيته
أمامنا لتمهده لنا.
ولوالدتي .. التي وضعت ثقتها في مركز وجودي،
قطعت على نفسي عهدًا بأنني لن أخذلها أبدا طالما عشت.

أريد أن أفصح لكم عن اعتزازي بكوني ابنتكم.

إخوتي وأخواتي .. ، ولعائلتي .. أنا ممتن لكم جميعا.

الى ذلك اليوم...

Summary

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List of Abbreviations

WaPOR : Water Productivity through Open-access of Remotely sensed derived data
WAPlugin : Water Accounting Plugin
FAO : Food and Agriculture Organization
RS : Remote Sensing
WP : Water Productivity
UWC : Uniformity of Water Consumption
RWD : Relative Water Deficit
TBP : Total Biomass Production
CWP : Crop Water Productivity

General Introduction

General Introduction

Water covers approximately 71% of Earth's surface and is its lifeblood. It's indispensable for maintaining ecological balance, supporting biodiversity, and regulating climate. Its uses extend to drinking, agriculture, industry, and energy production, making it an essential resource for human existence. Water resources are a fundamental pillar of agricultural development, as irrigation and improved crop productivity critically depend on them. With increasing population growth and expanding agricultural activities, pressure on water resources is escalating, especially in arid and semi-arid regions. This makes effective water management in this sector crucial for achieving food security and the sustainability of natural resources, particularly since agriculture accounts for about 70% of global water consumption. **(UNESCO, 2024)**

To address these global challenges, several water-related goals have been integrated into the Sustainable Development Goals (SDGs) within the 2030 Agenda, such as Goal 6 (ensuring the availability and sustainable management of clean water and sanitation for all) and Goal 14 (conserving and sustainably using oceans, seas, and marine resources). The use of inefficient traditional irrigation techniques, coupled with climate change and rainfall variability, exacerbates the challenges facing water resource management. Therefore, adopting effective strategies to improve water use in agriculture has become essential, including the application of modern technologies, water reuse, and consumption monitoring through remote sensing systems. Integrated Water Resources Management (IWRM) emerges as an urgent necessity to meet current needs without compromising the rights of future generations. This effective management requires accurate and reliable data for monitoring water resources, assessing their usage patterns, and anticipating future scenarios.

Historically, studies relied on direct field tools and methods (such as manual measurements and modeling), which suffered from significant limitations, including high human error rates, difficulty accessing remote areas, lengthy completion times, and an inability to track real-time changes. These challenges highlighted the pressing need to adopt more advanced and flexible technologies. Within this framework, remote sensing technologies have emerged as a revolutionary tool, bringing about a qualitative shift in natural resource monitoring and analysis. These technologies have proven effective in providing precise tools for monitoring and analyzing the distribution and use of water resources across time and space. Among the most notable initiatives in this field is "WaPOR," a portal for accessing remote sensing data developed by the Food and Agriculture Organization of the United Nations (FAO). This portal provides high-resolution, near real-time data on agricultural land productivity and water consumption in Africa and the Middle East. This data can be extracted using pywapor or through the WAPlugin add-on in QGIS, enabling the calculation of vital indicators that significantly contribute to the integrated and sustainable assessment and management of water resources . **(United Nations, 2023)**

Chapter I Literature Review & Background
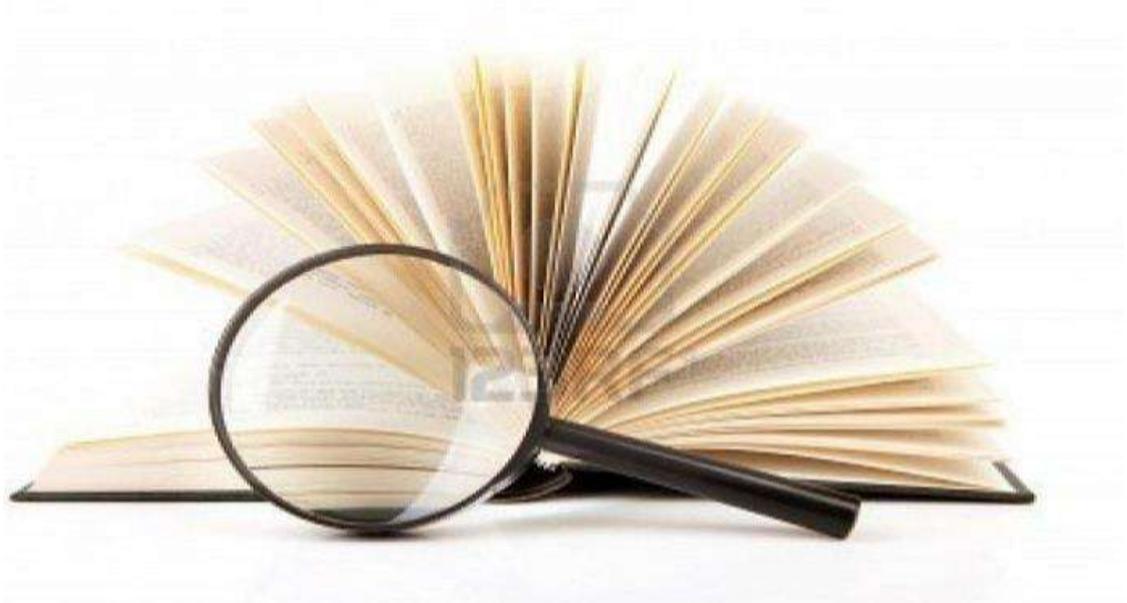
Chapter I: Literature Review & Background

I.1. Introduction

The increasing scarcity of water has become a growing challenge, necessitating improved management to ensure sustainable development. In this context, focusing solely on hydrological aspects and water quality is no longer sufficient; it has become essential to link water use with agricultural production outputs in order to measure the true efficiency of this vital resource's consumption. The importance of assessing water use efficiency emerges through measuring the amount of water utilized to produce biomass or crop yield, contributing to a deeper understanding of how water can be better managed and its productivity enhanced (García-Tejero & Durán-Zuazo, 2022)

Water productivity and irrigation performance have traditionally been assessed using conventional methods based on field measurements and modeling, while these methods can provide detailed local data, they are often labor-intensive, time consuming, and costly especially when applied over large agricultural areas.

However, recent technological advancements have introduced more accurate and reliable approaches, most notably the use of remote sensing technologies. Remote sensing offers vast capabilities for monitoring irrigation efficiency and water productivity over large areas with high temporal frequency, opening new horizons for improving water resource management. (Mati et al., 2019) .

I.2. Assessing water productivity and irrigation performance:
I.2.1 Water productivity (WP) and irrigation performance (IP)

Water productivity is defined as the amount of agricultural output, whether in terms of total biomass productivity or crop yield, achieved per unit of water used (Verschuren, Schults, & de Klerk, 2022).

This indicator is employed to assess the efficiency of water use in agriculture. It serves as a fundamental tool in water resource management, particularly in regions experiencing water scarcity, as it contributes to improving the allocation and utilization of water in a more efficient and sustainable manner. This indicator is directly influenced by the performance of irrigation systems.

Irrigation performance refers to how effectively and efficiently an irrigation system delivers and distributes water to crops. It's directly impacted by factors such as the uniformity of water application, the minimization of losses due to evaporation or seepage, and the system's ability to meet crop water requirements without waste. Highly efficient irrigation systems reduce these losses, thereby enhancing agricultural water productivity, whereas poor irrigation performance leads to significant water losses and reduced agricultural returns(FAO, 2012)

I.2.2. Traditional methods used for WP and IP evaluation:

There are several methods for assessing water productivity and irrigation performance, varying according to the required level of accuracy, the size of the study area, and the type of available data. Among these methods, the following are prominent:

a . Field Measurements:

Conventional methods for assessing water productivity rely on field data collection, which includes measuring water inputs and crop outputs. Irrigation water is measured using flow meters (debit meters) installed on the irrigation network, while rainfall is recorded using either a traditional rain gauge or an automatic rainfall recorder(Kay, 2001)

Regarding crop output, the economic yield is determined by harvesting a representative sample area (e.g., one square meter), accurately weighing it, and then extrapolating the value to the hectare scale. As for the total biomass, the entire plant is uprooted from the same sample area (one square meter), then oven-dried at 65°C until a constant weight is reached, weighed, and scaled up to a per-hectare value. This procedure is applied only to the sample, not the entire field. These values are then generalized to represent the entire field, assuming that the sample area is representative of overall field conditions. This method has limited accuracy due to spatial variability within the field (FAO. 2018a)

Water productivity is calculated as follows   (FAO, 2018b ; Verschuren, Schults, & de Klerk, 2022)

1 - Biomass Water Productivity Equation Using Total Biomass :

This measures the amount of biomass produced per unit of water consumed.

$$\textbf{BWP} = \frac{\text{TBP}}{\text{WR}}$$

(1)

Where:

- BWP : Biomass Water Productivity (kg/m³)
- TBP: Total Biomass Produced (kg/ha)
- WR: Water used (m³/ha)

2 - Crop Water Productivity Basic Equation Using Yield :

This indicator measures the amount of biomass (or crop yield) produced per unit of total water consumed.

$$\textbf{CWP} = \frac{\text{Y}}{\text{WR}}$$ Where:

(2)

- CWP: Water Productivity (kg/m³)
- Y: Yield (kg/ha)
- WR: Water used (m³/ha)

(FAO, 2018b ; Verschuren, Schults, & de Klerk, 2022) **b.**

Modeling:

Models are used to simulate agricultural and water-related processes through mathematical equations based on inputs such as weather, soil and crop data. These models allow for dynamic analysis of water productivity and irrigation performance under different scenarios (FAO. 2018a).

Models such as AquaCrop are used to:

- Simulate crop growth in response to water availability, temperature, and soil properties over time.
- Calculate biomass production, yield, and evapotranspiration.
- Use equations that describe the interactions between the plant, soil, and water(FAO, 2023)

The CROPWAT model is used to:

- Estimate crop water requirements.
- Develop appropriate irrigation schedules.
- Rely on climatic data and the Penman Monteith equation. (Clarke,1998.)

These models are applied at multiple spatial scales, ranging from individual agricultural plots (field level) to large farming regions, depending on the accuracy and comprehensiveness of the input data. From a temporal perspective, they are capable of simulating processes over various timeframes from daily irrigation cycles to long term assessments of climate impacts over several years(FAO, 2023 ; Clarke,1998.)

However, the effectiveness of modeling is limited by several factors. Most importantly, it heavily depends on high quality, accurate, and up to date input data, which is often not consistently available, especially in developing or remote areas. Additionally, models involve numerous assumptions and simplifications that may not accurately capture the complexity and variability of natural systems (Kephe & Ayisi, 2021).

I.3. Role of remote sensing in agriculture and water management

Remote sensing is a technology used to observe and study the characteristics of the Earth's surface without direct physical contact. It operates by collecting and analyzing data related to electromagnetic energy associated with objects or surfaces. This is typically accomplished using sensors mounted on satellites, and it is widely applied to monitor environmental factors such as water resources, vegetation cover, soil conditions, and surface temperatures(Merdaci, 2020). **a . Sensor Operation Mechanism:**

- Active Remote Sensing: The device emits a signal (such as radar or LiDAR) and then receives the reflected signal that bounces back from the target surfaceas illustrated in Figure 1 (NASA Earthdata , n.d . ; Merdaci, 2020)

- Passive Remote Sensing: Relies on detecting natural radiation such as sunlight or thermal energy emitted or reflected by objects. It primarily captures energy that has been absorbed and re emitted (especially in the thermal spectrum) as illustrated in Figure 1 (NASA Earthdata , n.d . ; Merdaci, 2020)
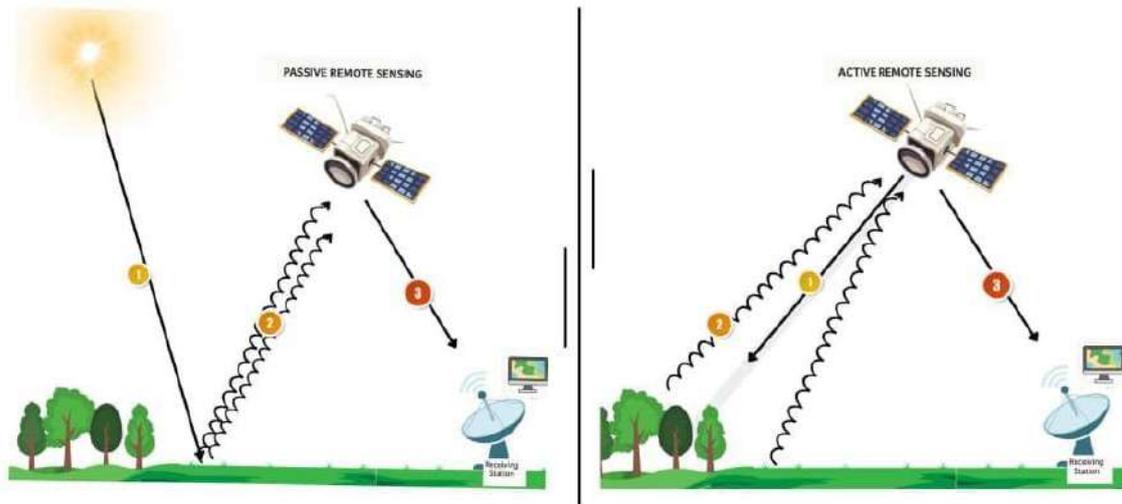
Figure 1 : Active and Passive Remote Sensing

b.   Electromagnetic Spectrum

The electromagnetic spectrum includes all types of electromagnetic radiation, which are arranged according to their frequency or wavelength. Each type of this radiation has unique characteristics and specific applications in the field of remote sensing, particularly in the context of water resources management. Electromagnetic waves range from short wavelength X rays to long wavelength radio waves, as shown in Figure 2, and each region of the spectrum serves a specific role in observation and sensing.
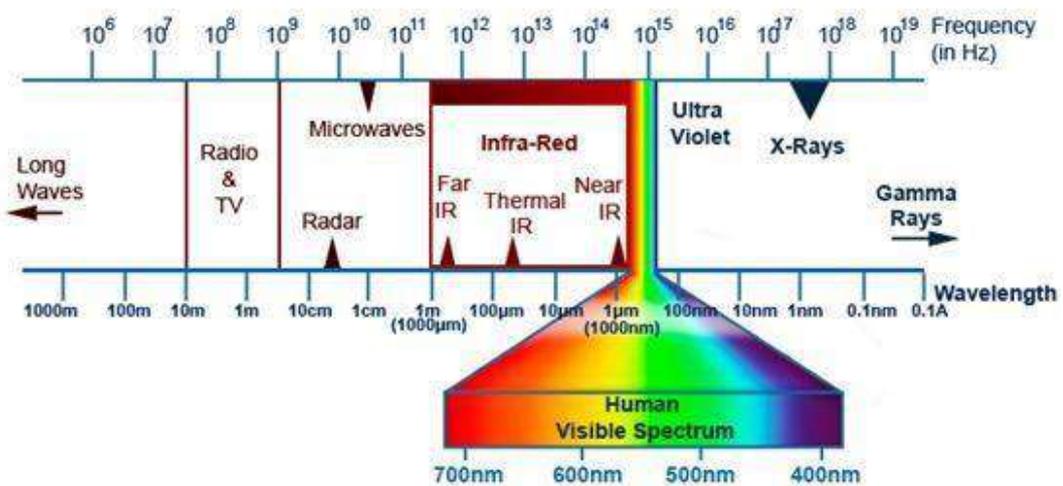
Figure 2 : The Electromagnetic Spectrum
Source:Quizlet(https://quizlet.com/419113416/metoder-flash-cards)

Table 1 summarizes the different parts of the electromagnetic spectrum, their approximate wavelengths, and their corresponding applications in the field of water resources management.
(NASA, n.d)

Table 1 : Applications of Electromagnetic Spectrum Bands in Water Resources Management

Electromagnetic Spectrum	Approximate Wavelength	Applications in Water Resources Management	References
X-rays	0.01 – 10 nm	Used to analyze soil mineral composition and detect heavy metals and nutrients affecting soil fertility and plant health.	(Alghamdi et al., 2025)
Ultraviolet (UV)	100 – 400 nm	Used to study solar radiation effects on plants and analyze upper atmospheric layers (e.g., ozone) relevant to agricultural climate.	(Valentakristin et al., 2020)
Visible Light	400 – 700 nm	Monitoring vegetation cover through multispectral imaging and assessing plant health using indices like NDVI.	(Su et al., 2017)
Near Infrared (NIR)	700 – 1300 nm	Evaluating plant health, measuring chlorophyll content, and detecting water stress and soil moisture.	
Mid Infrared (MIR)	1300 – 3000 nm	Analyzing physical and chemical soil properties, including organic matter and moisture content	
Thermal Infrared (TIR)	3000 – 14000 nm	Measuring land surface temperature, evaporation, and detecting thermal changes in vegetation and soil.	(Jones et al., 2011)
Microwaves	1 mm – 1 m	Sensing soil moisture, groundwater, and monitoring vegetation even under clouds or at night using radar (SAR).	
Radio Waves	> 1 m	Indirectly used for precise positioning (GPS) to map water resources and irrigation infrastructure.	

I.3.1 Advantages and disadvantages of remote sensing:

Remote sensing has several advantages, but it also has some disadvantages. The table below illustrates these advantages and disadvantages in detail (SkyWatch, n.d.)

Table 2 : Advantages and disadvantages of remote sensing

Advantages	Disadvantages
Covers large areas in a short time	Accuracy may be lower compared to direct field measurements
Provides consistent and repeated (temporal) data	Requires advanced image processing and interpretation
No need for physical presence in the field	High cost of some images or equipment
Access to remote or hard-to-reach areas	Image quality can be affected by clouds or weather conditions
Enables long-term monitoring of environmental and agricultural changes	Requires technical expertise to interpret data
Supports modeling and decision-making processes	Some sensors are limited during night-time or low-light conditions

Given the success of remote sensing (RS) data in water productivity (WP), many providers and platforms have been developed for this purpose, including the FAO's WaPOR (Water Productivity through Open access of Remotely sensed derived data) portal, which is the subject of our study.

I.4. The FAO WaPOR dataset

I.4.1 History and development of WaPOR by FAO

WaPOR (Water Productivity through Open-access of Remotely sensed derived data) is a project launched by the Food and Agriculture Organization (FAO) in 2009, with support from the Government of the Netherlands, aimed at monitoring agricultural water productivity in Africa and the Near East using satellite data (FAO, n.d.-b)

- **2009–2016: Foundation and Methodological Development**

The project began collecting data in 2009, focusing on developing a reliable methodology to produce data on evapotranspiration, biomass productivity, and land use. In October 2016, a workshop was held to review the methodology, which led to the release of the first beta version of the database in April 2017.

- **2018: Official Release of Version 1.0**

After independent evaluations by institutions such as IHE-Delft and the University of Twente, version 1.0 was launched in June 2018, featuring improvements in user interface and calculation methods. The improvements included more accurate actual evapotranspiration calculations, separation of evaporation components, and enhanced soil moisture estimations.(FAO, 2020a)

- **2019: Release of Version 2.0**

Version 2.0 was launched in June 2019 with enhancements in data quality, such as the use of minimum and maximum temperature data to calculate reference evapotranspiration, and updated crop light use efficiency values. It also included improvements in land cover layers and biomass productivity estimates.(FAO, 2020b)

- **2023: Release of Version 3.0** was released in October 2023, expanding global data coverage and adding new variables such as root zone soil moisture, while incorporating more recent sensors like Sentinel-2 and VIIRS. Processing algorithms were also improved, including the use of artificial intelligence techniques to enhance data quality.(FAO, n.d.-c).

I.4.2 Data description of the WaPOR

WaPOR include extensive data sets that can be categorized into:

- **Water-related data:** This includes variables such as Evaporation, Transpiration, Interception, Actual Evapotranspiration and Interception (AETI), Reference Evapotranspiration (ET$_0$), Precipitation, and Relative Soil Moisture, which provide essential insights into water availability and its use in agriculture.

- **Crop production data:** This category encompasses Net Primary Productivity (NPP), Total Biomass Production, Water Productivity, Economic Water Productivity, Phenology, and Harvest Index, focusing on crop growth, yield, and efficiency.
- **Land use data:** This includes Land Cover Classification and Land Use, which are used to analyze the types and distribution of land across various regions.
- **Climatic data:** Variables such as Land Surface Temperature, Solar Radiation, Vegetation Cover, and NDVI are included in this category, helping to understand the climate and vegetation conditions affecting agriculture.
- **Composite indicators:** Land Productivity and Gross Water Productivity are key indicators that combine various data to evaluate overall agricultural performance and water use efficiency.

Details about these datasets and their temporal and spatial resolution is presented in the table 3 (Lillesand et al., 2015)

Table 3 : WaPOR Dataset Structure by Level, Spatial Resolution, and Temporal Coverage

Level	Scope	Spatial Resolution	Data Products Available	Time Coverage
Level I	Global	300 meters	- Actual Evapotranspiration and Interception - Evaporation - Precipitation - Net Primary Production - Reference Evapotranspiration - Relative Soil Moisture - Total Biomass Production - Transpiration - Interception - Gross / Net Biomass Water Productivity - NDVI Quality	Annual, Dekadal, Monthly, Daily
Level II	Continental / National	100 meters	- Actual Evapotranspiration and Interception - Evaporation - Net Primary Production - Relative Soil Moisture - Transpiration - Net Biomass Water Productivity - Interception - NDVI Quality	Annual, Dekadal, Monthly

			- Actual Evapotranspiration and Interception	
Level III	Sub-national	20 meters	- Evaporation - Net Primary Production - Transpiration - Net Biomass Water Productivity - Interception - Relative Root Zone Soil Moisture - NDVI Quality	Annual, Dekadal, Monthly

I.4.3 Accessing WaPOR Data

WaPOR data can be accessed through two main interfaces: the official web portal and the dedicated QGIS plugin (waplugin)

I.4.4. WaPOR Official Portal

The official WaPOR portal (https://wapor.apps.fao.org)provides a user-friendly web interface that allows users to visualize satellite derived agricultural data. Through interactive maps and filtering options, users can select specific countries, regions, or time periods to explore variables useful for integrated resource analysis and management. For more advanced and controlled access to the data, familiarity with the Python programming language is recommended, as it enables users to download and analyze the data programmatically via the WaPOR API.

I.4.5. WAPlugin

b.1 History of WaPLUGIN

The development of WaPLUGIN began in 2020 during the WaterPIP Hackathon, an innovation challenge organized by the IHE Delft Institute for Water Education The plugin was designed to facilitate access to satellite-based water productivity data from the FAO WaPOR portal and integrate this data within the QGIS environment to support agricultural water management (IHE Delft, 2020).

The first official release, WaPLUGIN 1.0, came out in October 2021 and was made available through the official QGIS Plugin Repository. It introduced key features such as downloading WaPOR data directly into QGIS and computing indicators.

In March 2022, WaPLUGIN 2.0 was released during the Open Data Day event, focusing on performance improvements and bug fixes. Later, in September 2024, WaPLUGIN 3.0.3 was launched, integrating with WaporDL, improving user navigation across WaPOR data levels, and adding new analytical indicators (YouTube, 2022, ; QGIS Plugin Repository, 2024).

b.2 Downloading the Data:

Before starting to load the data, WAPlugin must first be added to QGIS. This can be done by:

1. Going to the Plugins menu in QGIS.
2. Selecting Manage and Install Plugins.
3. In the search box, type WAPlugin, then install it by clicking Install.

Data from the WaPOR platform can be downloaded using the WAPlugin in QGIS by selecting the area of interest in one of two ways:

- By importing a ready-made shapefile that defines the desired area.
- Or by using the QGIS Canvas Extent option.

After selecting the area, the desired time period and spatial resolution (20 m, 100 m, 300 m) can be chosen before ownloading (Figure 3). WaPLUGIN enables access to both WaPOR V2 and V3datasets.
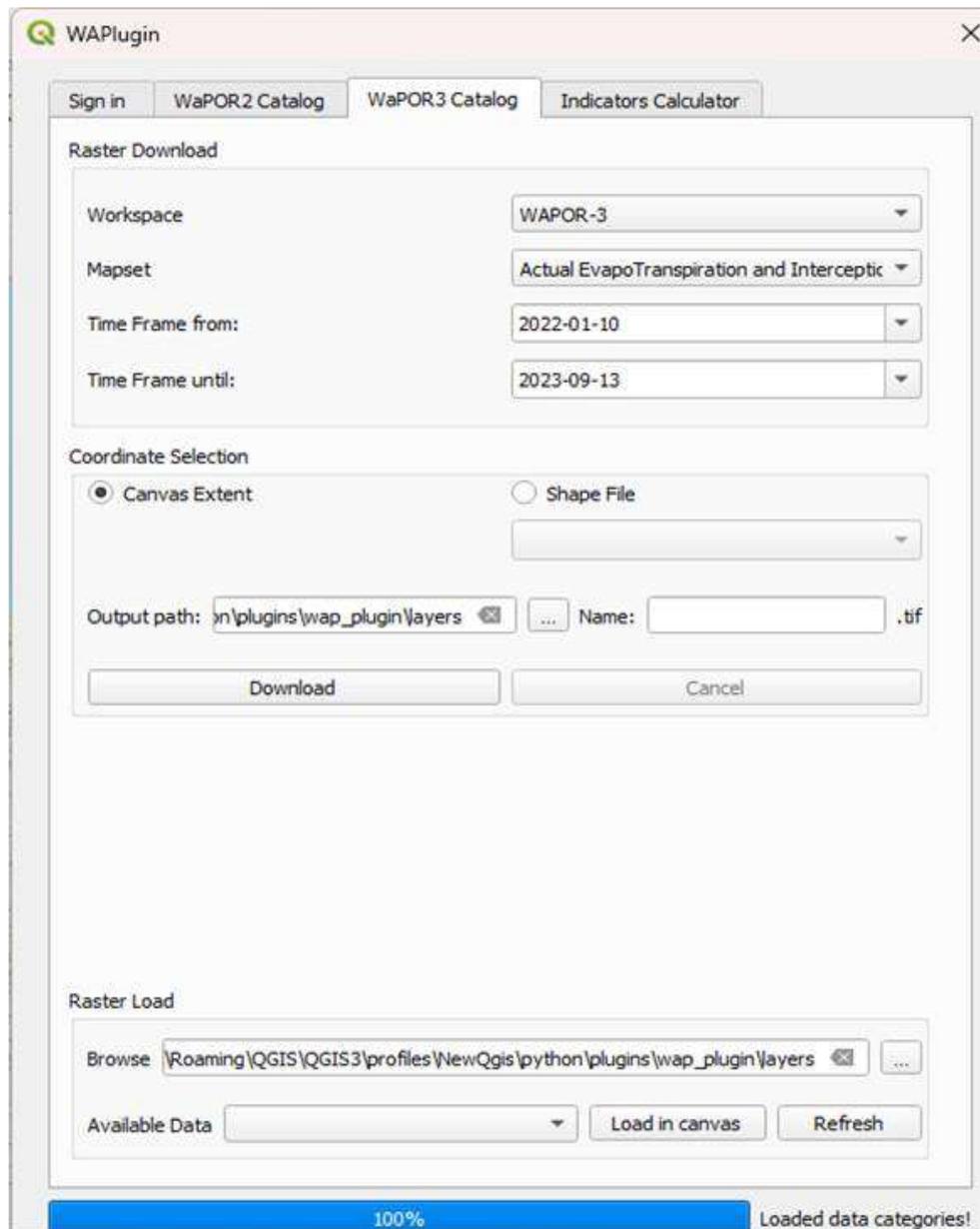

Figure 3 : Downloading the Data Used WAPlugin V3

b.3 Calculating Indicators Using WaPLUGIN:

WaPLUGIN enables calculating water productivity and irrigation performance indicators that are used to analyze water use efficiency in agriculture including:

- *Uniformity of Water Consumption*: Measures the evenness of water consumption distribution across the studied area.
- *Beneficial Fraction (BF):* Measures the portion of water that the crops effectively utilized.
- *Adequacy:* Assesses whether the available water is sufficient to meet the crop requirements.
- Relative water Deficit (RWD): Measures the gap between the water available from rainfall and the crop's water needs.
- Total Biomass Production (TBP): refers to the total amount of organic matter produced by crops per unit area, including leaves, stems, and sometimes roots and is typically expressed in kilograms per hectare (kg/ha) ☐ Biomass Water Productivity (BWP):
- Refers to the amount of biomass (such as leaves and stems) produced by crops per unit of water consumed (typically through evapotranspiration), usually expressed in kilograms per cubic meter of water (kg/m³).
- Yield: Measures the crop production relative to the water used.
- Crop Water Productivity (CWP): Assesses the efficiency of water use in crop production.

These indicators are used to evaluate water use efficiency and analyze the water productivity of crops. These indicators can be calculated directly within the QGIS environment using the data downloaded from WaPOR. Table 4 shows the different equations associated with each indicator..

Table 4 : Calculation of Indicators from WAPlugin

Indicator	Mathematical Relationship	Explanation of Variables
Uniformity of Water Consumption **(scalar value)**	$\text{equity} = (\dfrac{sd_{raster}}{mean_{raster}}) \times 100$	The analysis of uniformity was performed using the AETI raster layer. The type of data required is Actual Evapotranspiration and Interception, from which the standard deviation (sd_raster) and mean (mean_raster) were derivedsd_raster: Standard deviation obtained from the Raster. mean_raster: Mean obtained from the Raster. AETI: Actual Evapotranspiration and Interception.
Beneficial Fraction(Raster value)	$BF = (\dfrac{T}{AETI})$	T: Transpiration. AETI: Actual Evapotranspiration and Interception.

Adequacy(Raster value) **(Relative Evapotranspiration)**	$$AD = \left(\frac{ETa}{ETP}\right)$$	ETa: Actual Evapotranspiration and Interception. ETp: 95th percentile of AETI.
Relative Water Deficit (Raster value)	$$RWD = 1 - \left(\frac{AETI}{ETX}\right)$$	AETI: Actual Evapotranspiration and Interception. ETx: 99th percentile of the Raster.
Total Biomass Production (Raster value)	$$TBP = \left(\frac{(NPP * 22.22)}{1000}\right)$$	NPP: Net Primary Production. The value 22.222 is used to convert NPP in gC/m² to biomass production in kg/ha. To convert to ton/ha, the result is divided by 1000.
Yield (Raster value)	$$TBP = \left(\frac{1}{(1 - MC)}\right) \times fc_{(TBP)} \times AOT \times HI$$	MC: Moisture content (dry matter over fresh biomass). fc: Light use efficiency correction factor. AOT: Above-ground over total biomass production ratio. HI: Harvest Index. TBP: Total Biomass Production.
Crop Water Productivity (Raster value)	$$CWP = \left(\frac{Yield}{AETI}\right) \times 100$$	Y: Yield. AETI: Actual Evapotranspiration and Interception. The multiplication by 100 corrects the units to kg/m³ (from AETI in mm/season and yield in tons/ha).

I.5.Conclusion

In light of increasing water scarcity, evaluating water productivity and irrigation performance has become essential for achieving sustainable agricultural development. While traditional field-based methods and modeling tools such as AquaCrop and CROPWAT have long served this purpose, they face limitations in scalability and data availability. Remote sensing technologies now offer powerful alternatives, enabling large-scale, timely, and consistent monitoring of water use and crop production. The FAO's WaPOR platform, combined with the WAPlugin for QGIS, represents a significant advancement in this field, providing open-access satellite-derived data and analytical tools that support informed decision-making. These innovations mark a critical shift toward more efficient, data-driven management of agricultural water resources.

Chapter II
Presentation of the study area

Chapter II: Presentation of the study area

II.1. Introduction

The Mitidja Plain is one of the most important plain in northern Algeria due to its significant geographical, climatic, and agricultural characteristics. This vast plain is known for its fertile soils and abundant groundwater resources, making it a central hub for national agricultural activity. However, in the face of urban expansion, environmental pressures, and increasing water demand, major challenges have emerged related to water resource management and improving water use efficiency especially in the context of climate change and population growth.

II.2. Geographical and climatic context

a. Location and general description of the Mitidja Plain

The Mitidja Plain is located in the north of Algeria and is considered a vast coastal sub-plain surrounding the capital, Algiers. It spans an area of approximately 1,300 square kilometers, covering parts of four provinces: Tipaza, Blida, Algiers, and Boumerdes. The plain is characterized by a west-southwest/east-northeast orientation and extends longitudinally about 100 kilometers, with a width ranging from 8 to 10 kilometers. To the northeast, it is bordered by the Mediterranean Sea, to the west by the coastal region, to the south by the Blida mountain range with its towering peaks like the Sidi Abd el-Kader summit (1629 m), to the east by the Palestro mountains, and to the west by the Zahra mountains, where Mount Zgar stands at 1560 meters. Several valleys run through the plain, originating from the Atlas Mountains and extending vertically across the terrain, converging into a single stream towards the mouth, which enhances groundwater recharge and supports agricultural activities (Nemer, 2024.)
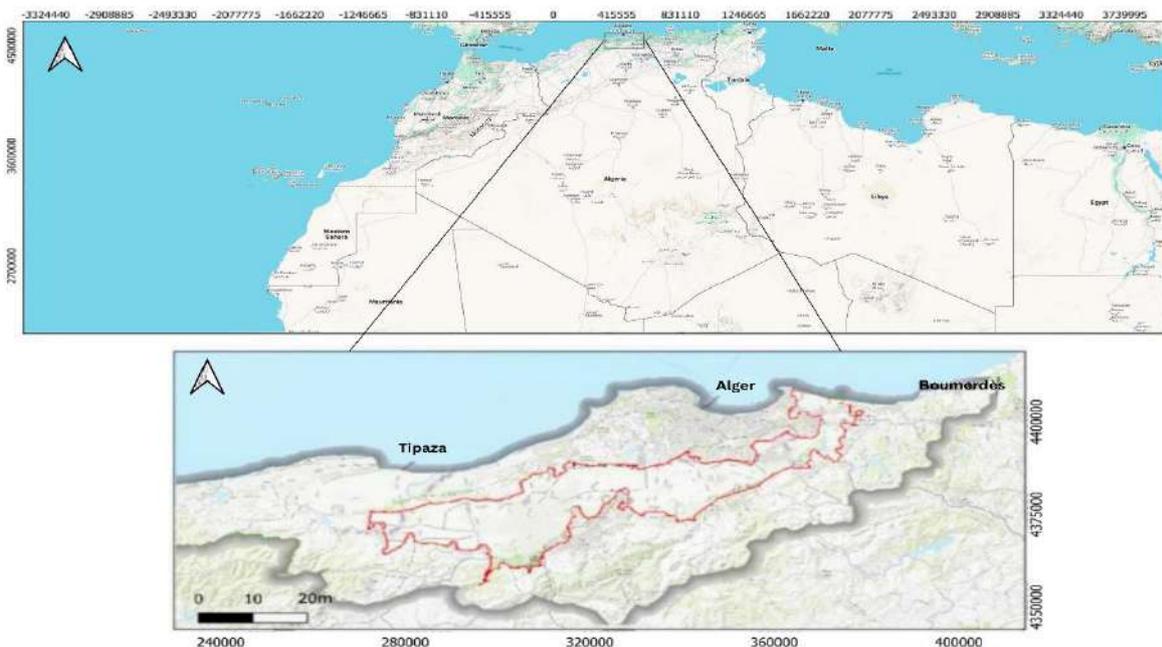

Figure 4 : Geographical location of the Mitidja

b . Climatic conditions

The Mitidja Plain has a semi-arid Mediterranean climate, characterized by hot and dry summers and mild, wet winters. Annual rainfall ranges between 600 and 1000 mm, with the majority of precipitation occurring between October and April.

Climatic data obtained from the meteorological stations of Dar El Beida, El Hamiz Dam, and Reghaïa show a gradient in rainfall distribution: it decreases in the northern coastal areas and increases progressively toward the south, in the direction of the Blidean Atlas, reflecting the region's topographical variation and its influence on precipitation patterns (Nemer, 2024, p. 67)

The average annual temperature is approximately 18.1°C, with significant seasonal variation. In summer, temperatures reach their peak during July and August, often exceeding 35°C.   In winter, temperatures drop to their lowest levels in December and January, ranging between 5°C and 7°C (Hameidia & Medjerabe ,2024 ; Nemer, 2024,)

II.3. Agricultural importance & water resources

II.3.1.Role of Mitidja in Algeria's agricultural sector

Mitidja enjoys a diverse economy that relies primarily on the agricultural sector.Over time, it has become a specialized agricultural production basin that meets the country's needs for various products. According to the General Agricultural Census of 2001, the Mitidja plain represented: 2.6% of the country's utilized agricultural area, which is approximately 217,936 hectares In 2010, it contributed between 40% and 50% of the national citrus production. Moreover, a significant portion of the plain's utilized agricultural area about 26.5% was dedicated to irrigated land (in 2015) (Nemer, 2024.)
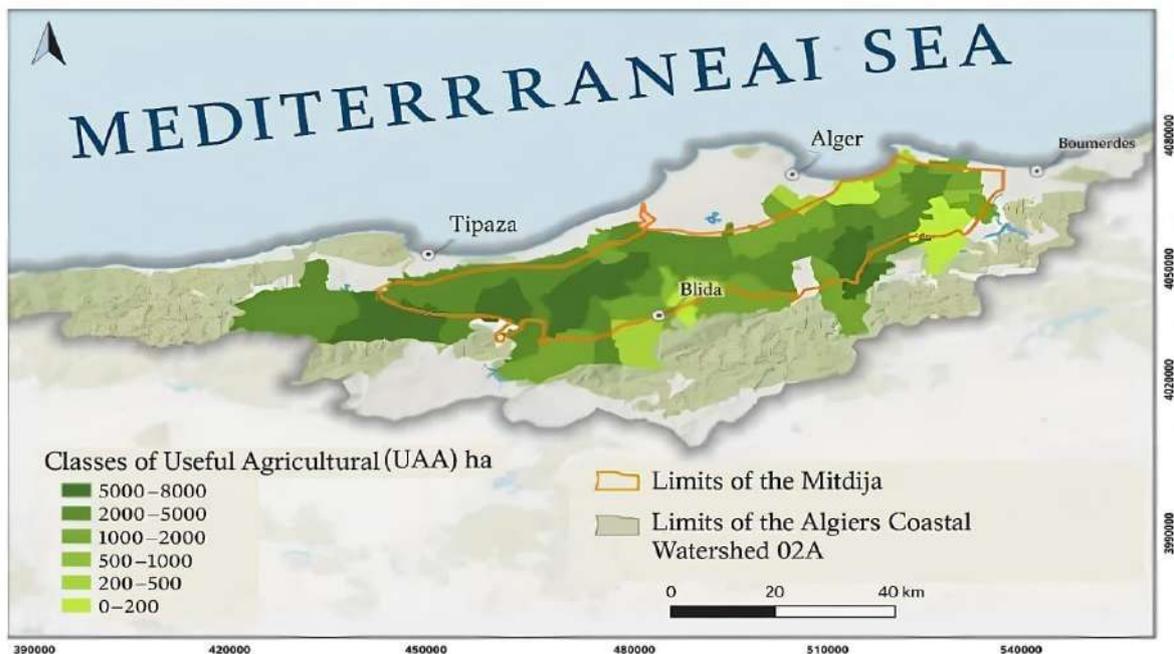

Figure 5 : Distribution of Utilized Agricultural Areas in the Mitidja Plain between 2005 and 2007 (INSID) (Translated into English by the author from (Nemer, 2024.)

II.3.2. Main crops

The Mitidja plain benefits from flat terrain, a rich topsoil layer, and favorable climatic conditions, making it a region with highly homogeneous and fertile soil. Around 75% of its area offers suitable conditions for a variety of crops, such as:

- Cereals
- Vegetables
- Fodder
- Citrus fruits ☐ Vineyards (grapes)

The eastern part of the plain is particularly known for vegetable cultivation, especially in the regions of: Boumerdès and Algiers (Nemer, 2024.)

A field survey was conducted in 2015 using a stratified random sample of 112 farmers from the western part of the Mitidja plain (West Mitidja II), which covers an area of approximately 38,500 hectares. This survey confirmed the presence and distribution of the main crops in the area. The table below presents the crop distribution percentages among the surveyed farms (Azzi et al., 2018):

Table 5 : Crop Distribution in the Western Part of the Mitidja Plain (Based on a Sample of 112 Farms, 2015) (Azzi et al., 2018)

Type of Crop	Percentage in the Sample
Citrus fruits	34.5%
Vegetables (horticulture)	41.8%
Fruit trees	13.3%
Cereals	10.4%

II.3.3. Water Availability: Hydrological and Hydrogeological Aspects

Water resources in the Mitidja Plain result from a complex interaction between surface water components (hydrological) and subsurface systems (hydrogeological), giving the region a diverse yet fragile water regime that is increasingly vulnerable to anthropogenic and climatic pressures.

Table 6 : Water resources in the Mitidja Plain

Surface water ressources	Groundwater
Main Wadis: El Harrach Wadi , Mazafran Wadi , Chiffa Wadi , Boumerdes Wadi , Isser Wadi , Boufarik Wadi , Meftah Wadi. Djemaa Wadi , Guer Wadi ,Sahel Wadi . **Main Dams:** Beni Amrane Dam , Boukourdane Dam , Keddara Dam , Oued El Chiffa Dam , Bouroumi Dam (El Moustakbel) , Hamiz Dam , Beni Slimane Dam , Ghrib Dam , Koudiat Acerdoune Dam	Aquifers : Quaternary shallow aquifer Astian deep aquifer

II.3.4. Irrigation systems

II.3.4.1 Distribution of Agricultural Areas and the Adopted Irrigation System in Mitidja

Mitidja Plain on the Algerian coast, which covers an area of more than 90,000 hectares, includes:

The Irrigated Perimeter of East Mitidja (IPEM): 17,000 hectares.

The Irrigated Perimeter of West Mitidja (IPWM): Composed of two sectors:

Sector 1 (IPWM S1): 8,600 hectares.

Sector 2 (IPWM S2): 15,600 hectares.(Chabaca et al., 2014)

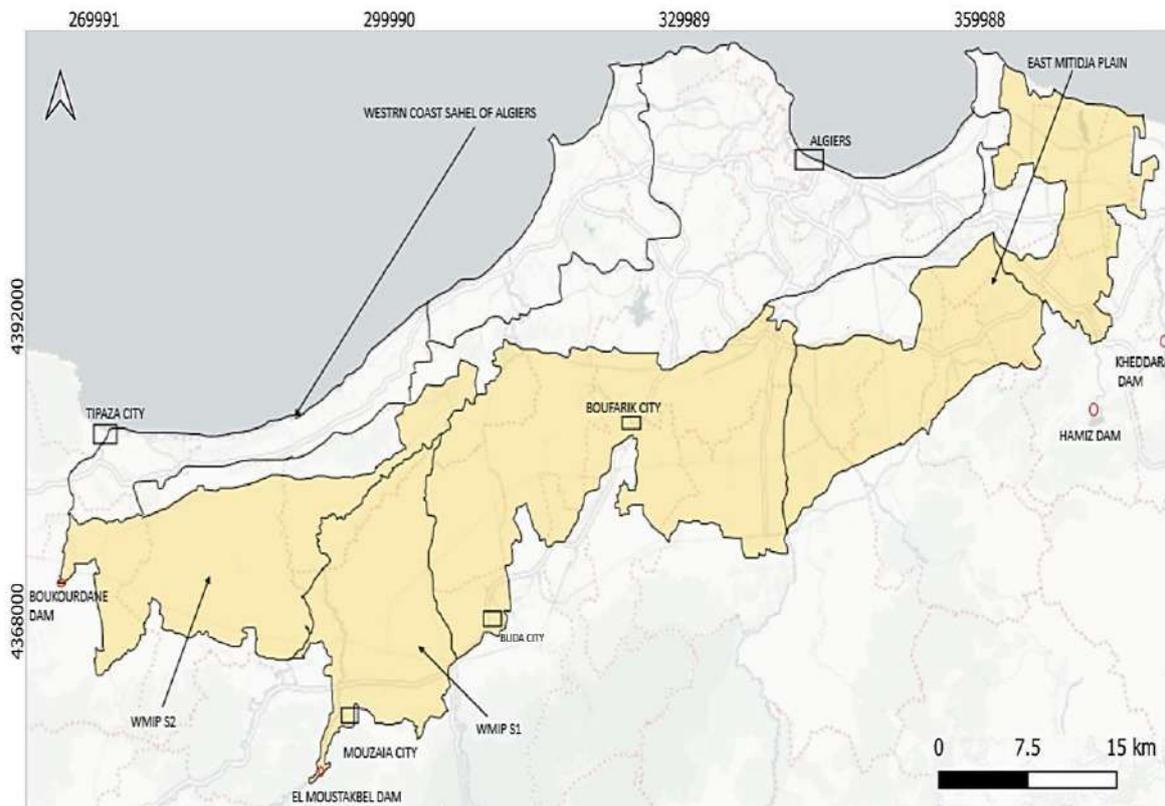Figure 6 : Distribution and Classification of Cultivated Agricultural Areas in Mitidja Plain

II.3.4.2 Western Mitidja Perimeter (IPWM)

Established in 2004, the Western Mitidja II irrigation perimeter covers an area of 15,600 hectares, distributed between the Wilaya of Tipaza (14,400 hectares) and the Wilaya of Blida (1,200 hectares). Being relatively recent, its water distribution infrastructure has not yet undergone significant deterioration. Moreover, its socioeconomic characteristics and encountered issues reflect those of many public irrigated agricultural areas in Algeria.

The perimeter is divided into seven sectors. The first three sectors receive pressurized water supplied by the National Office of Irrigation and Drainage (ONID), whereas the remaining sectors do not benefit from this service. All sectors are supplied with water from the Bouroumi Dam, located to the south of the irrigated area, except for Sector C, which is supplied by the Boukourdane Dam, situated to the west of the area.(Calatrava, 2018)

Table 7 : Main characteristics of the seven sectors of West Mitidja II irrigation district

Sector	Irrigable Area (ha)	Irrigated Area (ha)	Pressurized Irrigation	Serving Dam
A	2,450	2,250	Yes	Bouroumi
B	2,330	1,983	Yes	Bouroumi
C	3,020	2,389	Yes	Boukourdane
D	3,620	3,130	No	Bouroumi
E	1,750	1,470	No	Bouroumi
F	650	547	No	Bouroumi
G	1,780	1,632	No	Bouroumi

https://sjar.revistas.csic.es/index.php/sjar/article/view/12073/3880

Table 8 : Evaluation of Water Management Practices in Agriculture :(Calatrava, 2018).

Farm	Legal Status	Flow Rate Q (L/s)	Crops	Type of Cultivation	Plot Area (ha)	Irrigation Method
A	Tenant / Owner	8.3 / 8.3	Sweet Pepper (Lipari) / Citrus (Washington Navel)	Greenhouse / Open Field	0.12 / 1	Drip / Surface Irrigation
B	Tenant	7	Lettuce	Open Field	1	Sprinkler Irrigation
C	Owner	7.5	Apple (Royal Gala)	Open Field	1	Surface Irrigation
D	Owner	7.5	Citrus (Washington Navel)	Open Field	1	Surface Irrigation
E	Owner	7.4	Apple (Royal Gala)	Open Field	1	Surface Irrigation
F	Tenant	8.0	Sweet Pepper (Lipari)	Greenhouse	0.12	Drip Irrigation

Also, there is a greater reliance on groundwater irrigation due to the limited surface irrigation network. A large number of private wells can be observed in this area.(Imache, Hani, & Remaoun, 2006)

II.3.4.3 The Irrigated Perimeter of East Mitidja (IPEM) :

The Eastern Mitidja region, which includes the provinces of Algiers, Boumerdes, and Bouira, is considered one of the most important agricultural areas in Algeria. This region relies heavily on groundwater to meet its agricultural needs due to the limited surface irrigation networks □ **Water Sources**

1. **Groundwater** Groundwater forms the primary source of irrigation in Eastern Mitidja. However, these resources face significant challenges due to over-exploitation and climate change.

Studies indicate a significant decline in groundwater levels between 1973 and 2020, with decreases ranging from 10 to 80 meters, reflecting a negative trend in groundwater levels. This decline coincides with a shortage in rainfall during the period from 1973 to 2018(Makhlouf et al., 2023)**.**

2. **Surface Water**

Despite the presence of dams such as the Kadara Dam and Hammam Melouane Dam, their contribution to irrigation is limited compared to groundwater.

◻   **Irrigation Systems Used**
   The irrigation systems in Eastern Mitidja vary between flood irrigation and drip irrigation.
   "Studies indicate that the use of modern irrigation techniques, such as drip irrigation, remains limited due to the financial and technical challenges faced by farmers."
   (Laoubi & Yamao, 2009)

II.3.5. Challenges in Irrigation Management in Mitidja

Irrigation management in Mitidja faces several challenges that affect its efficiency and sustainability. These challenges are distributed across organizational, technical, financial, and social levels. Below is an overview of the main problems:(Loubie & Yamao, 2009)

Table 9 : Challenges in Irrigation Management in Mitidja (Belaidi et al., 2022)

Type of Problem	Description
Weak coordination between institutions	There is a lack of coordination between the ministries and institutions in charge (e.g., water resources, agriculture departments, and irrigation agencies), which causes disruptions in scheduling water releases from dams especially when the same source is used by multiple users (agricultural and urban). This issue persists despite monthly meetings.
Lack of farmer participation in management	Although follow-up committees for the irrigation season have been created with the involvement of various actors (departments, agricultural chambers, ONID, etc.), most provinces have failed to truly involve farmers in seasonal planning, with the exception of Algiers.
Unreliable data held by agencies	Government agencies sometimes lack accurate and reliable data regarding available resources, cultivated areas, and consumption volumes, which hinders effective planning and distribution.
Difficulty estimating actual water consumption	Agencies face challenges in measuring how much water is actually consumed by each farmer, making effective management and fair pricing difficult.
Conflicting data on cultivated areas	Inaccurate information provided by farmers about their cultivated areas results in unfair water distribution.

Poor maintenance of irrigation networks and infrastructure	A lack of maintenance and water availability in some areas leads some farmers to delay their agricultural activities, negatively impacting the performance of the network.
Incompatibility of irrigation network components with current agricultural layout	Some components of the network, such as hydrants and supply points, are no longer suitable for effectively distributing water to small or subdivided plots.
Difficulty delivering water to subdivided communal lands	The fragmentation of communal lands into individual ownership has led to disputes among beneficiaries over water usage. This issue is well documented in official studies.
Late debt settlements by farmers	Farmers with outstanding debts tend to settle them only at the start of the irrigation season, depriving the agency of the financial resources needed for prior preparation.
Weak financial returns from groundwater sources	The use of unlicensed wells deprives the agency of vital funding needed for network management and maintenance, compromising its financial sustainability. This issue has persisted since the 1990s.
Farmers' delays in requesting water allocations	Some farmers only request their water shares after the season has started i.e., once water is already flowing through the network disrupting advance planning.
Competition at water supply points	Farmers often compete at the network inlets or main supply points, which causes disputes and local tensions, undermining field discipline.
Inequitable water distribution among crop types	Orchards (fruit trees) are prioritized in water distribution over other crops, causing resentment and jealousy among farmers.
Heavy reliance on unregulated groundwater	After the destruction of the "El Mostakbal" dam in the 1990s, over 90% of farmers in western Mitidja relied on groundwater, with many unlicensed wells recorded, resulting in aquifer depletion.
Theft of irrigation water	Water theft is reported within irrigation networks, causing major financial losses. For example, in 2006, over 1.1 million m³ of water was stolen in eastern Mitidja's irrigation scheme more than 23% of total losses compared to 350,000 m³ stolen between 1996 and 2005.
Deterioration of modern irrigation equipment and lack of maintenance	Some newly installed irrigation networks suffer from poor maintenance, leading to damage to pipes, emitters, and drip systems. Combined with a lack of farmer awareness on proper usage, many revert to traditional methods such as flood irrigation.

II.3.6. The need for evaluating water productivity in Mitidja

Water is a vital resource upon which the agricultural sector in the Mitidja region depends, making the improvement of water use efficiency one of the top priorities to ensure agricultural sustainability. This evaluation requires studying how water is used in agriculture and its impact on productivity and crops, as well as the environmental effects of irrigation. By measuring water productivity, the most efficient methods of utilizing this precious resource can be identified, contributing to enhancing agricultural sustainability in the region.

a. The Importance of Monitoring Water Use Efficiency

Monitoring water use efficiency is crucial in the Mitidja region, where water is a limited resource that must be used effectively to ensure maximum crop productivity. In the face of challenges such as climate change and population growth, improving water use efficiency becomes an urgent necessity. By studying water consumption and determining the best irrigation methods, waste can be minimized, and a balance between supply and demand for water can be achieved, contributing to the long-term sustainability of these vital resources.

b. The Impacts of Irrigation Performance on Agricultural Sustainability :

Irrigation system performance directly affects water use efficiency in agriculture. The use of poorly designed irrigation systems or traditional irrigation techniques may result in significant water loss, negatively impacting crop productivity and increasing operational costs. Furthermore, inefficient irrigation can lead to serious environmental problems such as salinization and contamination. The increased use of water for irrigation without sufficient study can lead to soil salinization due to the accumulation of salts, as well as groundwater contamination from nitrate leakage caused by chemical fertilizers. (Mimouni, 1989.)

II.4.Conclusion

In light of the above, it is clear that the Mitidja Plain represents a strategic agricultural area in northern Algeria, endowed with significant natural resources and favorable climatic conditions, making it one of the country's key agricultural production hubs. However, this natural advantage faces increasing challenges related to the degradation of water resources, both surface and groundwater, due to urban expansion, climate change, and the inefficiency of irrigation systems. The study revealed disparities in the use of modern irrigation techniques, alongside a continued heavy reliance on well water, amid weak institutional coordination and limited farmer participation in resource management.

In this context, there is an urgent need to evaluate water productivity and irrigation performance as a fundamental step toward rationalizing the use of this vital resource and ensuring its sustainability. Developing effective strategies for managing agricultural water, especially through adopting modern monitoring tools such as remote sensing technologies and open data platforms, constitutes a cornerstone for addressing future challenges and achieving food security under changing climatic and social conditions.

Chapter III
Methodology , Results and discussion

II.1. Introduction

The first part presents the comprehensive methodology employed in this research to assess water productivity and irrigation performance indicators in the Mitidja region of Algeria. The methodology integrates remote sensing technology, geographic information systems, and advanced data processing techniques to evaluate water use efficiency and agricultural productivity across the study area from 2018 to 2024.

The research framework is designed to address the critical need for accurate assessment of water resources management in agricultural systems, particularly in semi-arid regions where water scarcity poses significant challenges to sustainable farming practices. By utilizing satellitederived data and established computational models, this study aims to provide quantitative insights into irrigation effectiveness, crop water consumption patterns, and overall agricultural water productivity in the Mitidja plain.

III.2. Methodology

The methodological approach follows a systematic workflow that begins with data acquisition from multiple sources and progresses through various analytical stages to produce meaningful indicators for water management decision-making. This integrated approach ensures comprehensive coverage of the study area while maintaining the temporal resolution necessary to capture seasonal and annual variations in agricultural water use patterns.

III.2.1.Data Sources and Processing Framework

The methodology centers on the utilization of satellite-derived data processed through specialized software platforms designed for agricultural water assessment. The primary data source consists of remote sensing imagery spanning the period from 2018 to 2024, providing a robust temporal dataset for trend analysis and performance evaluation.

III.2.3.QGIS Integration and Spatial Analysis

The Geographic Information System (GIS) component of the methodology utilizes QGIS software as the primary platform for spatial data management, processing, and analysis. QGIS provides the foundational framework for integrating multiple data layers, performing spatial operations, and generating cartographic outputs essential for the research objectives. The software's open-source nature and extensive plugin ecosystem make it particularly suitable for complex agricultural water assessment studies.

III.2.4.WAPlugin Implementation

The core analytical component of the methodology employs the Water Accounting Plus Plugin (WAPPlugin), a specialized tool designed for comprehensive water productivity assessment. This plugin serves as the primary computational engine for processing satellite data and generating water-related indicators. The WAPPlugin integrates seamlessly with the QGIS environment, allowing for efficient processing of large spatial datasets while maintaining accuracy in calculations.

III.2.5. Data Processing Pipeline

The methodology incorporates Version 3 (V3) data processing protocols, which represent the latest standardized approach for agricultural water assessment using remote sensing technology.

This processing pipeline handles three primary data streams: Actual Evapotranspiration and Interception measurements at 20-meter spatial resolution, Net Primary Productivity calculations at 20-meter resolution, and Transpiration estimates also at 20-meter resolution. The 20-meter spatial resolution provides an optimal balance between computational efficiency and analytical detail, allowing for field-level assessments while maintaining processing feasibility across the entire Mitidja region. This resolution is particularly appropriate for the agricultural landscape of the study area, where field sizes typically range from small family plots to larger commercial operations.

III.2.6 Indicator Calculation and Assessment Framework

The methodology generates eight primary indicators that collectively provide a comprehensive assessment of water productivity and irrigation performance in the Mitidja region. These indicators are systematically calculated using standardized algorithms implemented through the WAPPlugin framework.

III.2.7.Primary Water Productivity Indicators

The uniformity of water consumption indicator assesses the spatial distribution of water use across the study area, providing insights into irrigation system efficiency and management practices. The beneficial fraction indicator quantifies the proportion of water consumption that contributes directly to agricultural productivity, distinguishing between productive and nonproductive water use.

Adequacy measurements evaluate whether crop water requirements are being met under current irrigation practices, while relative water deficit calculations identify areas experiencing water stress. Total biomass production indicators provide quantitative measures of agricultural output, serving as a foundation for productivity assessments.

III.2.8.Advanced Performance Metrics

Biomass water productivity represents a crucial indicator that relates agricultural output to water consumption, expressed as kilograms of biomass produced per cubic meter of water consumed. This metric provides direct insight into the efficiency of water use in agricultural production systems.

Yield calculations incorporate crop-specific factors to estimate actual agricultural production, while crop water productivity indicators specifically focus on the relationship between harvestable crop yield and water consumption. These indicators collectively provide a comprehensive framework for assessing agricultural water use efficiency at multiple scales, from individual fields to the entire regional system.

The temporal analysis component of the methodology enables tracking of performance trends over the six-year study period, facilitating identification of improvement or degradation patterns in water use efficiency and agricultural productivity across the Mitidja region.

The methodology and different indicators are illustrated un the flowchart below.
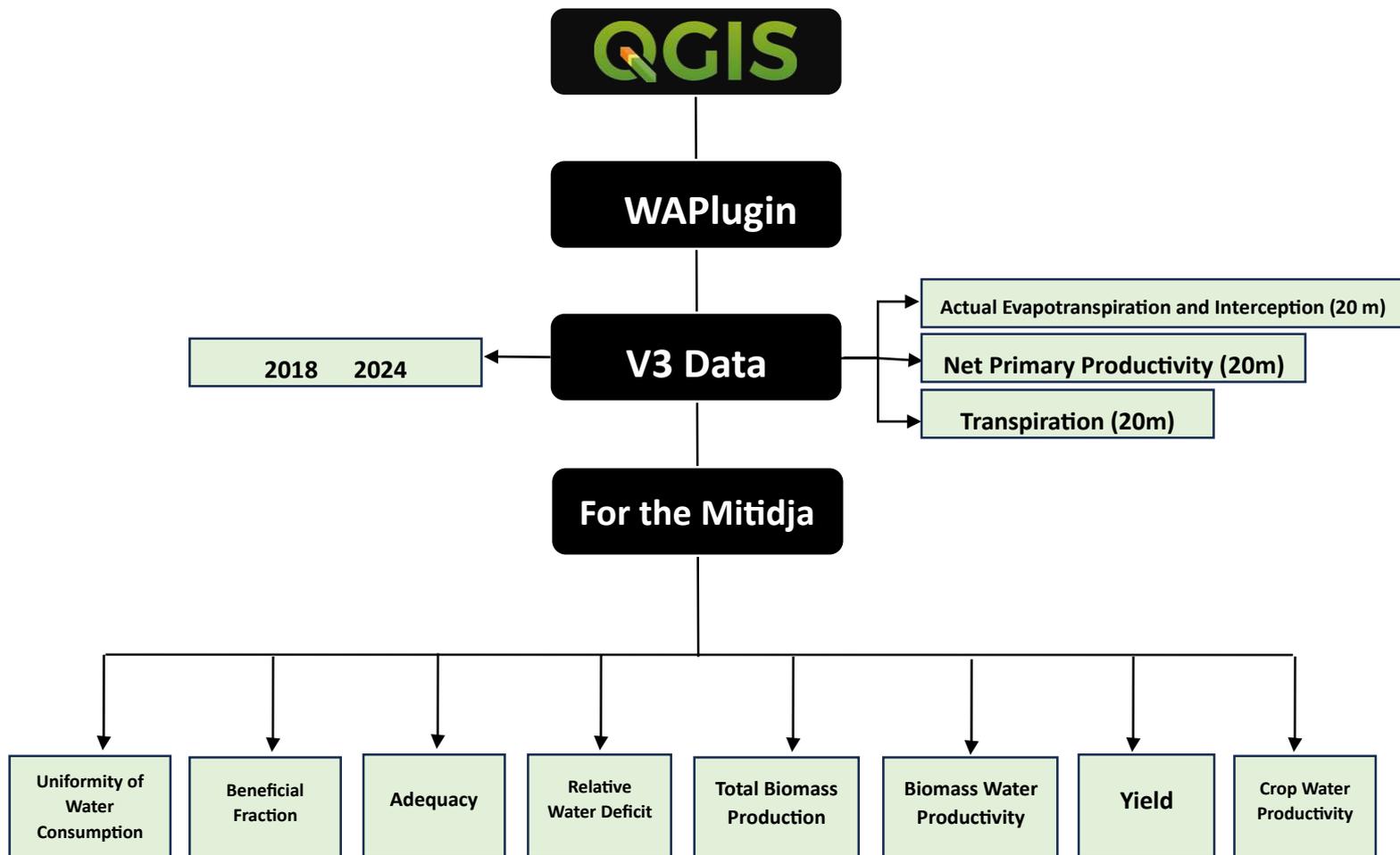
Figure 7 : Methodology Flow Chart

III.3. Results of the Indicators

III.3.1. Uniformity of Water Consumption

The UWC index was evaluated over the period from 2018 to 2024. As for the other indices, the focus was placed solely on the month of March, as it represents the growing season for most crops and is considered one of the most significant months in terms of recorded changes. Data for the other months have been included in the appendices.

The UWC indicator is presented as a percentage with values from 0 to 10% representing good uniformity, values from 10 to 25% representing fair uniformity, and values greater than 25% are considered poor uniformity. The UWC is affected by hydro-climatic conditions and adopted irrigation practices. All recorded UWC values during the study years were above 25%, indicating poor water distribution, with varying severity of this issue from one year to another. UWC values for the Mitidja irrigation scheme ranged between 35%, recorded in April 2018, and a maximum of 60%, recorded in July 2023 (Figure 8). 2023 was a year characterized by reliance on groundwater (Algerian Press Service, 2023). For the remaining years, UWC values coincided with precipitation levels (Figure 9).

Typically, the months with the lowest uniformity (highest UWC values) are from June to September (summer). Conversely, the months where uniformity is highest (lowest UWC values) are usually from March to May. The results indicate an uneven distribution of water throughout the study area, even during irrigation months. This could be due to the different irrigation techniques used, which may not transport water evenly to all areas. It could also be attributed to the different types of crops that require varying irrigation schedules, as this analysis

was not performed based on crop types. To better understand these results, a detailed analysis for each crop is required.
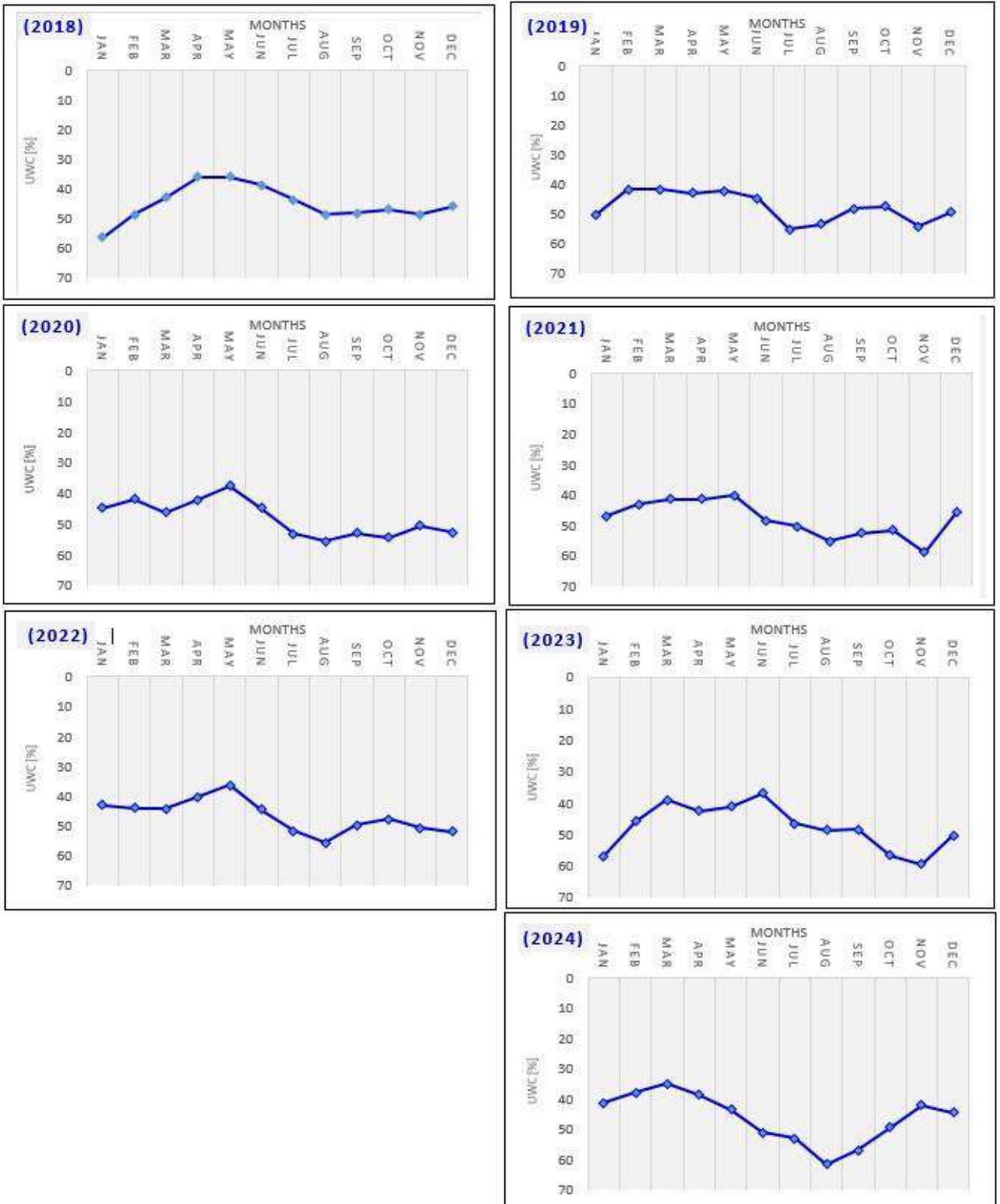
Figure 8 : Uniformity of Water Consumption (UWC) curves over the period from 2018 to 2024
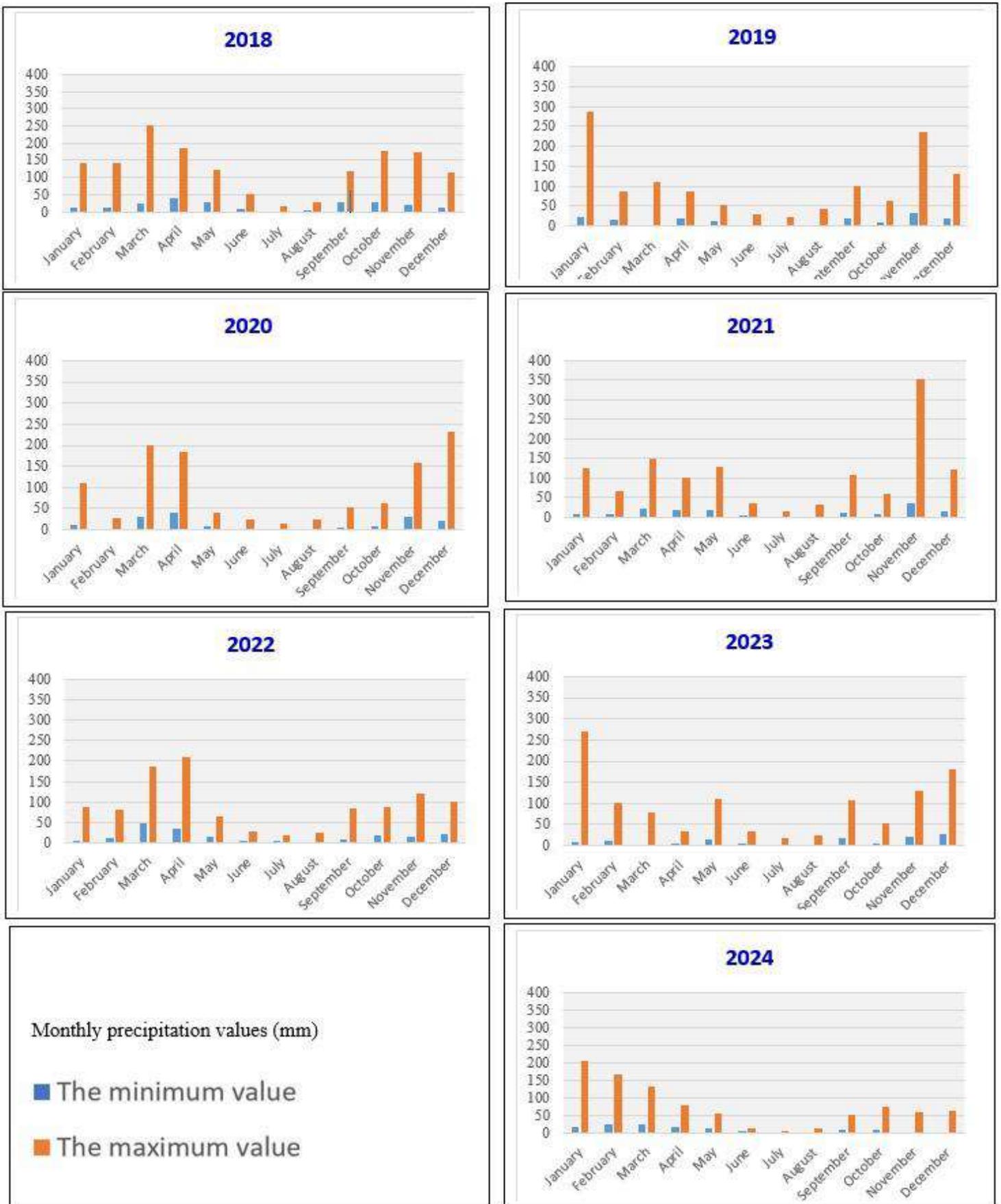
Figure 9 : Bar charts representng the maximum and minimum monthly rainfall in Mitdja

III.3.2 Adequacy in March Across Years in Mitidja Plain

Adequacy is the measure of the agreements between the water used and the actual amount of water that has been consumed by the crops. The values range from 0 to 1, with values approaching 1 representing higher adequacy. The output of this indicator is a raster. Monthly adequacy was computed for each year from 2018 to 2024. The maps are presented so the adequacy distribution for a given month can be compared over the entire study period. For this analysis, we selected maps of March. The maps show an uneven distribution with the highest values distributed in the central part of the study area and the lowest recorded in the eastern part. The highest rates were recorded in 2023 and 2024, years during which irrigation was supported by groundwater. Meanwhile, the lowest rates were recorded in 2020, which marked the COVID period, and this might be due to limited crop production. This deficit also continued relatively into 2022, a year of cumulative drought.(Figure 10)

NB : To improve the visual representation of the Adequacy index, the color scale was extended to 2 due to some cases slightly exceeding the value of 1. This remains within the acceptable margin of uncertainty.
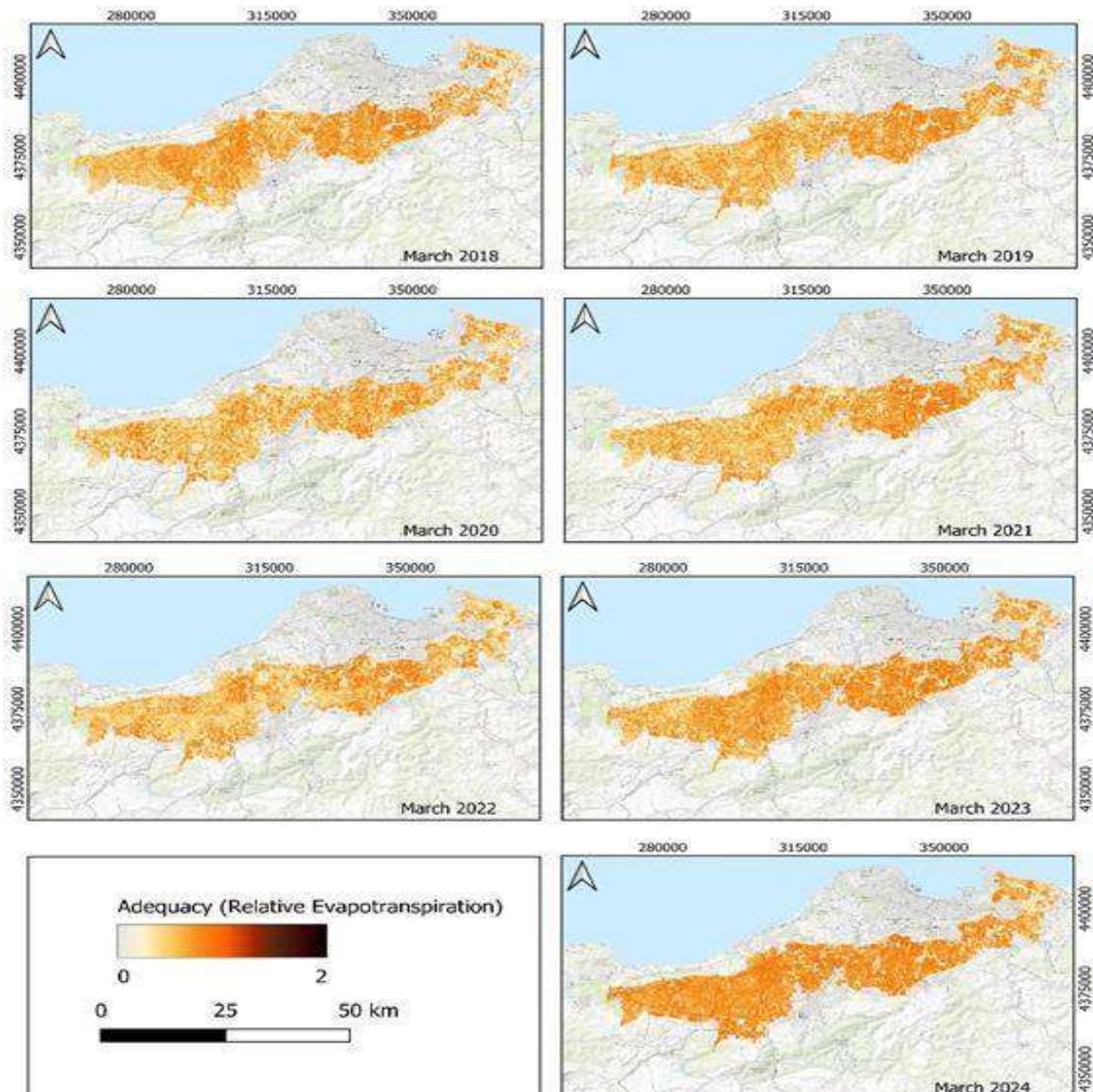
Figure 10 : Adequacy Maps for March from 2018 to 2024

III.3.3 Relative Water Deficit in March Across Years in Mitidja Plain

Refers to the amount of water that is available relative to the demand or the requirement for that water. It exists when the water demand exceeds the availability of supply and occurs due to a variety of factors.

When interpreting RWD maps (Figure 11), higher deficit ratios are represented by darker colors. Analyzing these maps, we observe that the highest deficit ratio was in 2020, while the lowest deficit ratios were recorded in 2023 and 2024.
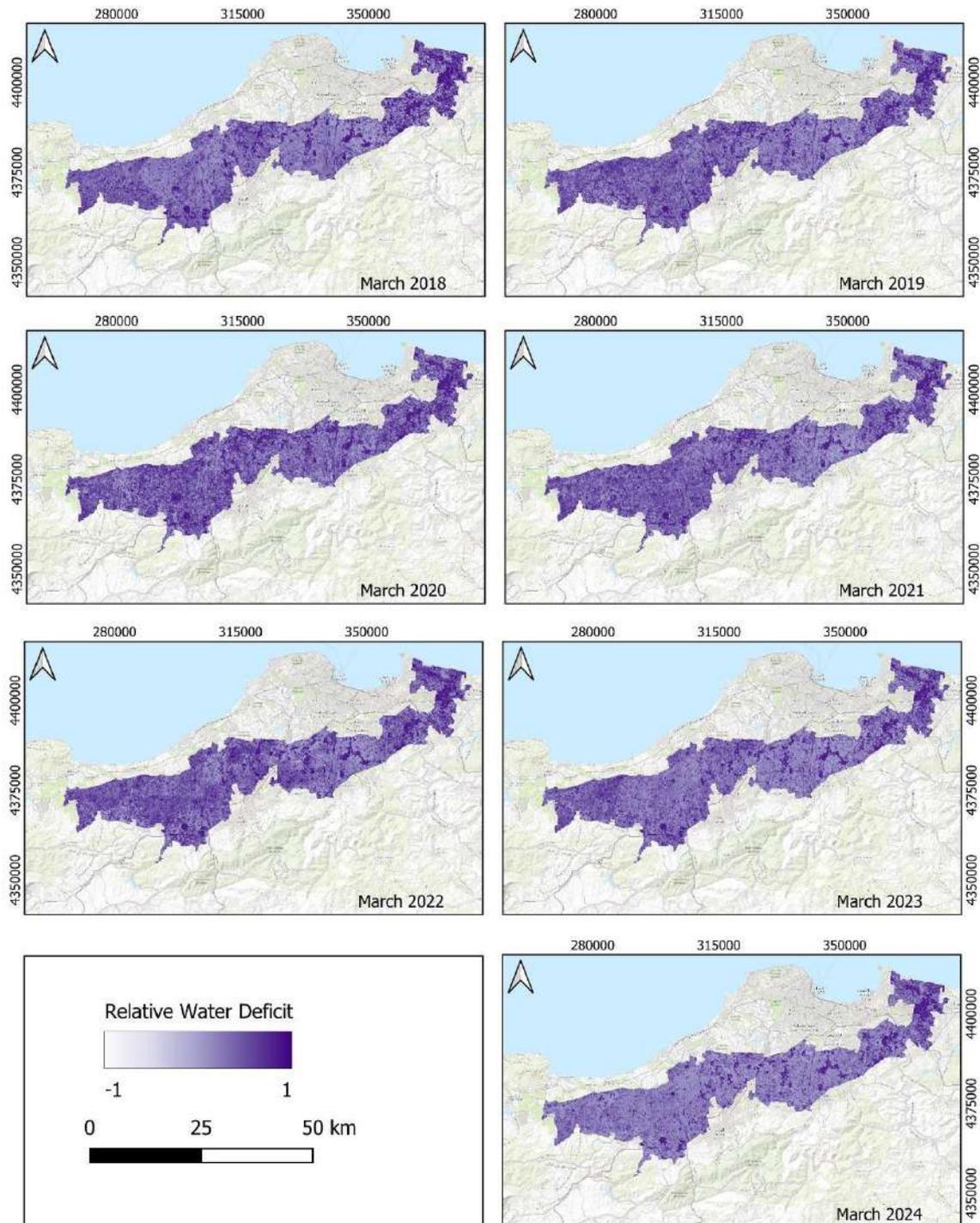
Figure 11 : Relative Water Deficit Maps for March from 2018 to 2024

III.3.4 Beneficial Fraction (BF) in the Mitidja Plain

The Beneficial Fraction (BF) is the portion of the water that is effectively used by crops and contributes to their growth compared to the total amount of water applied. It also evaluates the effectiveness of the irrigation system in delivering water to plants.

The lowest ratio was in 2022, which was due to cumulative drought. The highest ratios were in 2023 and 2024. (Figure 12).
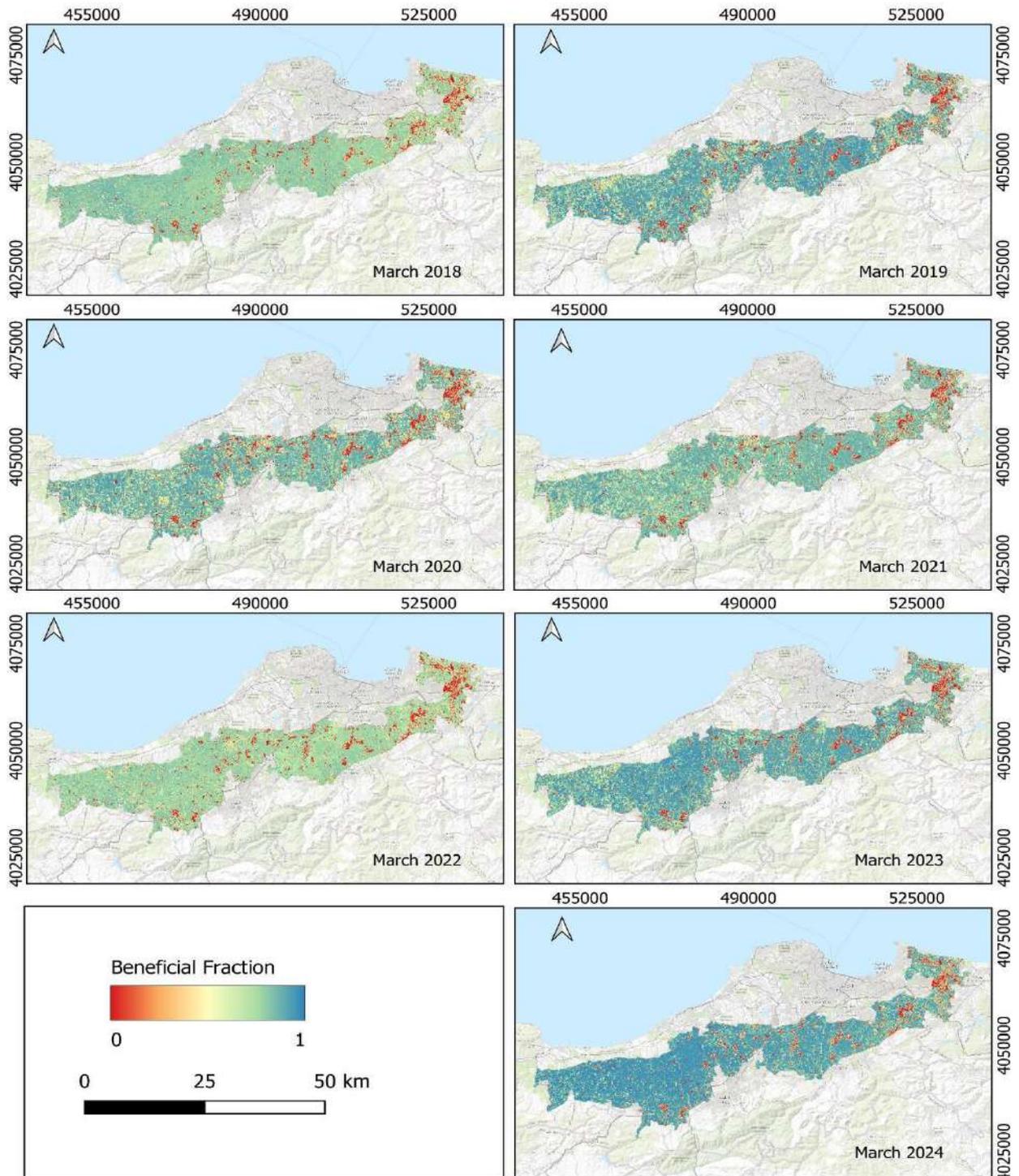
Figure 12 : Beneficial Fraction Maps for March from 2018 to 2024

III.3.5 Total Biomass Production (TBP) in March Across Years in Mitidja Plain

Total Biomass Production (TBP) is a quantitative measure of overall plant growth (Figure 13). This indicator is directly linked to water use efficiency: high production values indicate optimal utilization of water resources for crop growth, while low values reflect water stress. The Beneficial Fraction (BF) is the key indicator of how efficiently water is converted into biomass, making it the primary driver of crop yield and overall TBP (Figure 12). Meanwhile, Adequacy is a necessary condition for plants to achieve high BF efficiency (Figure 11).

2018

In 2018, the central areas of Mitidja recorded "acceptable" water adequacy, allowing for high BF values in those regions (Figure 12). This directly translated to the TBP maps (Figure 13), which showed high values across most of the plain, indicating healthy and productive plant growth due to efficient water use. Conversely, surrounding areas that suffered from low adequacy and water deficit (Figure 10) showed lower BF values (Figure 12) and consequently recorded lower TBP values (Figure 13) due to uneven rainfall distribution (Figure 9).

2019

With moderate adequacy (Figure 10), the BF maps (Figure 12) showed average to good beneficial fraction values over most of the area. This directly led to the TBP maps (Figure 13) achieving average to good values, reflecting acceptable plant growth.

2020 and 2021

This period saw a gradual decrease in adequacy (Figure 10) and an increase in Relative Water Deficit (RWD) (Figure 11), negatively impacting water use efficiency. Accordingly, the BF maps (Figure 12) show a gradual decline in beneficial fraction values across most of the plain. This decrease in efficiency was directly reflected in the TBP maps (Figure 13), which showed a gradual reduction in production values, due to the initial drop in dam water levels and the affected availability of supplemental irrigation.

2022

This was the driest year (Figure 9), with a high and severe water deficit (Figure 11). These conditions led to very low BF values across most of the Mitidja Plain (Figure 4), reflecting a significant weakness in water use efficiency. Consequently, the TBP maps (Figure 13) show very low values, indicating a significant deterioration in crop growth and overall productivity. Despite a relative improvement in adequacy in March (Figure 10), this temporary improvement did not prevent the overall decline in BF and production due to cumulative drought and severe water scarcity during the rest of the year, as well as high Unproductive Water Consumption (UWC) (Figure 14).

2023

With intensive reliance on groundwater to improve adequacy (Figure 10) and reduce water deficit (Figure 11), the BF maps (Figure 12) show a notable improvement in beneficial fraction values compared to 2022. This improvement in water use efficiency was directly reflected in the TBP maps (Figure 13), which recorded a significant improvement in production values.

2024

The improvement in BF values (Figure 12) continued during March 2024, aligning with the improvement in adequacy (Figure 10) and the decrease in water deficit (Figure 11). This improvement in BF, and consequently in TBP (Figure 12), is primarily attributed to the return of significant rainfall in late 2023 and early 2024 (Figure 9), along with the continued exploitation of groundwater for irrigation. These combined factors contributed to supporting water use efficiency and biological productivity, which was also reflected in a relative stability or slight improvement in UWC (Figure 8) with the return of better water conditions.
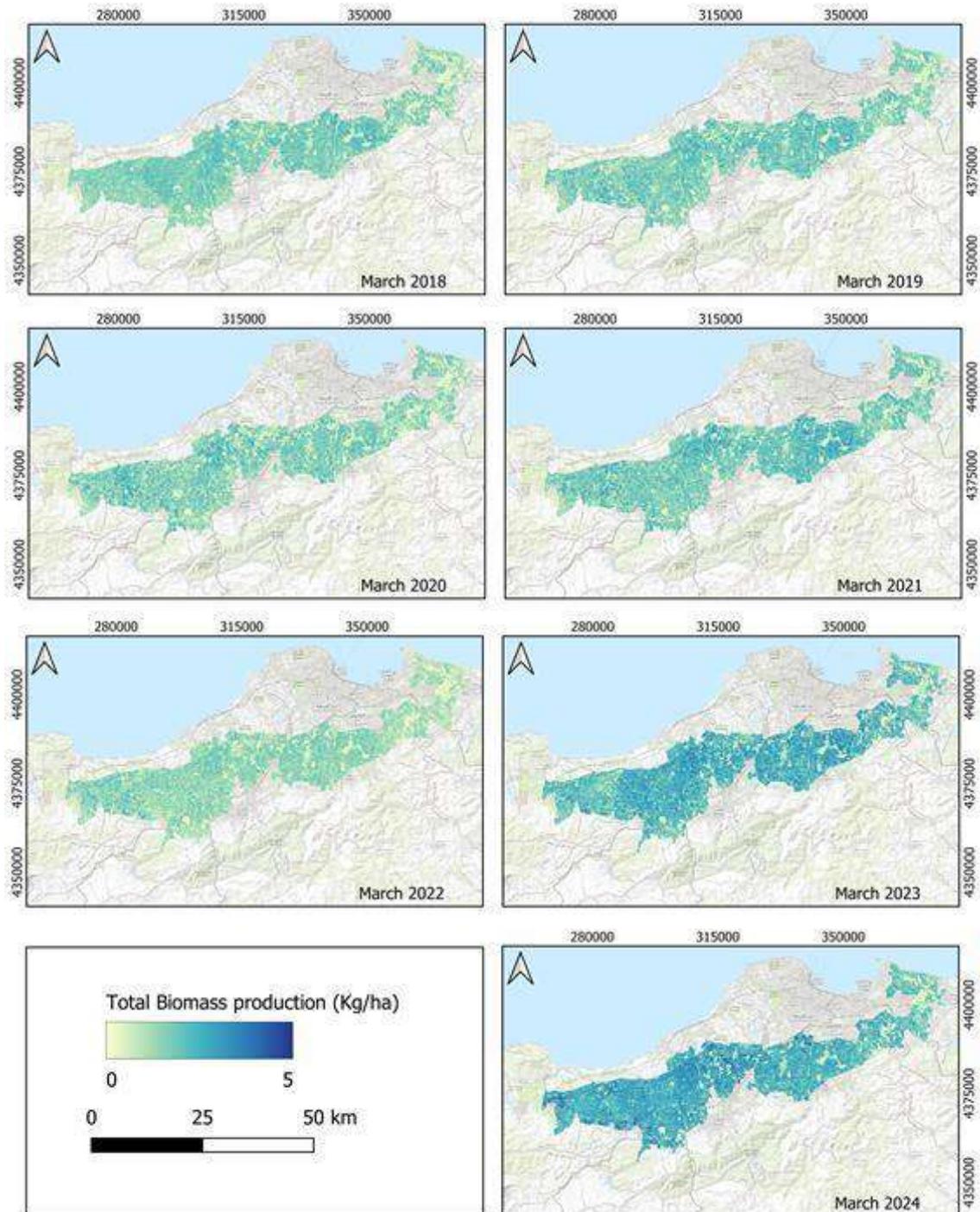
Figure 13 : Total Biomass production Maps for March from 2018 to 2024

III.3.6 Water Biomass Productivity (WBP) in the Mitidja Plain

Water Biomass Productivity (WBP) is a vital indicator that measures the efficiency with which water actually consumed by crops (total transpiration) is converted into biomass. Unlike Total Biomass Production (TBP), which measures the overall quantity of the harvest (Figure 13), WBP maps (Figure 14) show how efficiently each unit of water produces this biomass. This conceptual difference sometimes explains why WBP behaves inversely compared to indicators like Adequacy, Beneficial Fraction (BF), and TBP.

WBP Analysis Across the Years:

2018:

WBP values were low in 2018 (Figure 13), even though Adequacy was "acceptable" and Total Biomass Production (TBP) was high. This indicates inefficient water productivity; the large amount of water available, and likely the amount of water wasted through inefficient evaporation or excessive transpiration, was significantly greater compared to actual production, leading to low productivity per unit of water consumed.

* 2020 and 2021:

During these two years, water use was not substantial due to its limited availability (decreased Adequacy and increased water deficit), and consequently, TBP was not high either. These conditions led to moderate WBP (Figure 13). This might reflect that plants consumed relatively less water, and therefore, the ratio of biomass produced per unit of water consumed was acceptable despite the generally difficult conditions.

2022:

2022 was a very dry year (Figure 9) and saw significant variability in water distribution (Figure 8), which impacted Adequacy (Figure 10) and resulted in variable TBP. This extreme variability in conditions led to similar variability in WBP (Figure 13). Some areas suffering from severe water stress (especially those forced to utilize groundwater) might show different WBP values, reflecting very limited water use efficiency or very minimal water consumption.

2023:

This year saw an improvement in Adequacy thanks to the intensive reliance on groundwater, leading to a notable improvement in TBP. WBP maps (Figure 13) show that water productivity was relatively high, indicating that the consumed water (from both surface and groundwater sources) was efficiently converted into biomass.

2024:

WBP values in 2024 (Figure 13) were slightly lower than in 2023, despite the significant biomass production (TBP) that continued to improve (Figure 12) as a result of the return of good precipitation (Figure 9) and continued groundwater exploitation. This relative decrease in WBP is attributed to the substantial difference in the amount of water used between the two years, while the difference in total biomass production was not proportionally as large. This means that a greater amount of water was used per unit of production in 2024 compared to 2023.
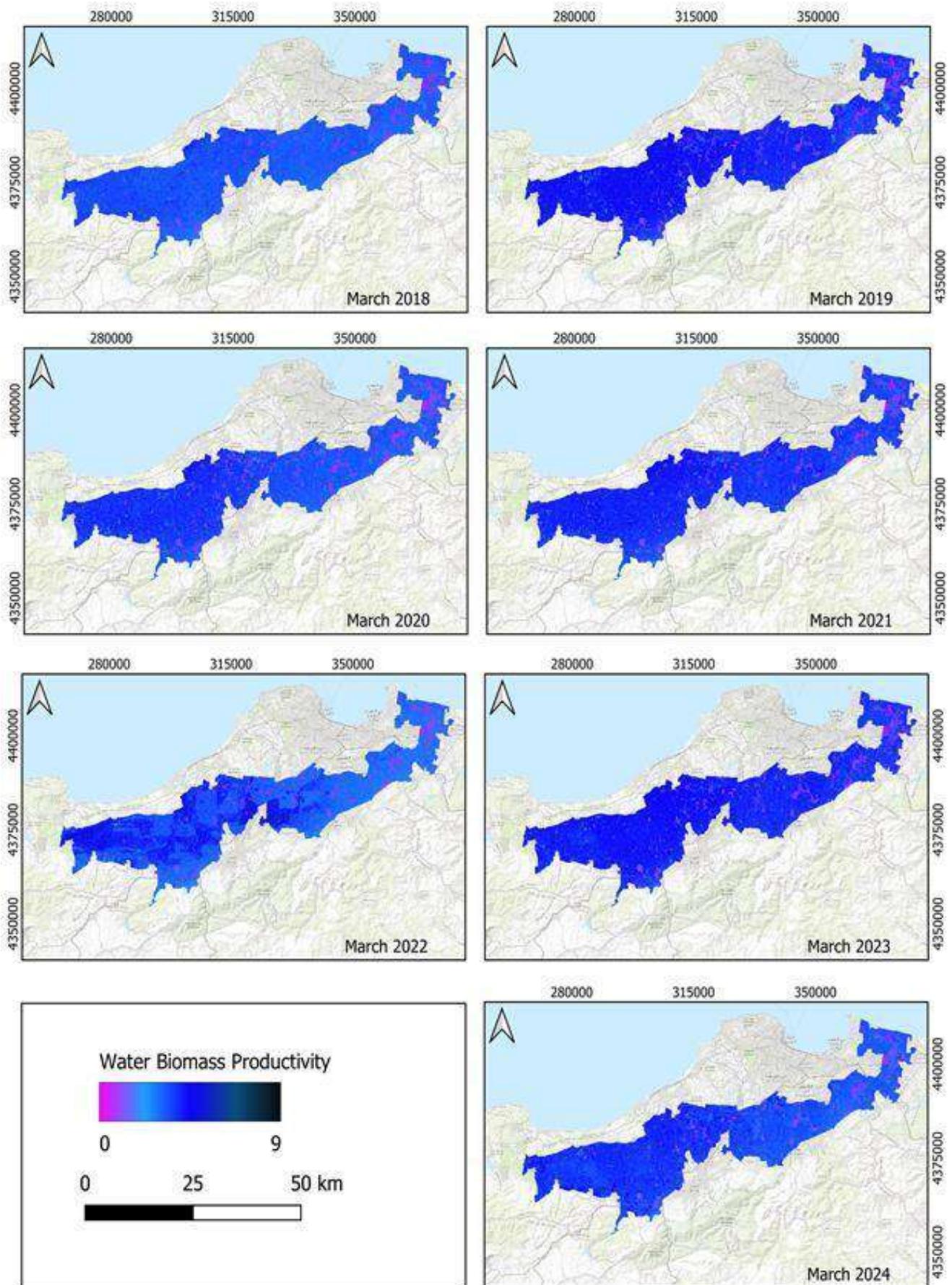
Figure 14 : Water biomass Productivity Maps for March from 2018 to 2024

III.3.7. Yield and Crop Water Productivity

This map represents the spatial distribution of Crop Water Productivity (CWP) for two major crop types, potatoes and citrus trees, within the Mitidja Irrigation Scheme in northern Algeria, for the year 2019. To produce this map, we first delineated the boundaries of fields cultivated with potatoes and citrus trees using a combination of field data, visual interpretation of highresolution satellite imagery, and agricultural land use information. We then utilized the WAPlugin, developed to interface with the WaPOR Level 2 database, to extract biomass production at a spatial resolution of 20 meters for the year 2019. The yield was calculated using a set of crop-specific parameters: moisture content, light use efficiency correction factor, ratio of above-ground to total biomass, and the harvest index, values which were carefully selected based on crop physiology and literature. These parameters allowed us to convert WaPOR's total biomass into harvestable yield in kilograms.

Once yield was estimated, we computed Crop Water Productivity by dividing the yield by the total actual evapotranspiration (ETa), also obtained from WaPOR data, for each pixel during the growing season. The resulting CWP values are expressed in kilograms per cubic meter of water used (kg/m³). The map visually distinguishes areas cultivated with potatoes (outlined in yellow) and citrus trees (outlined in red), and displays CWP using a color gradient: for potatoes, values range from 0 to 2970 kg/m³, while for citrus trees, the range is from 3215 to 4518 kg/m³.

Interpretation of this map reveals clear spatial variability in water productivity within each field. For potato fields, we observe lower CWP values in some patches, particularly in the northern and central parts, which may suggest over-irrigation, suboptimal fertilization, pest pressure, or soil-related constraints (e.g., poor drainage or salinity). Conversely, higher CWP values in the western and southern sections of the potato plots indicate more efficient water use, possibly linked to better soil fertility, more precise irrigation, or healthier crop growth. For citrus orchards, the CWP values are generally higher and more uniform, reflecting the perennial nature of the trees and possibly more stable water and nutrient management. However, some localized areas in the eastern part show reduced CWP, which may require field-level investigation to assess irrigation adequacy or tree health.

Overall, this map serves as a valuable tool to monitor and compare water use efficiency across crop types and spatial zones. It helps identify high- and low-performing areas within the irrigation scheme, enabling targeted recommendations for improving irrigation scheduling, soil management, or agronomic practices. Such insights are crucial for increasing agricultural productivity under water-scarce conditions and ensuring the sustainability of water resources in the Mitidja Plain.
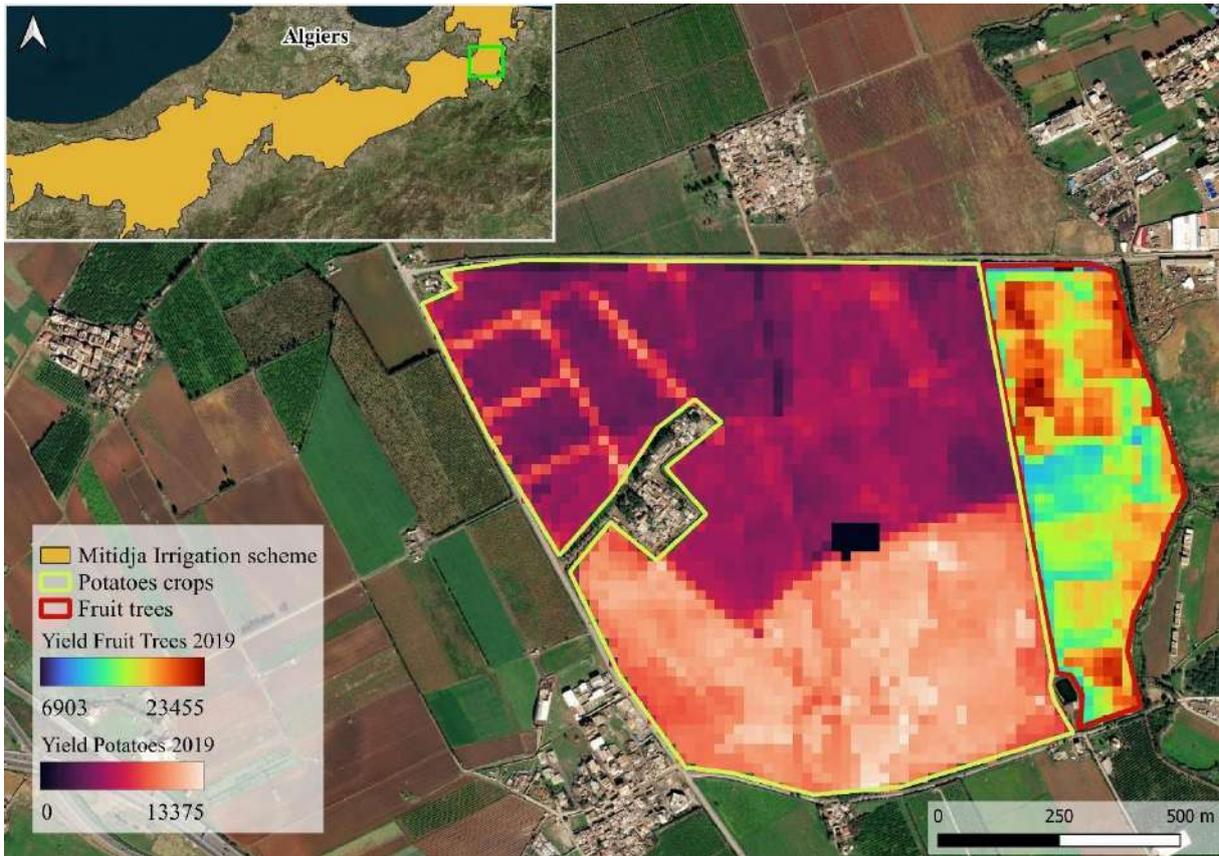
Figure 15 : Yield map of the potatoe field and citrus fruit trees field
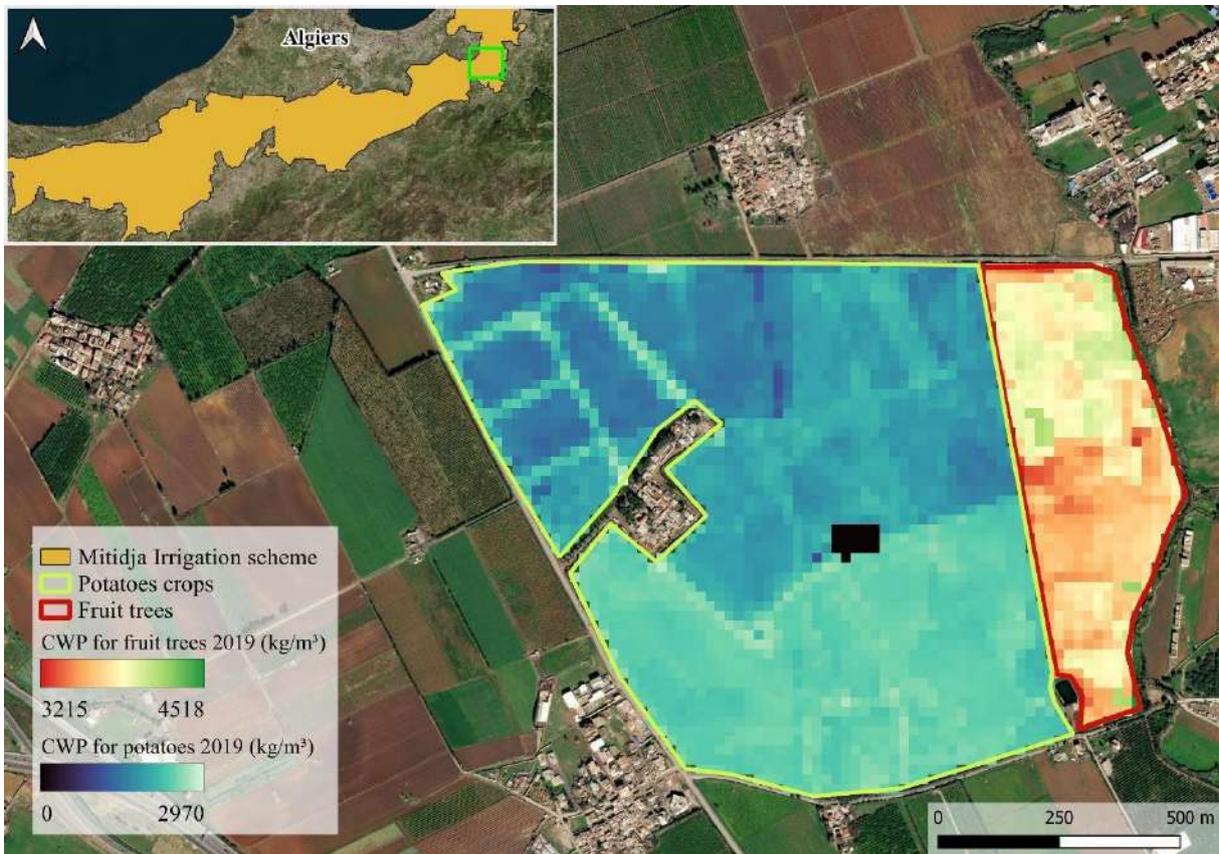
Figure 16 : Crop water productivity in the potatoes and fruit trees fields

III.4. Conclusion

This chapter demonstrated the effectiveness of using the WaPOR platform within the QGIS environment via the WAPlugin for evaluating irrigation performance and water productivity in the Mitidja Plain, one of Algeria's most vital agricultural regions. By leveraging remote sensingbased quantitative indicators, the adopted methodology enabled detailed spatial and temporal analyses, offering valuable insights into the functioning and efficiency of irrigation systems over multiple years.

The findings revealed a clear year-to-year variability in agricultural system performance, which can be largely attributed to fluctuations in climatic conditions and persistent inefficiencies in irrigation management. Such variability underscores the critical need for adaptive strategies in water resource planning and agricultural practices, especially in the context of increasing climate variability and water scarcity. Moreover, the integration of WaPOR data into GIS platforms proves to be a powerful decision-support tool for stakeholders, policymakers, and water managers aiming to improve the sustainability and productivity of irrigated agriculture. It allows for data-driven interventions and the identification of priority areas where water use can be optimized.

General Conclusion

IV.GENERAL CONCLUSION

This work represents a scientific endeavor to evaluate water productivity and irrigation system performance in the Mitidja Plain, utilizing remote sensing data derived from the WaPOR platform within a Geographic Information System (QGIS) environment. The use of WaPOR data proved effective in providing accurate and rapid indicators across various aspects of the agricultural cycle, particularly concerning water productivity. This reinforces the position of remote sensing technologies as an effective decision-support tool in water resource management.

The study's chapters progressed from analyzing the geographical and hydrological context of the Mitidja Plain to the practical application and spatio temporal analysis of indicators such as Uniformity of Water Consumption, Beneficial Fraction, Adequacy, Relative Water Deficit, Total Biomass Production, Yield, and Crop Water Productivity. The results showed that the plain, classified as a semi-arid region, suffers from imbalances in water resource distribution and variations in irrigation sources, with a clear dominance of flood irrigation over modern methods like sprinkling and drip irrigation. This pattern, along with climate variability and economic pressure, led to significant disparities in irrigation efficiency and agricultural water productivity from year to year.

The study revealed periods of poor performance, especially in drought years like 2020 and 2022, and periods of relative improvement in productivity indicators during years such as 2023 and 2024. This improvement was a result of increased reliance on groundwater and a relative improvement in rainfall. Furthermore, analyses of Water Biomass Productivity (WBP) showed that the efficiency in converting consumed water into biomass was not always linked to water abundance, but rather to the efficiency of its use compared to its productivity. Similarly, the analysis of Crop Water Productivity (CWP) for 2019 showed a significant disparity among the studied crops, with citrus recording higher efficiency levels compared to potatoes. This highlights the significant impact of crop type on determining water productivity, alongside other factors such as soil quality, agricultural practices, and adopted technologies.

These results reflect the need to adopt accurate local assessments that consider spatio temporal variations in agricultural and water performance. This will enable guiding policies and measures towards poorly performing areas to improve efficiency and ensure sustainable resource use. Therefore, this study recommends expanding the scope of this type of assessment to include other irrigated areas, with the necessity of integrating field data and strengthening the nexus between remote sensing data and public policies. This will ensure improved economic viability of water, contribute to achieving food security, and promote agricultural sustainability amidst the growing challenges of climate change, ultimately leading to the desired sustainability.

Recommendations

V.RECOMMENDATIONS

Given the scarcity of water resources and increasing climatic and demographic pressures, it has become essential to adopt effective and sustainable agricultural water management, based on accurate knowledge and integrated data. Based on the results of this study, the following recommendations can be made:

Enhance Data Integration for Effective Water Governance:

To ensure science-based decision-making, it is recommended to enhance the integration of field data with remote sensing data (such as that available through the WaPOR platform), and to incorporate them into the public policy making framework related to water and agriculture. This integration will contribute to improving planning effectiveness, achieving food security, and enhancing resource sustainability in the face of future climate challenges.

Gradual Transition Towards Modern Irrigation Technologies:

The study revealed imbalances associated with the use of traditional irrigation methods, especially flood irrigation, and the resulting variations in efficiency and water waste. Therefore, a gradual transition towards localized irrigation techniques (such as drip or sprinkler irrigation) is recommended, especially in areas that showed low efficiency indicators. This transition requires technical and financial support programs from the state, along with providing appropriate training and agricultural extension for farmers.

Expand the Use of WaPOR Data and Remote Sensing Technologies:

The study results proved the effectiveness of WaPOR data in accurately and objectively assessing water productivity and monitoring irrigation system performance. Accordingly, it is recommended to expand the use of these tools to include other agricultural areas in Algeria, while working on building the capacities of local users (engineers, technicians, planners) in spatial data analysis and interpretation of agricultural and water indicators.

Encourage Applied Research and Local Experiments:

It is recommended to support applied studies and agricultural experiments that aim to test different irrigation doses and frequencies according to the specific characteristics of each region and crop, with the goal of developing technically, economically, and environmentally appropriate irrigation methodologies that align with the local context.

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VI.BIBLIOGRAPHIC REFERENCES

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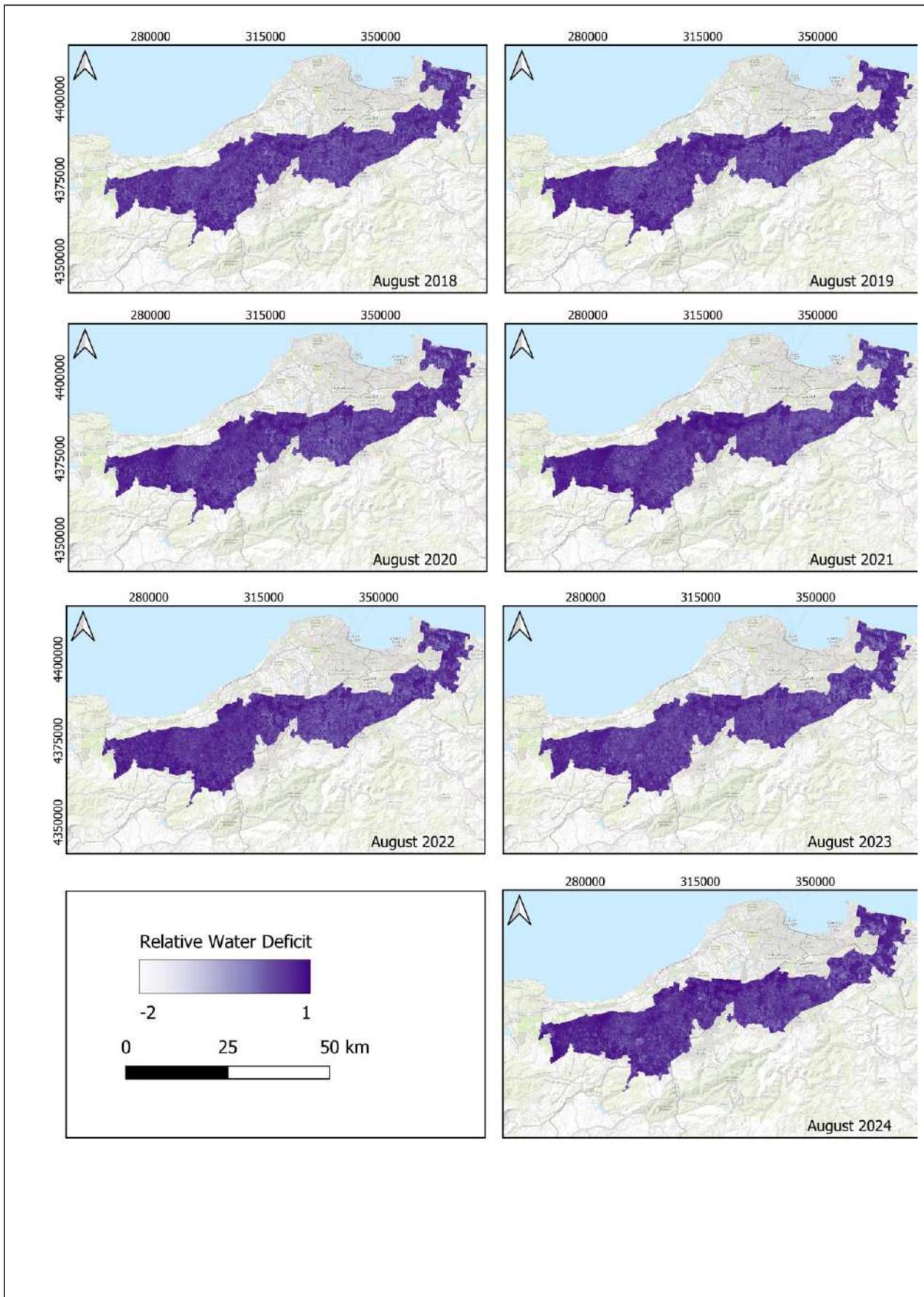
APPENDICES

VII. APPENDICES

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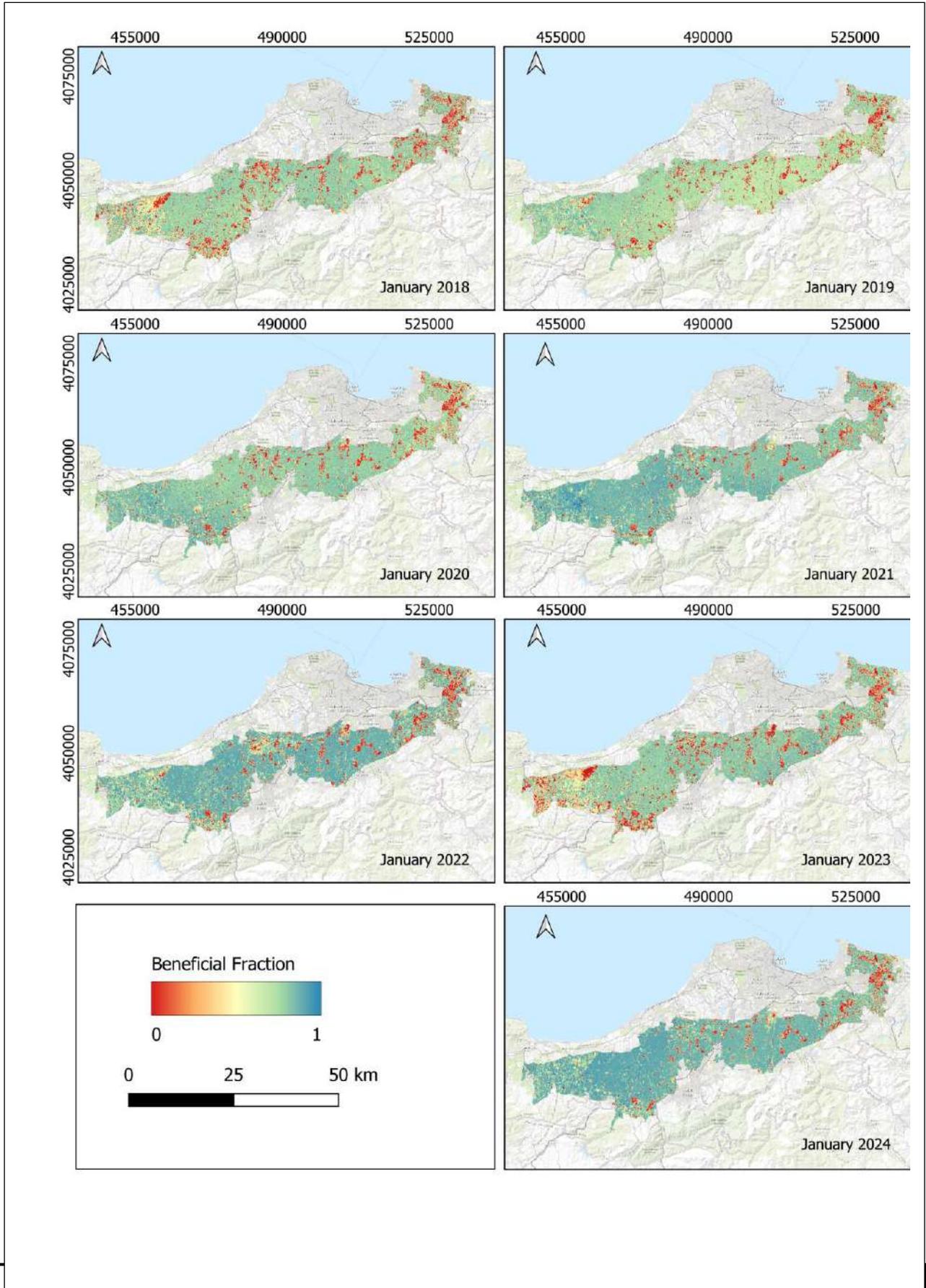
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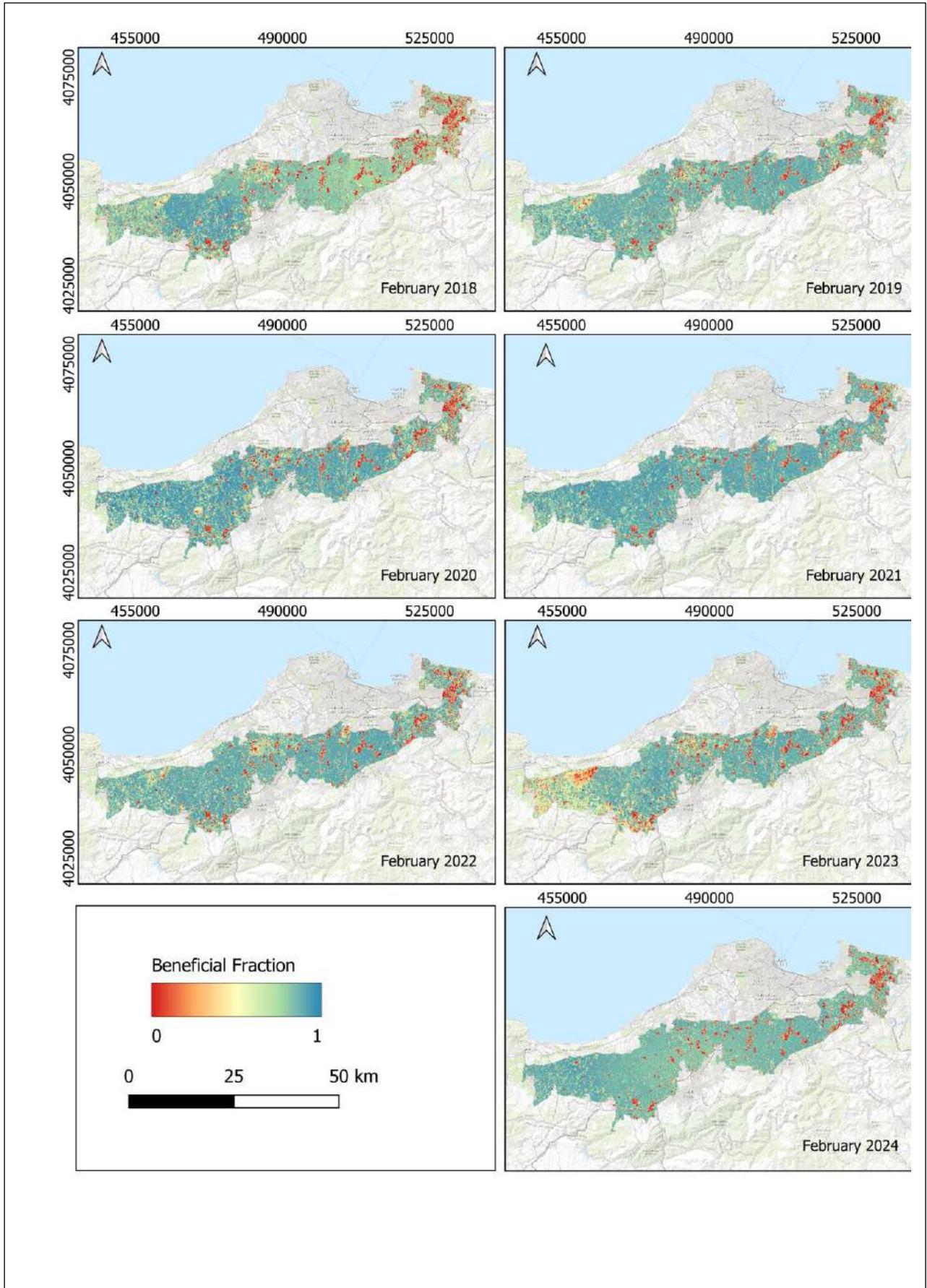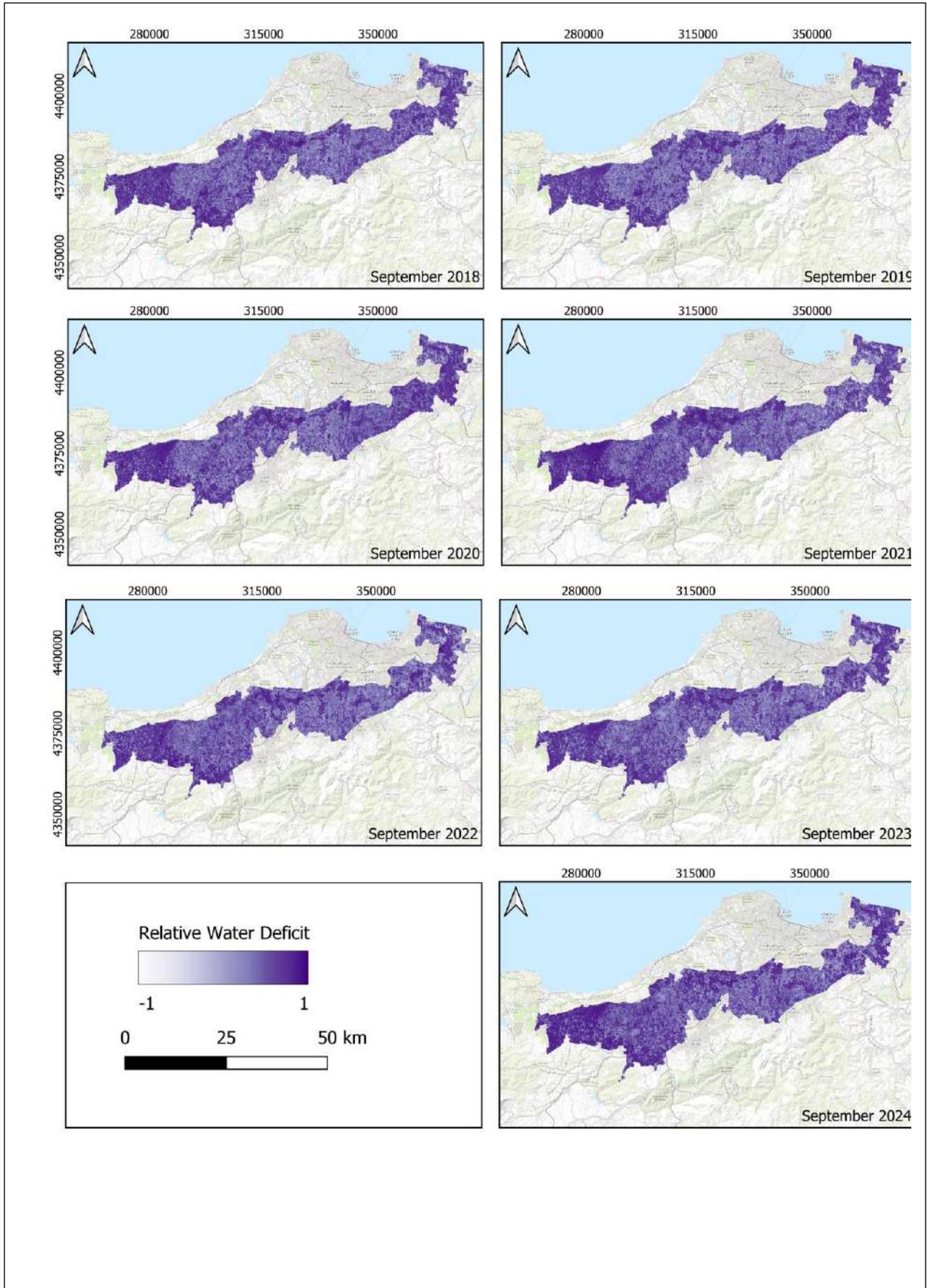
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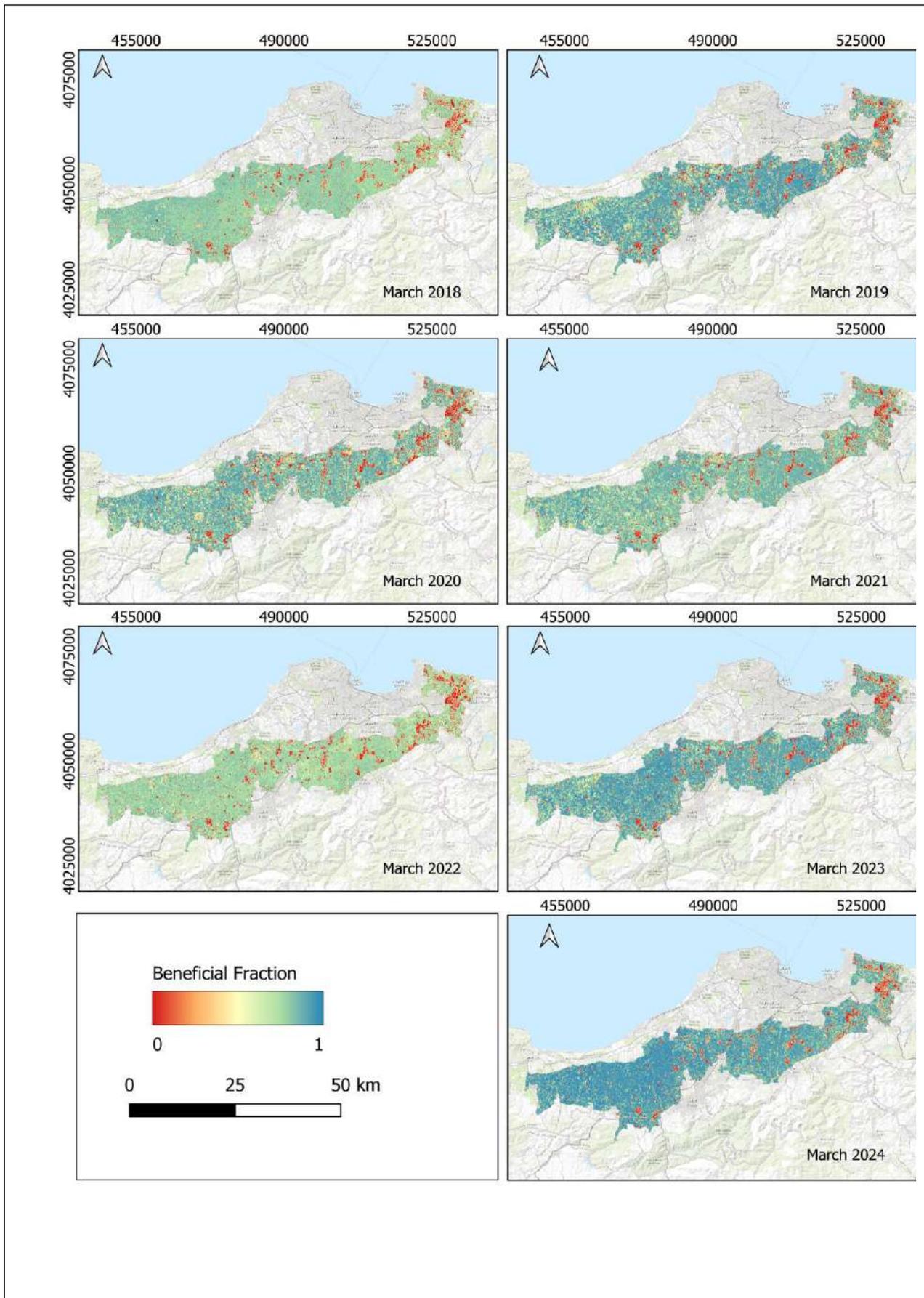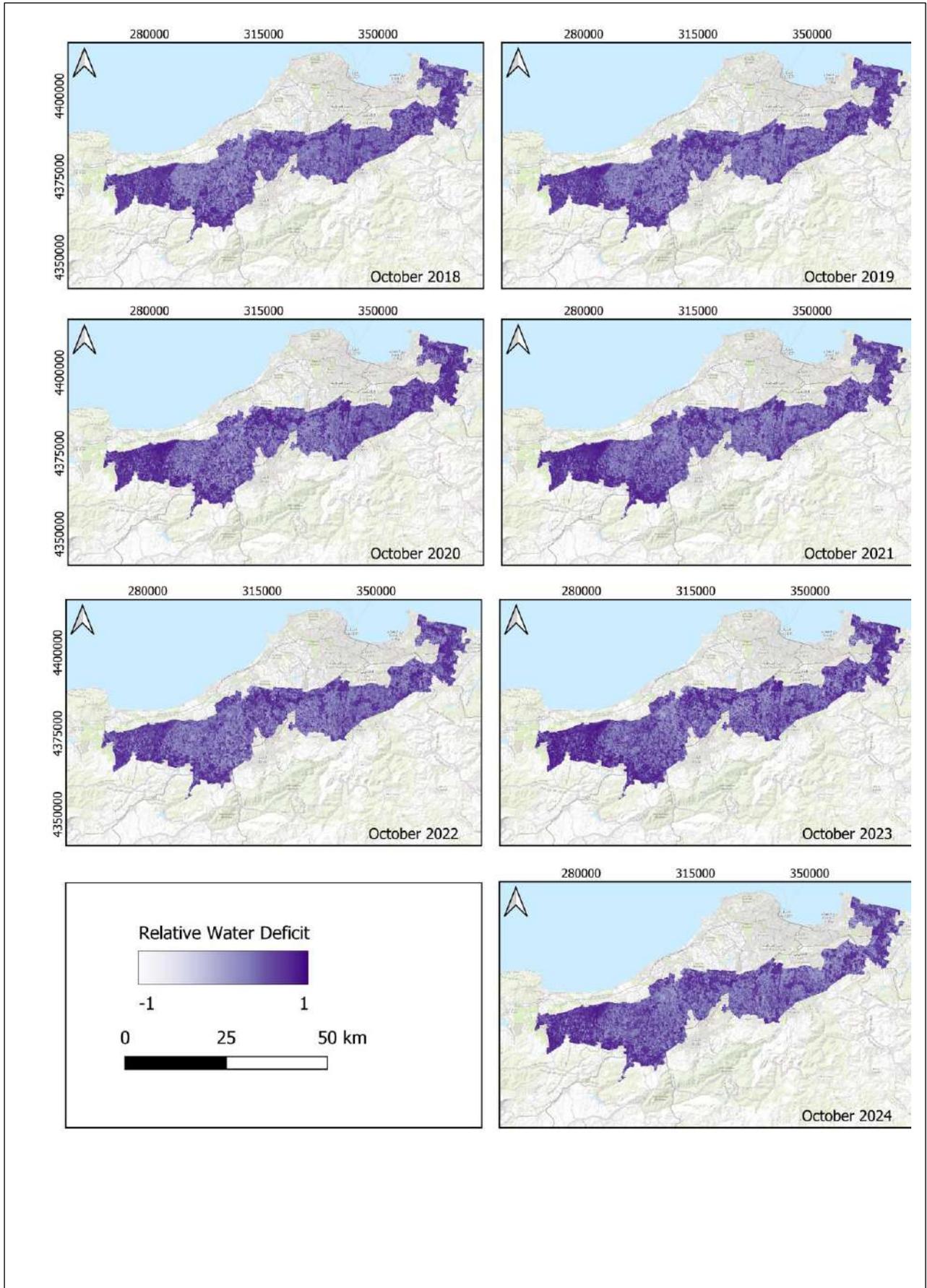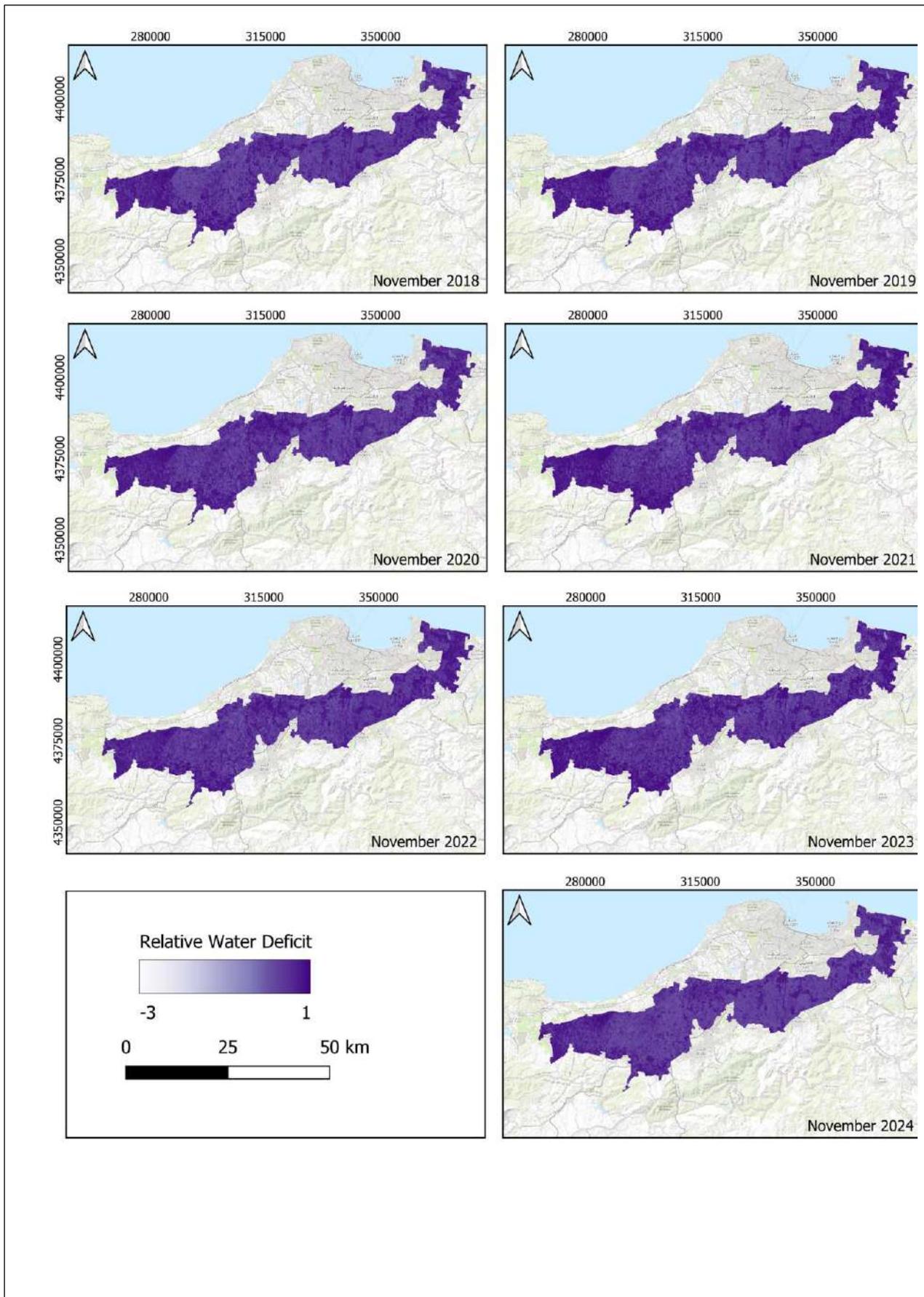
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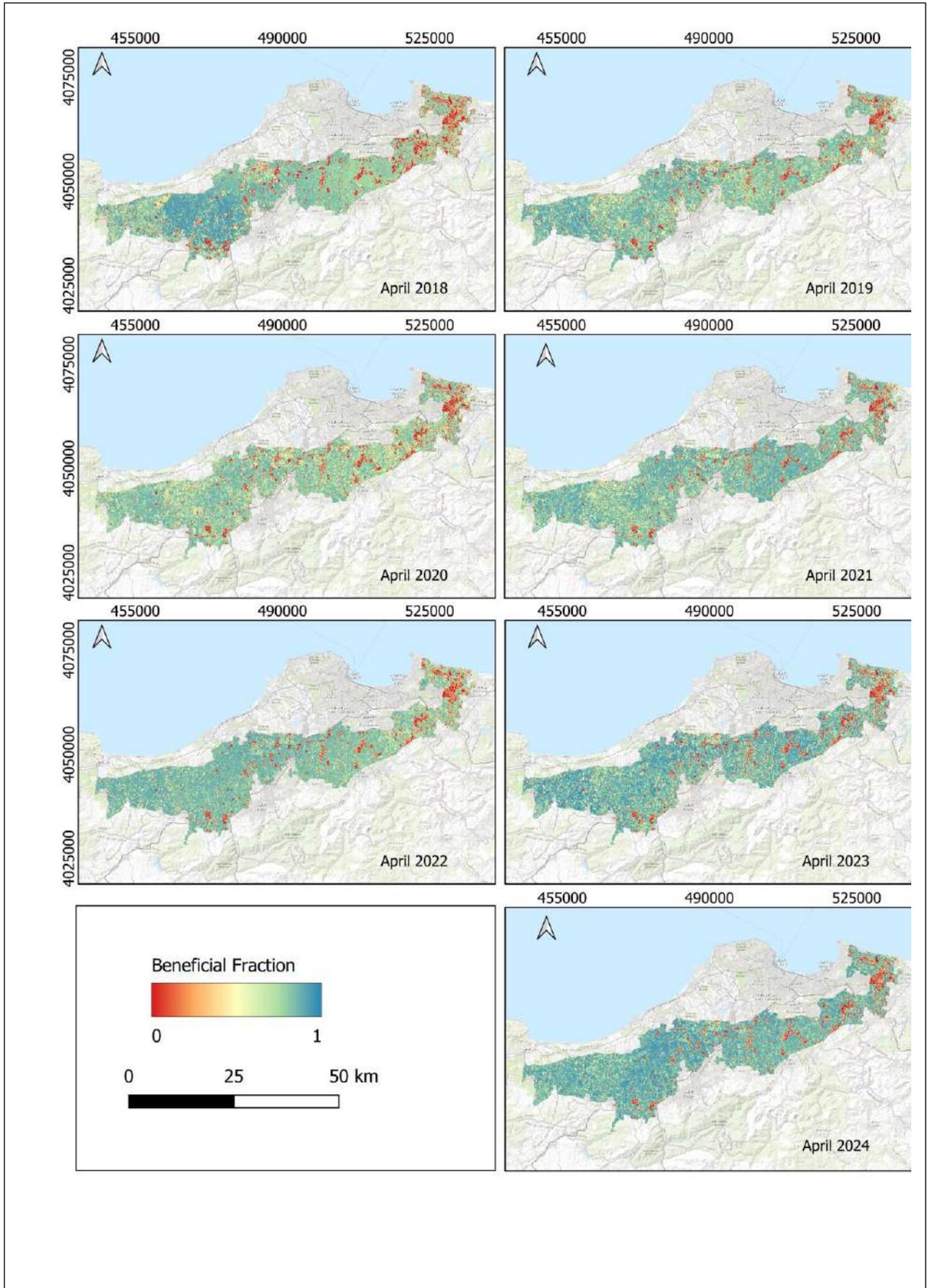
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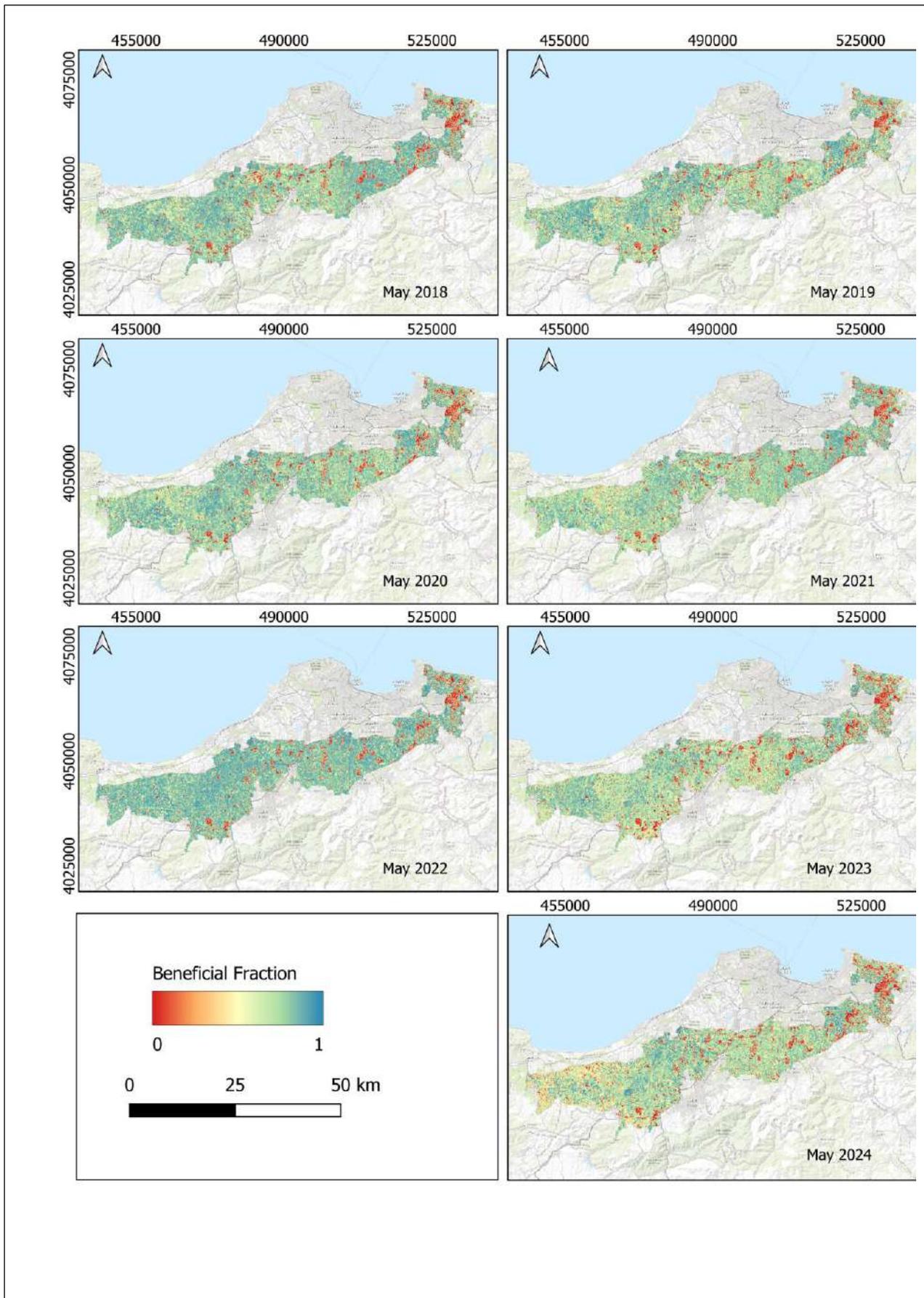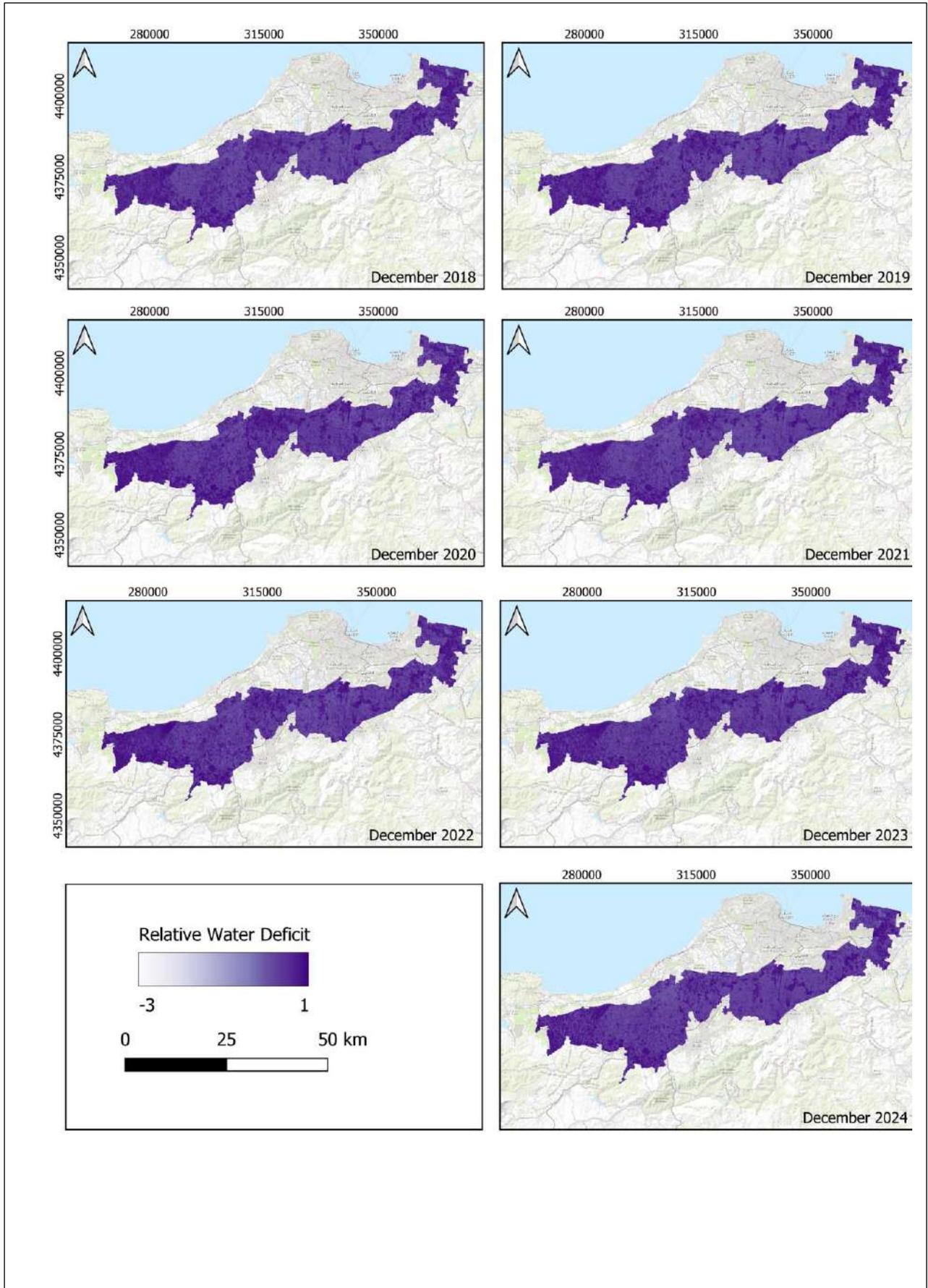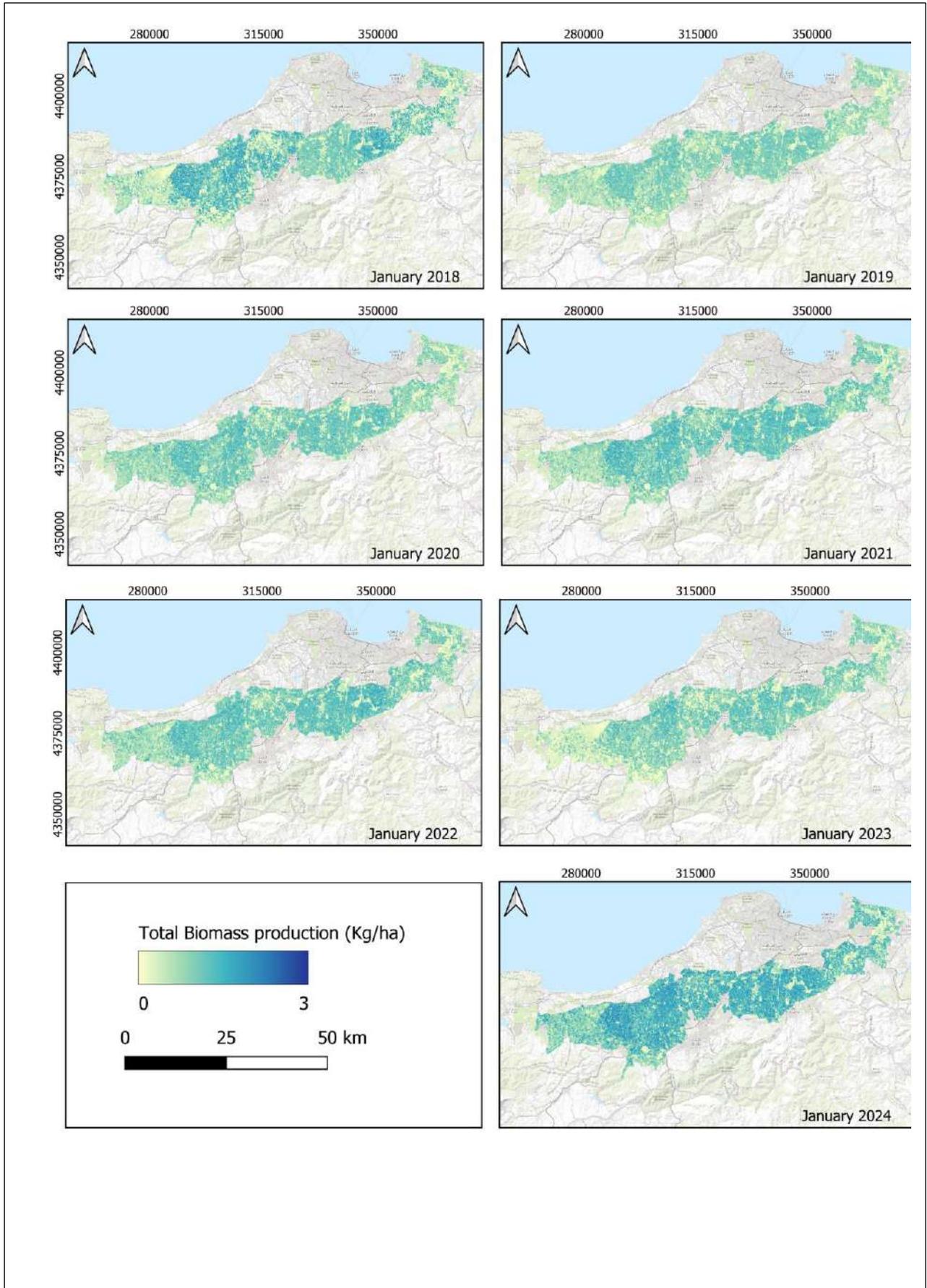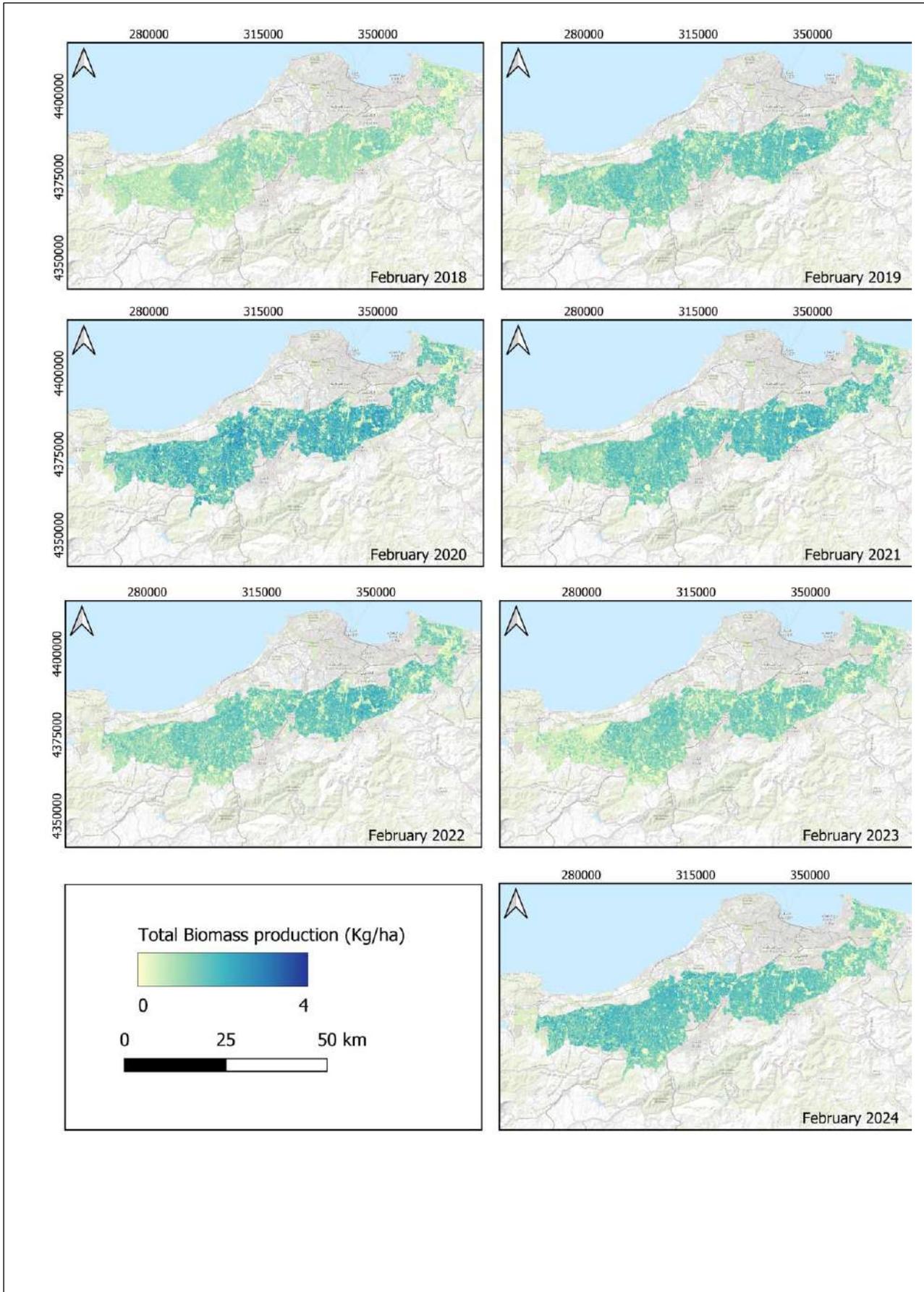
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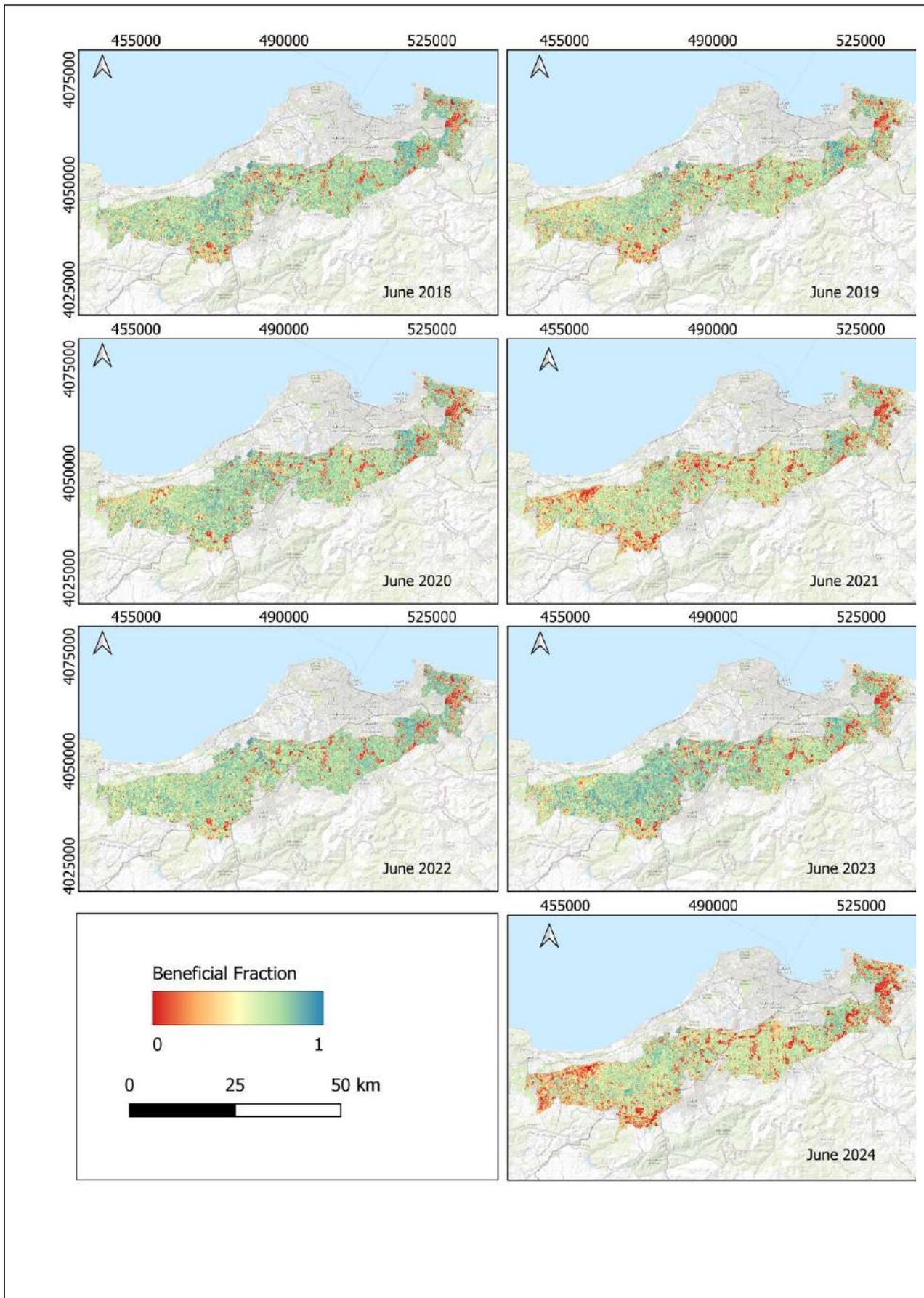
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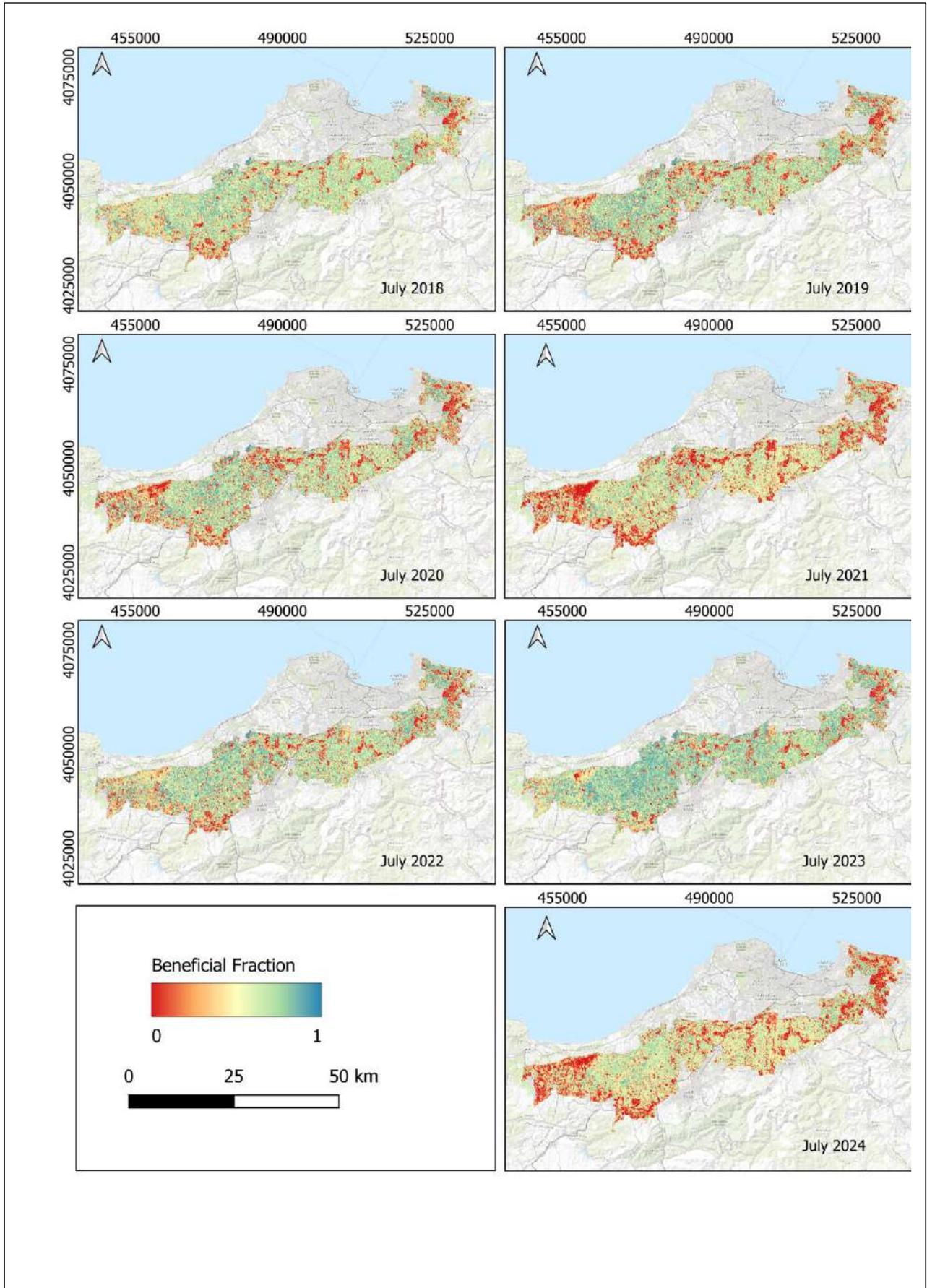
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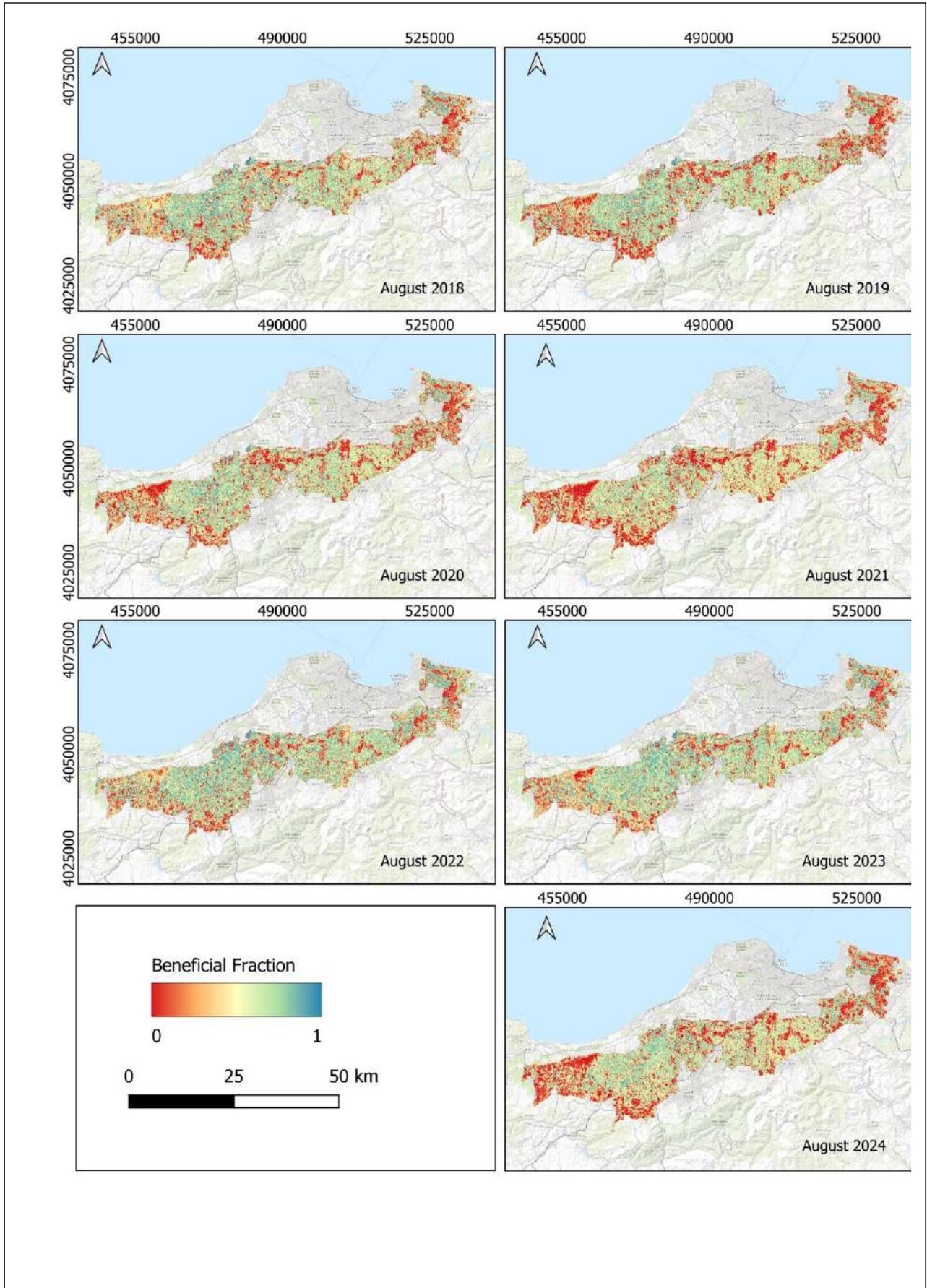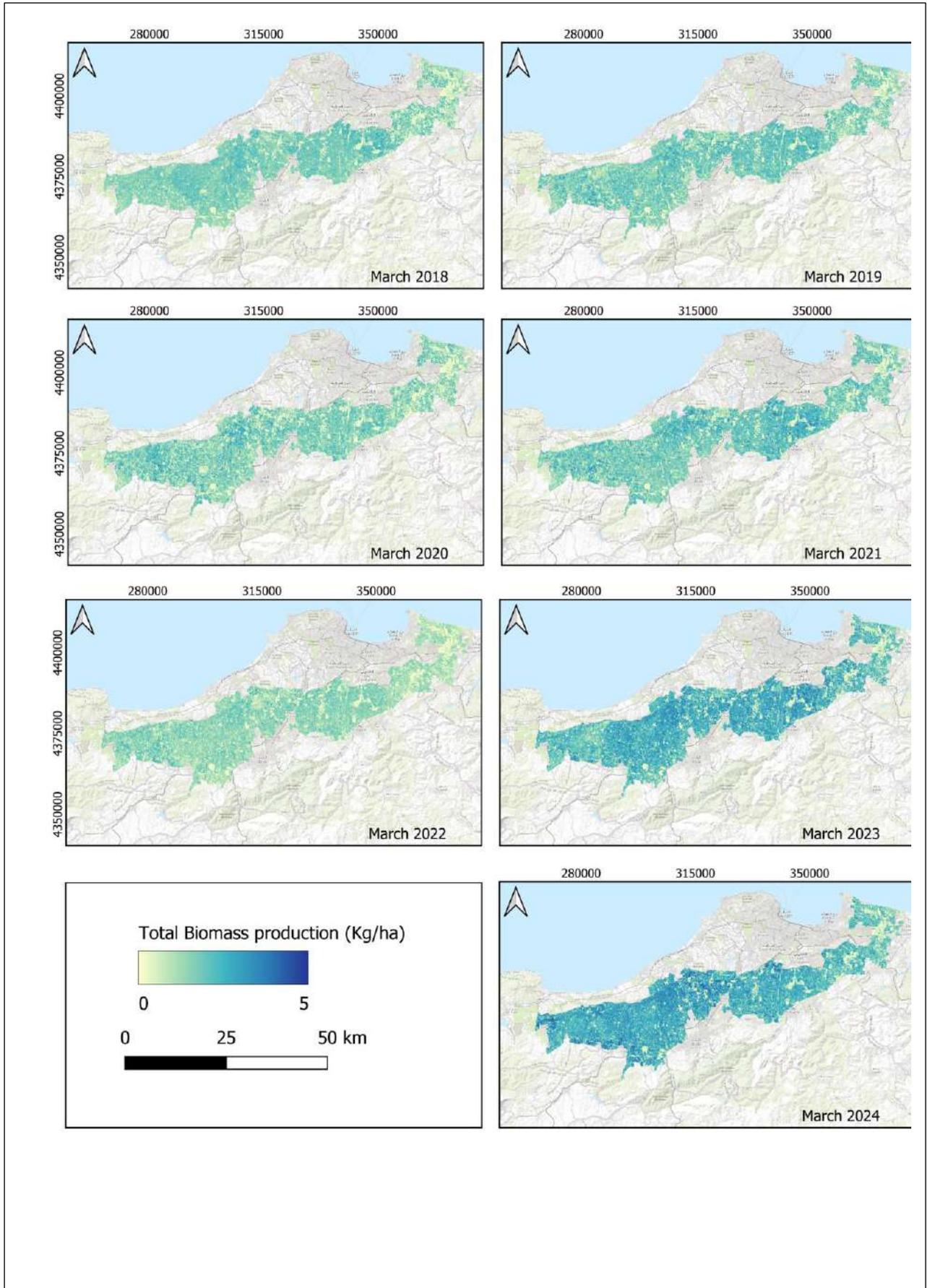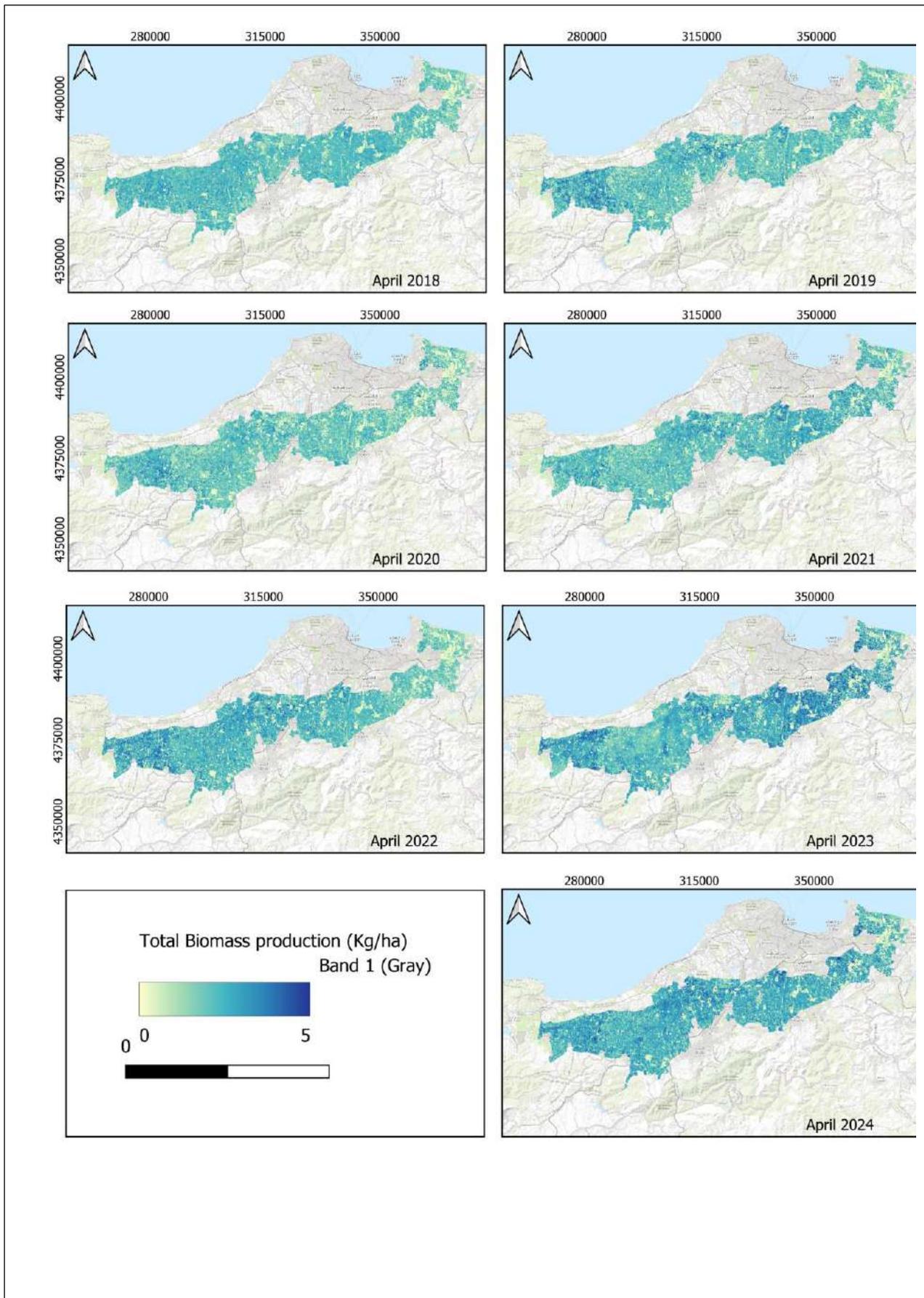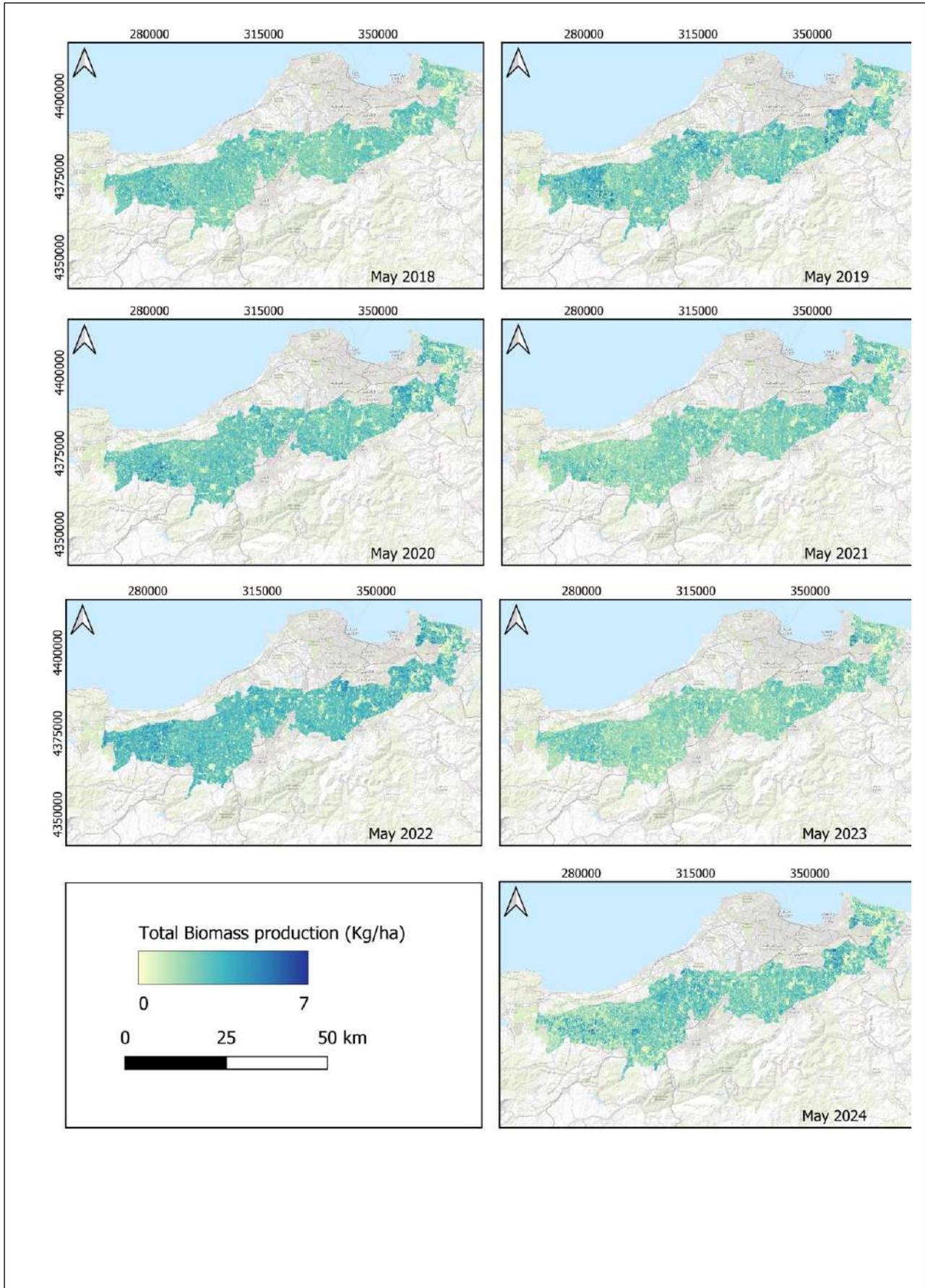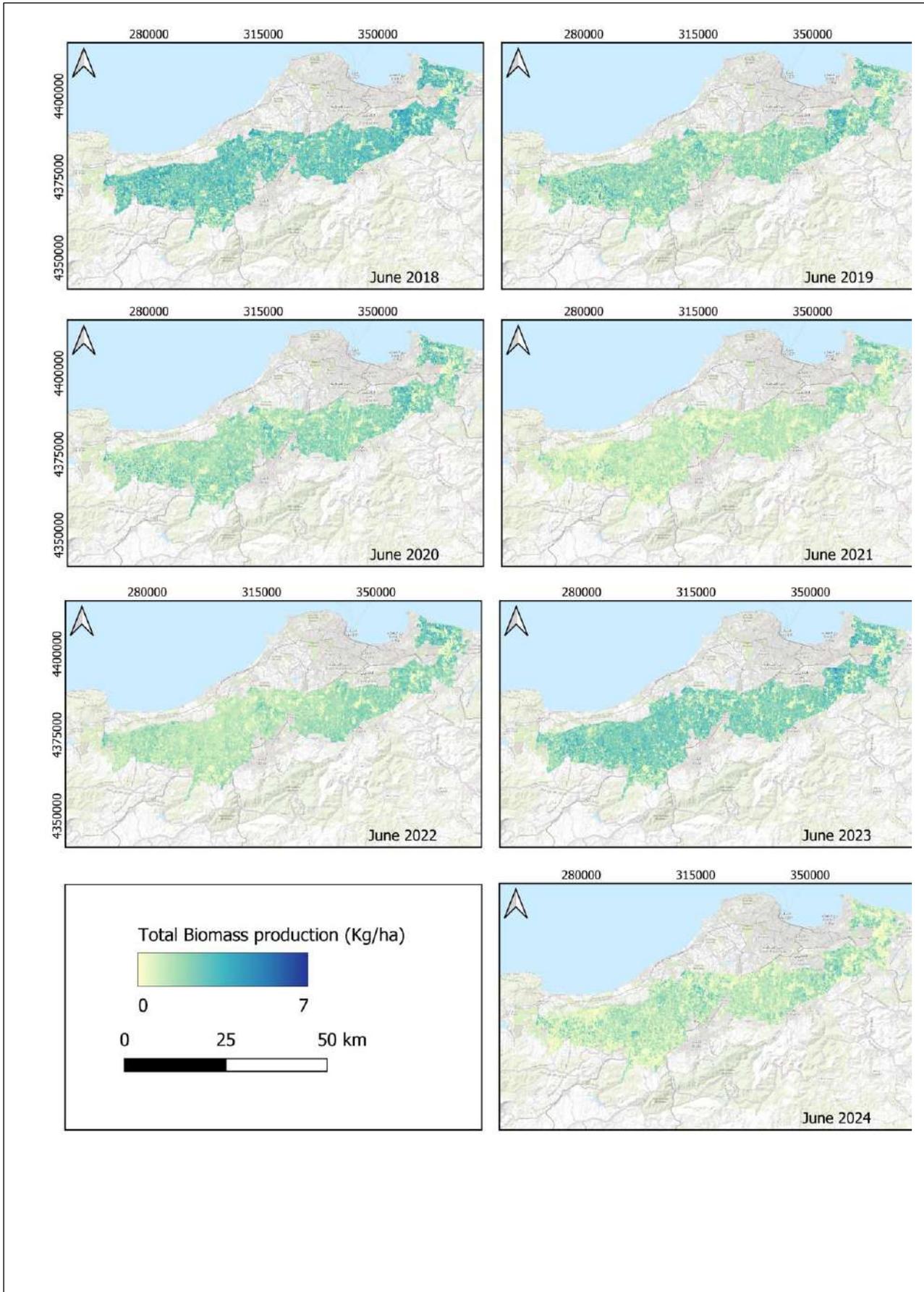
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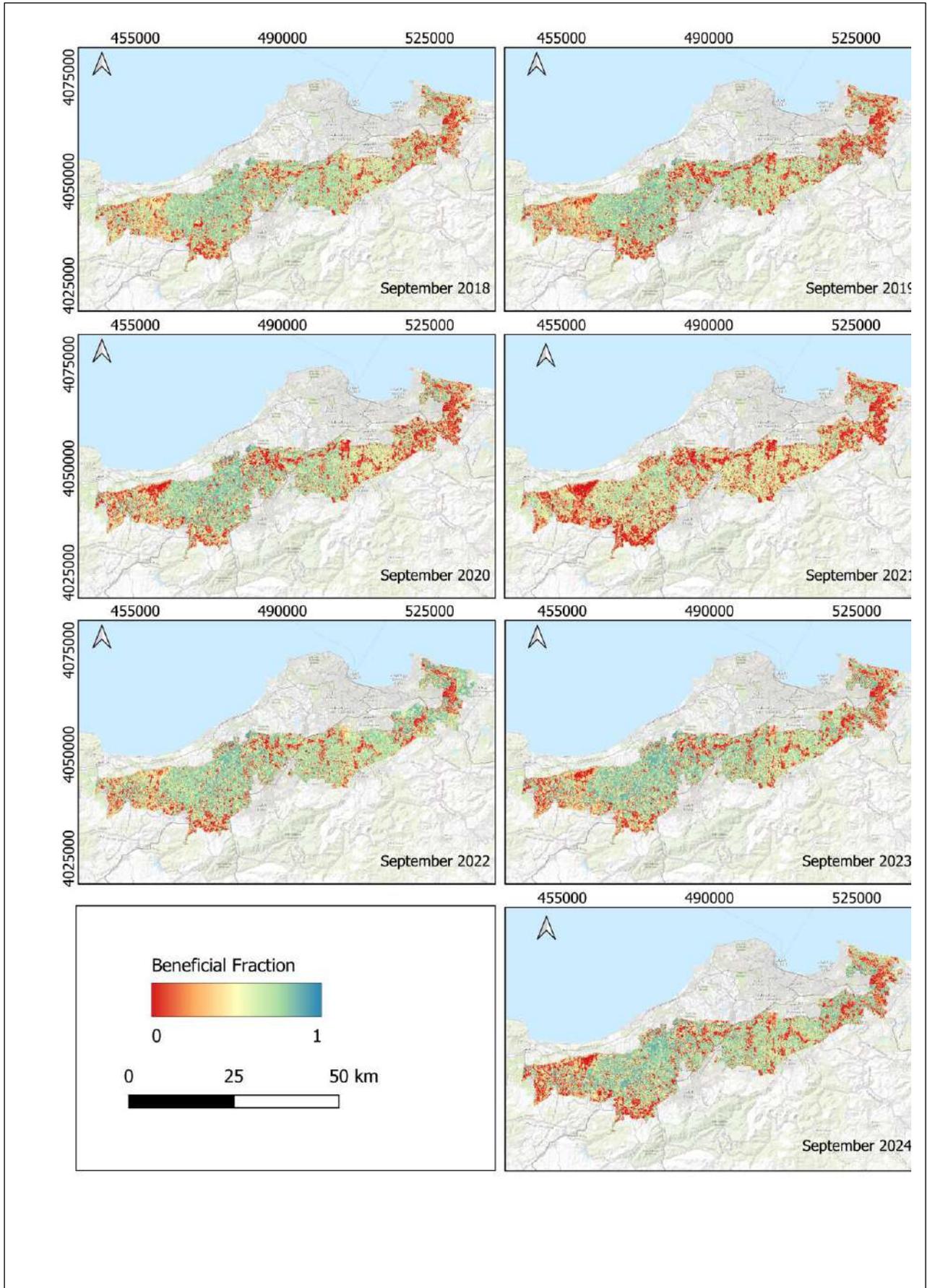
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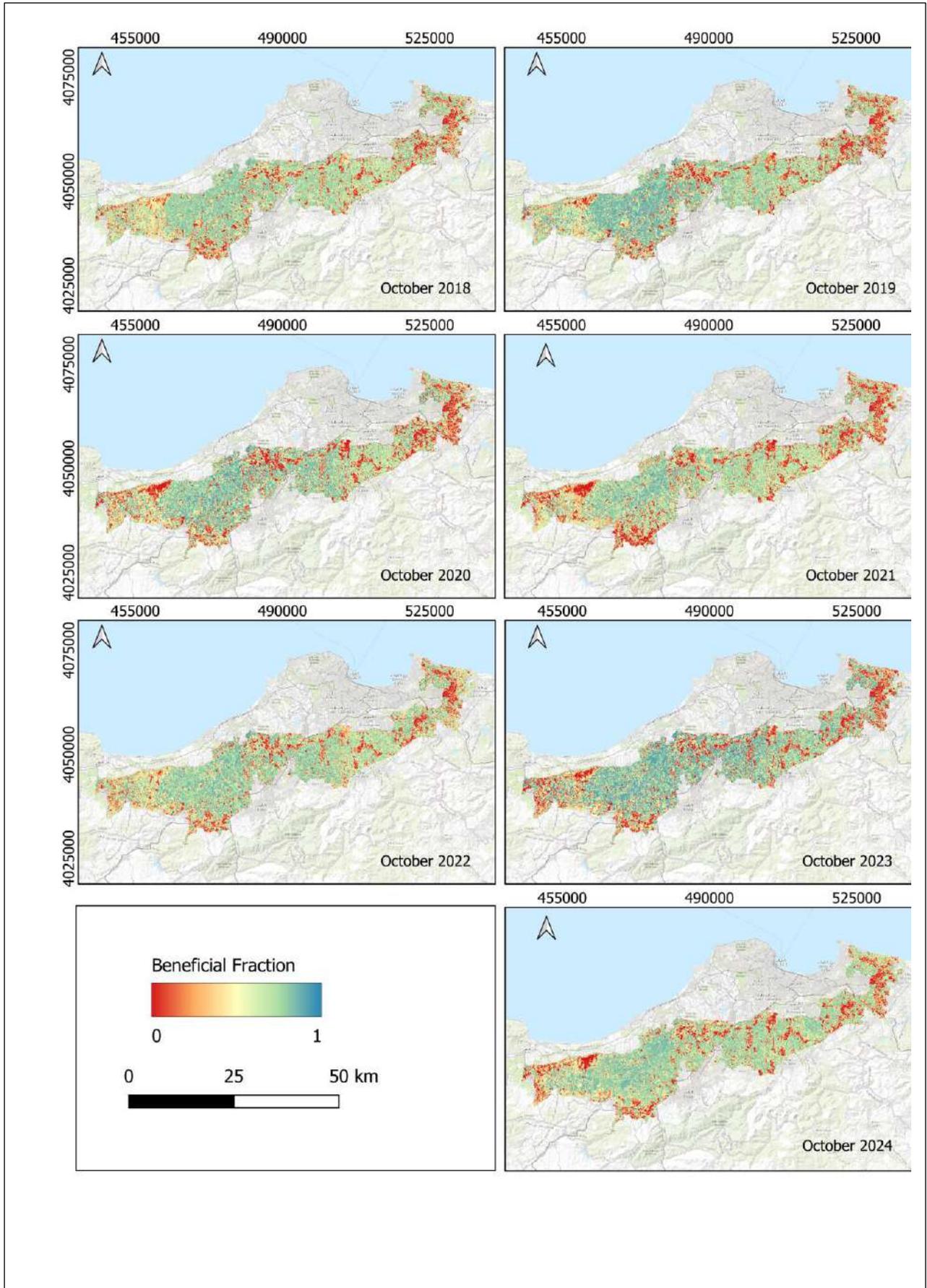
ANNEX No 11

ANNEX No 12

ANNEX No 13

January 2018

January 2019

January 2020

January 2021

January 2022

January 2023

Adequacy (Relative Evapotranspiration)

0   2

0   25   50 km

January 2024
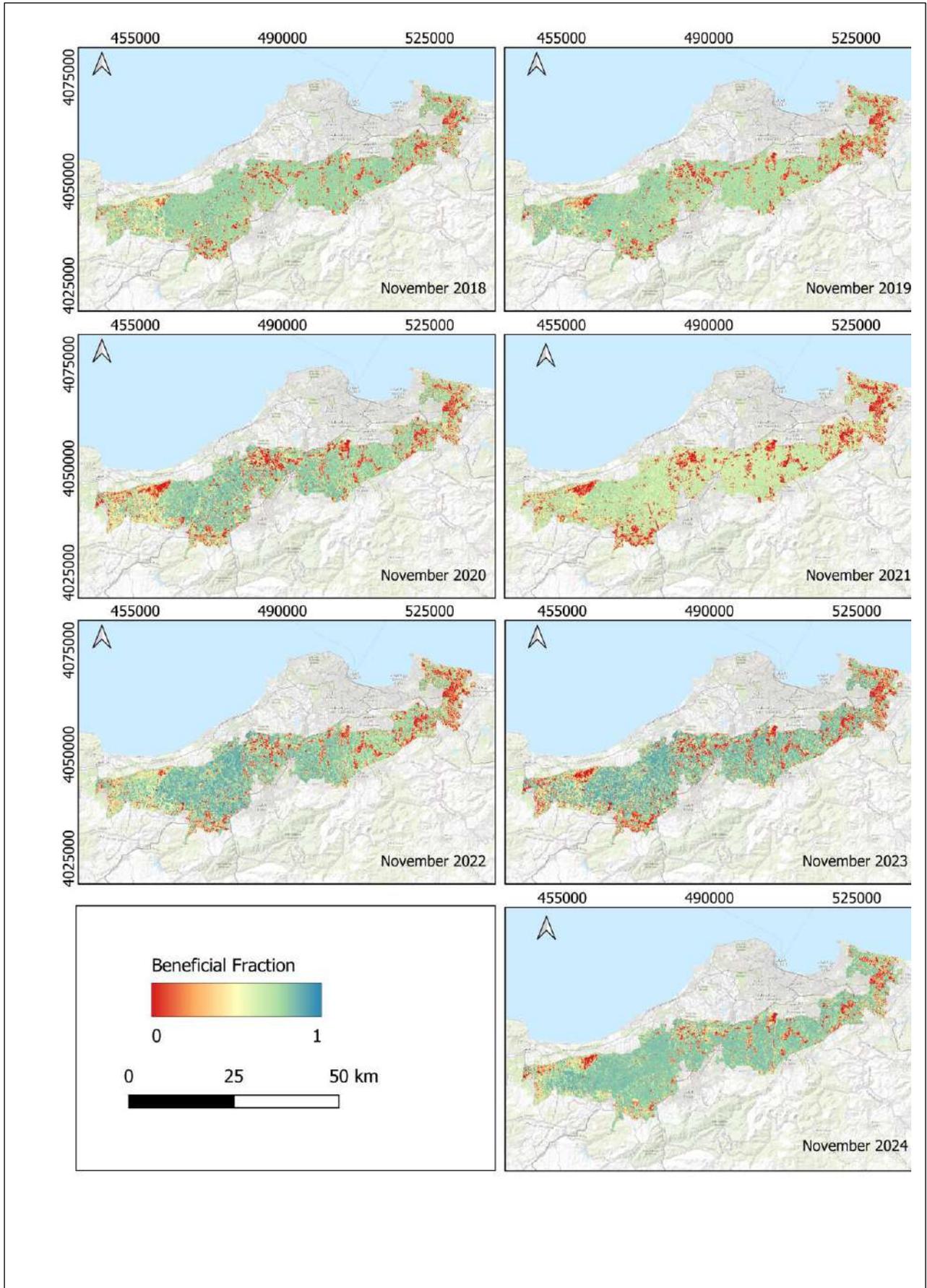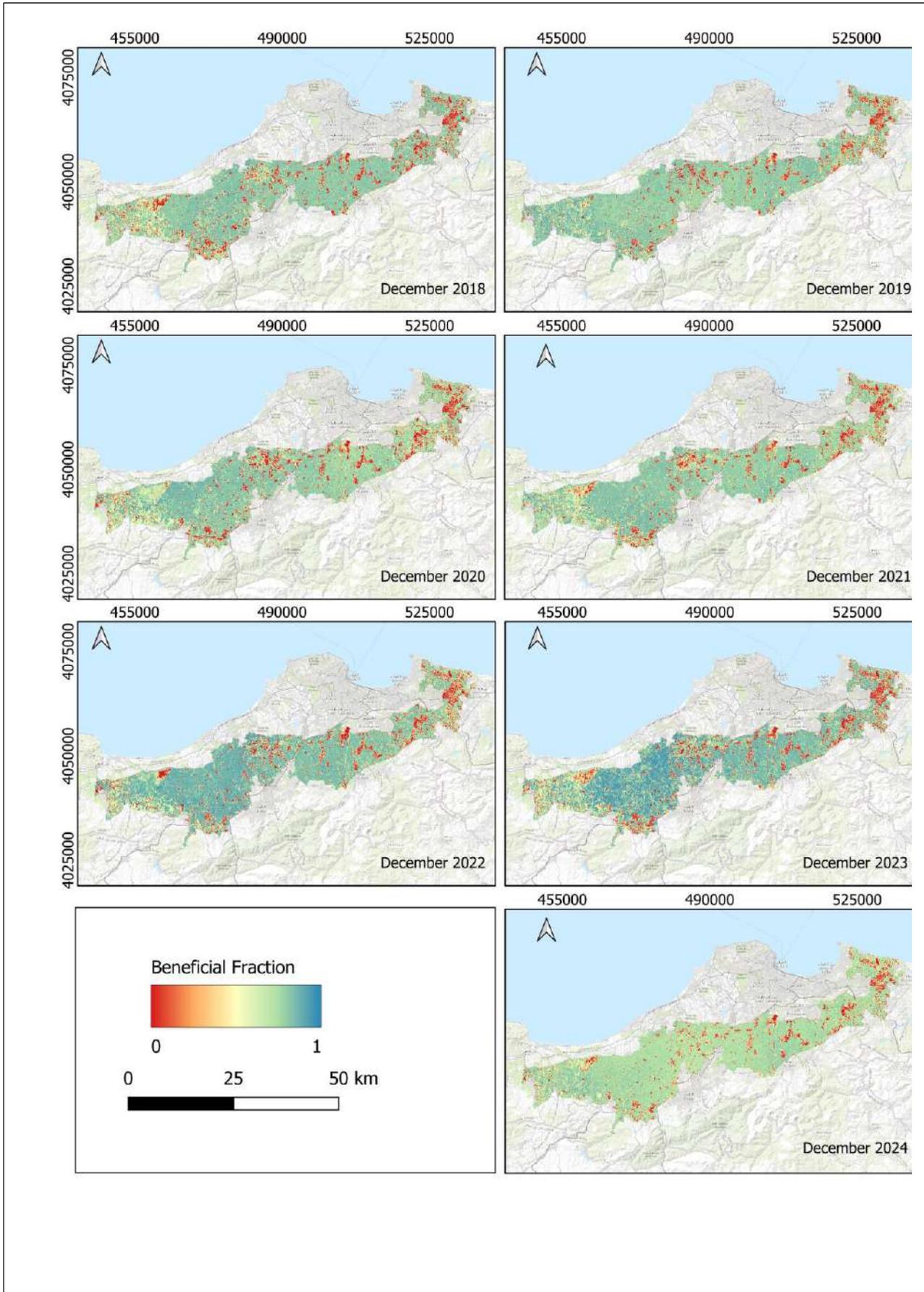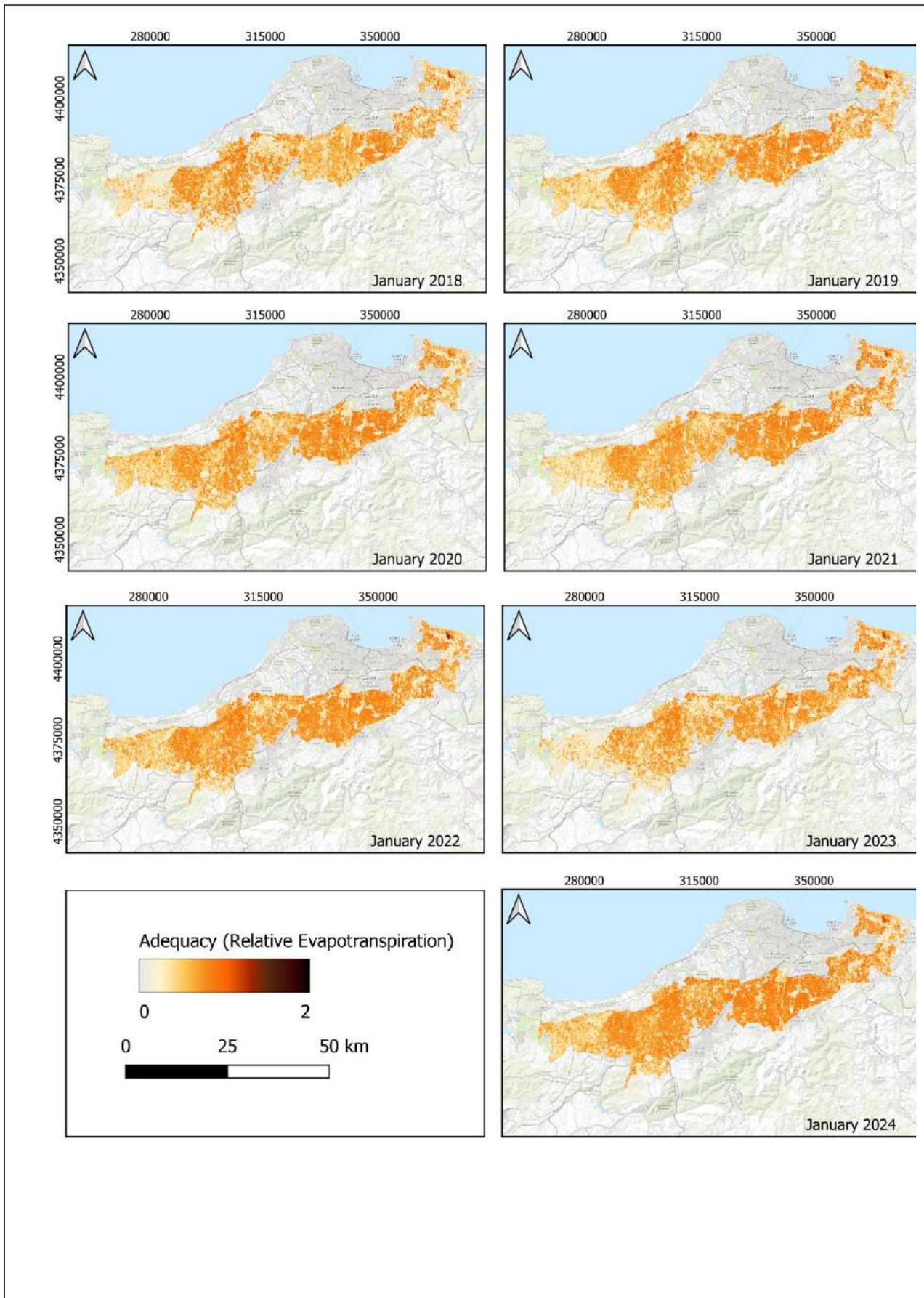
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Adequacy (Relative Evapotranspiration)

April 2018

April 2019

April 2020
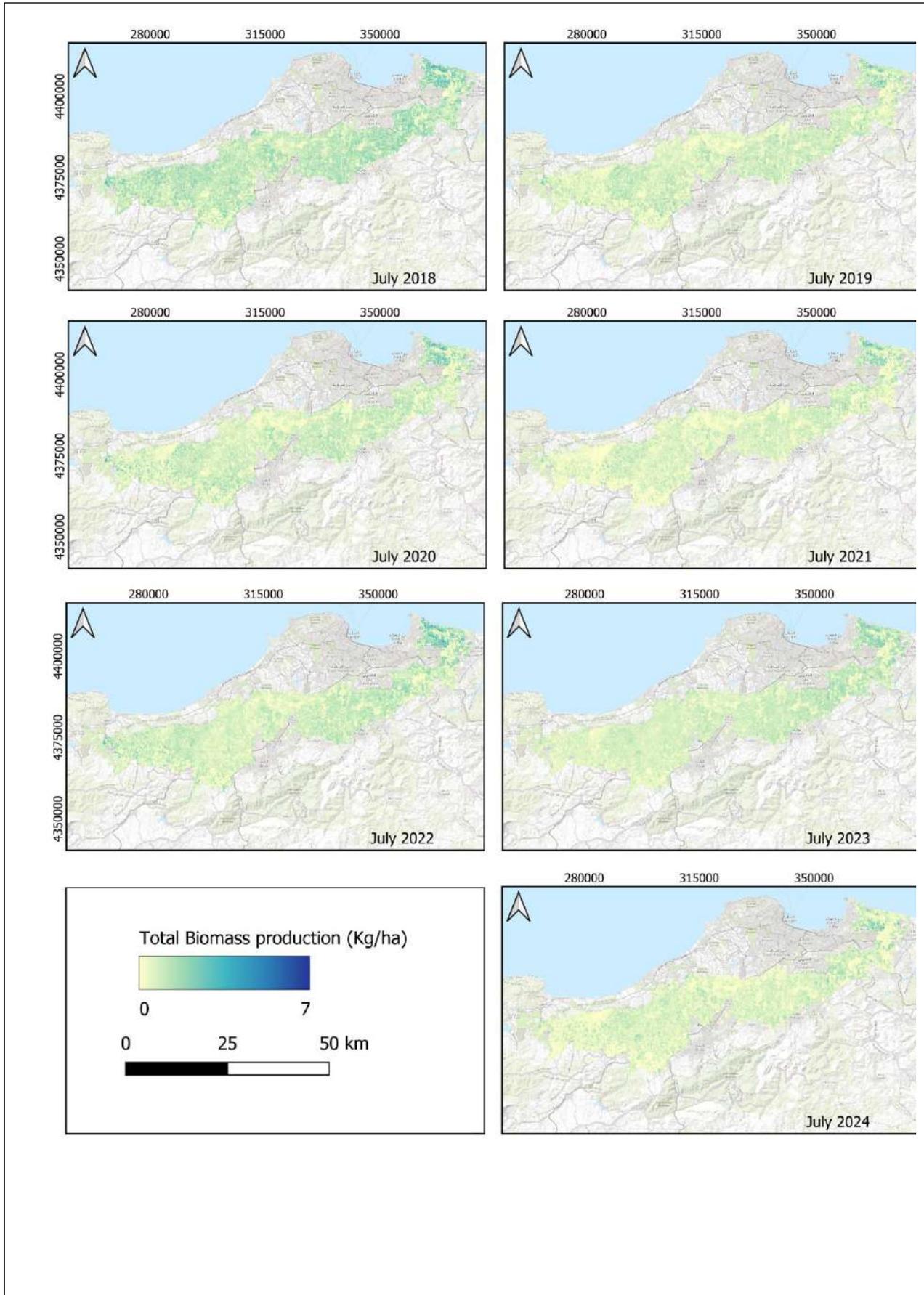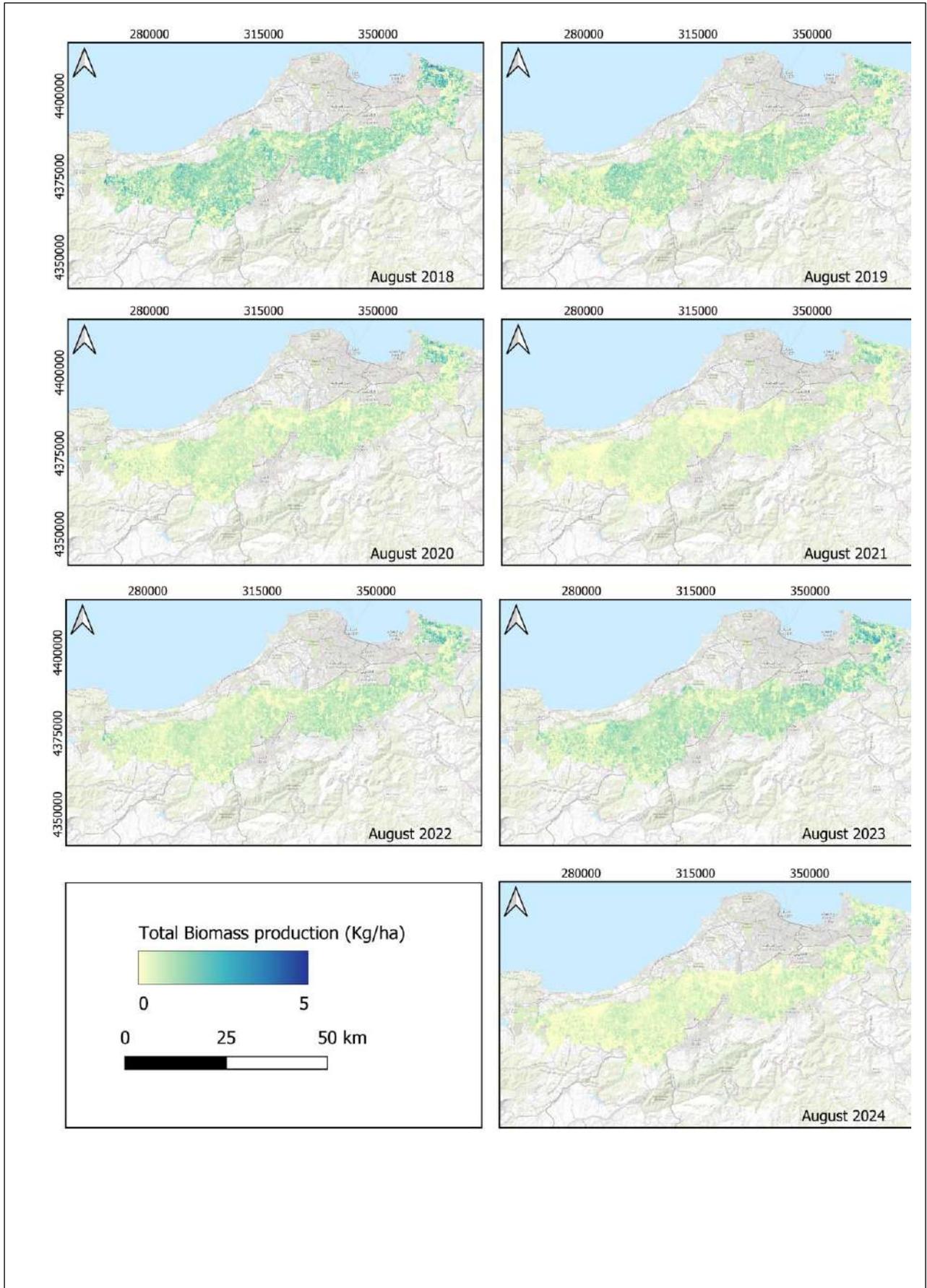
April 2021

April 2022

April 2023

April 2024
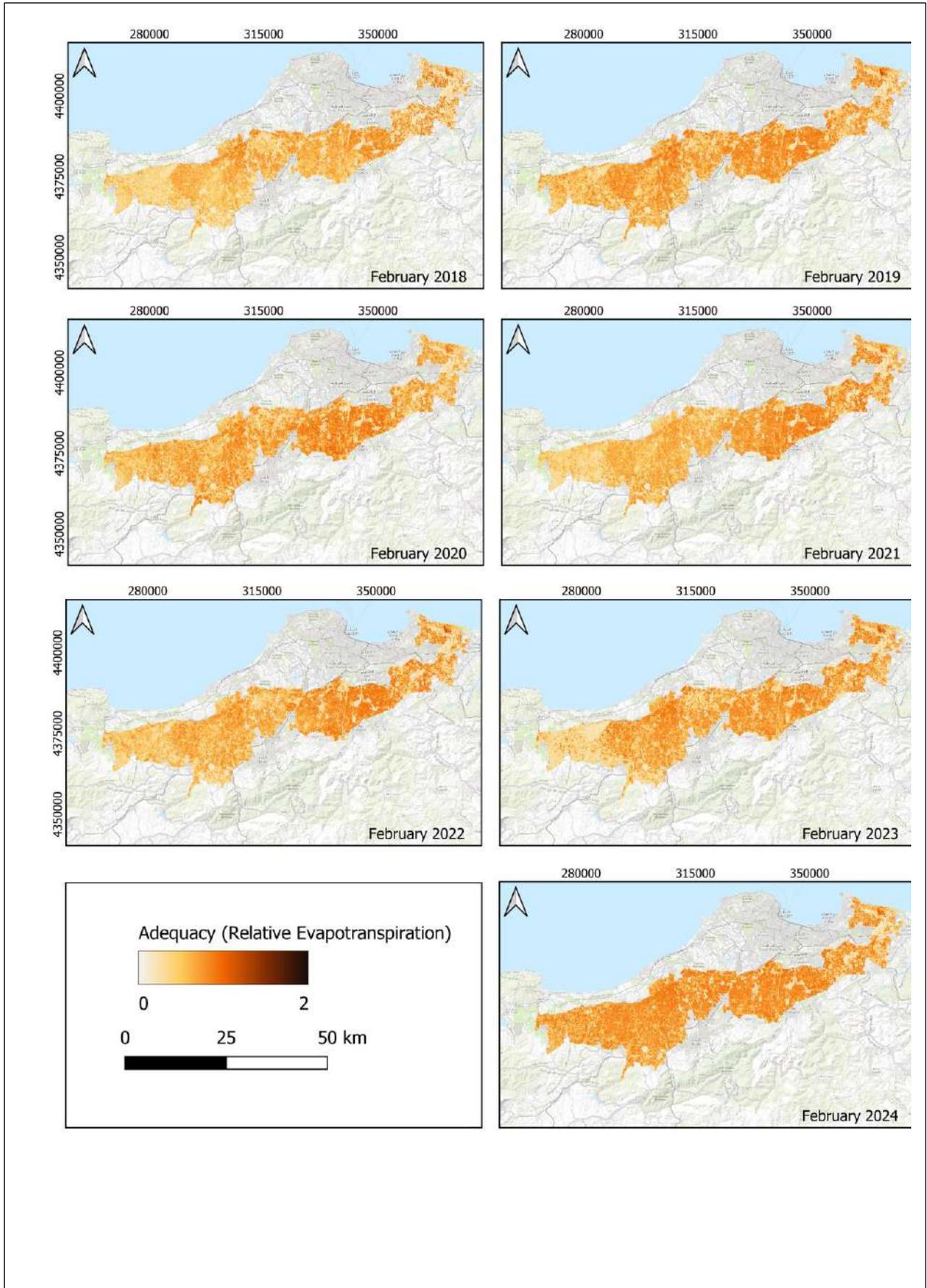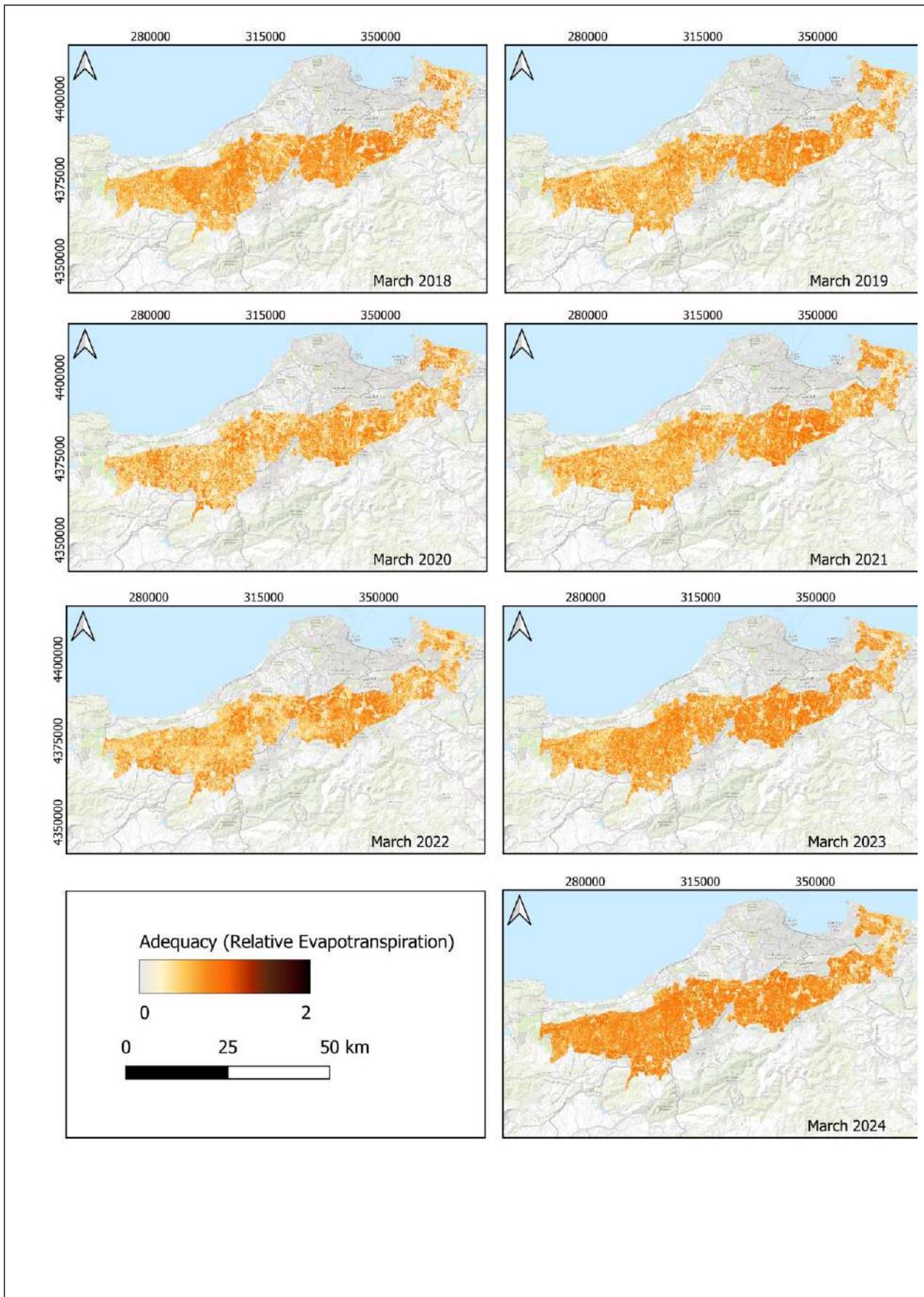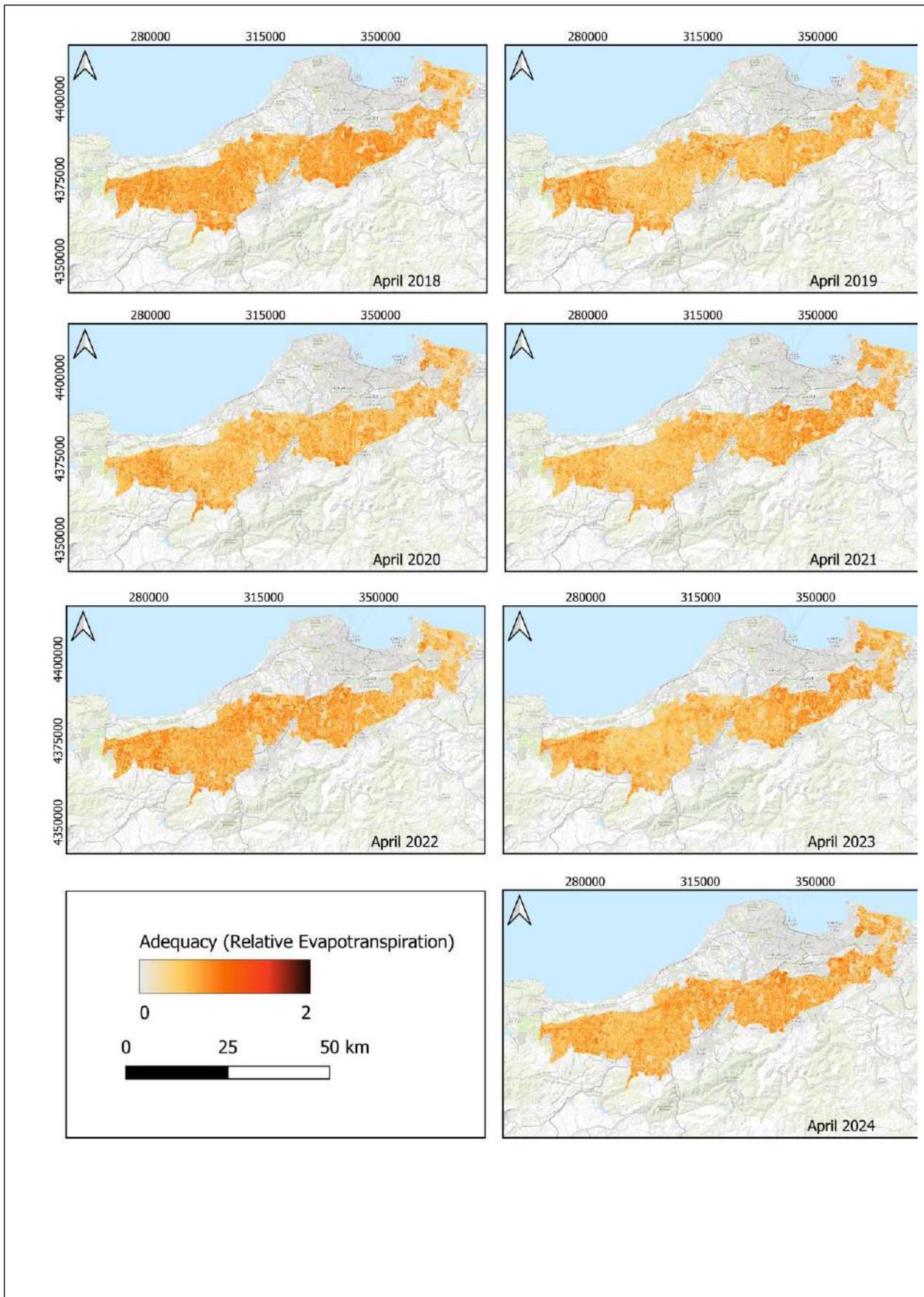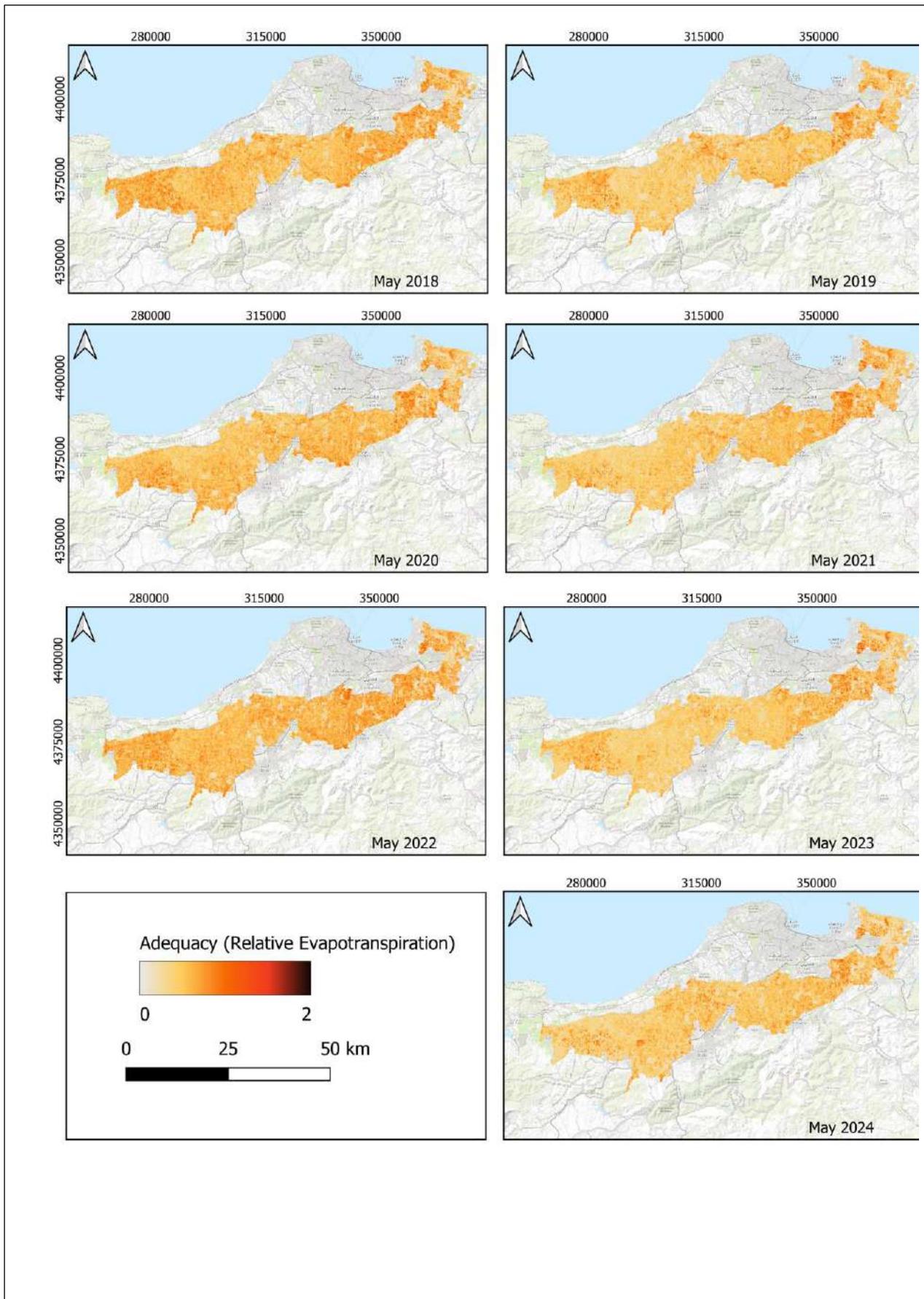
ANNEX No 17

ANNEX No 18

ANNEX No 19

ANNEX No 20

Adequacy (Relative Evapotranspiration)

0   2

0   25   50 km

ANNEX No 21

September 2018

September 2019

September 2020

September 2021

September 2022

September 2023

Adequacy (Relative Evapotranspiration)

0   2

0   25   50 km

September 2024

ANNEX No 22

October 2018

October 2019

October 2020

October 2021

October 2022

October 2023

Adequacy (Relative Evapotranspiration)
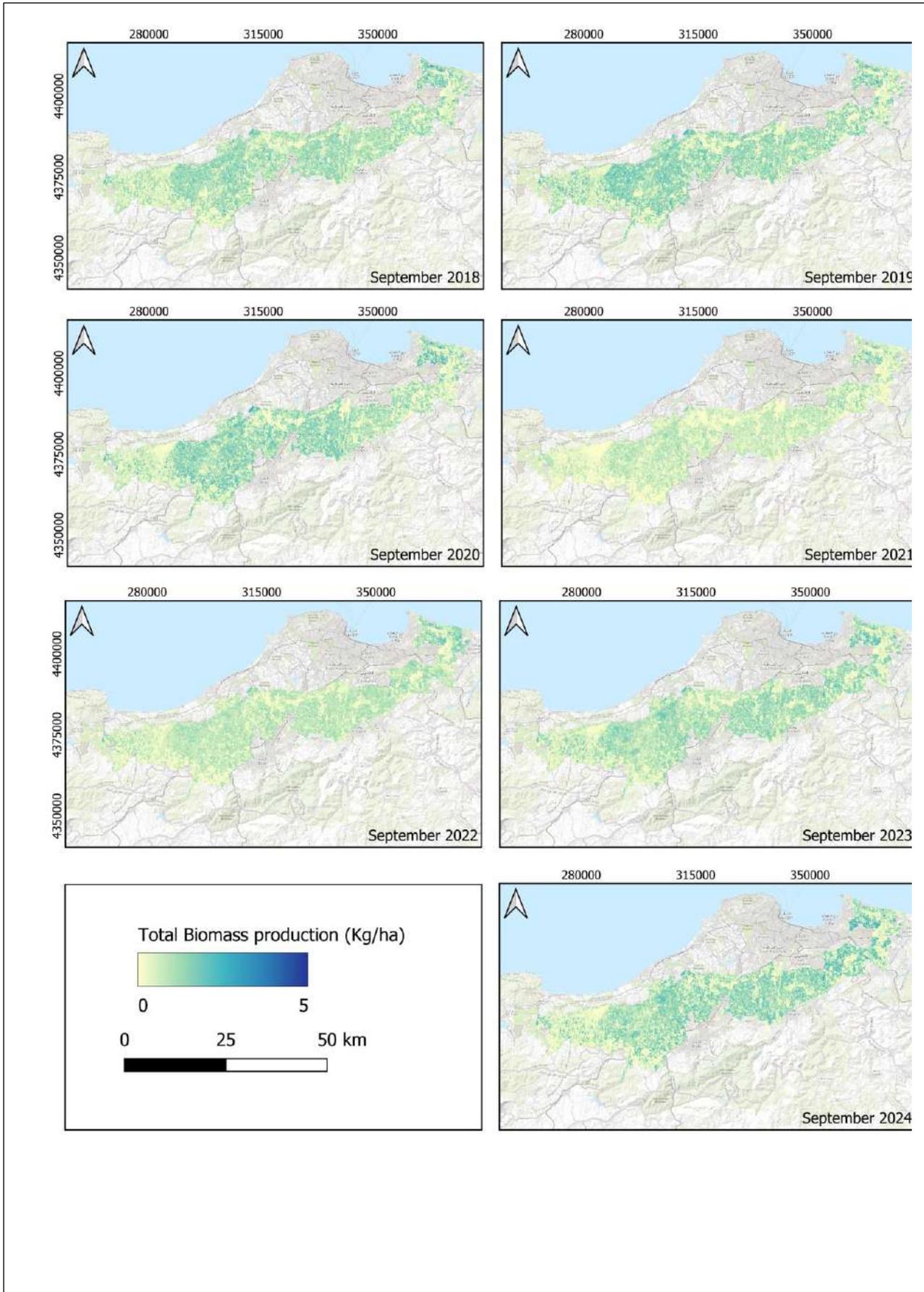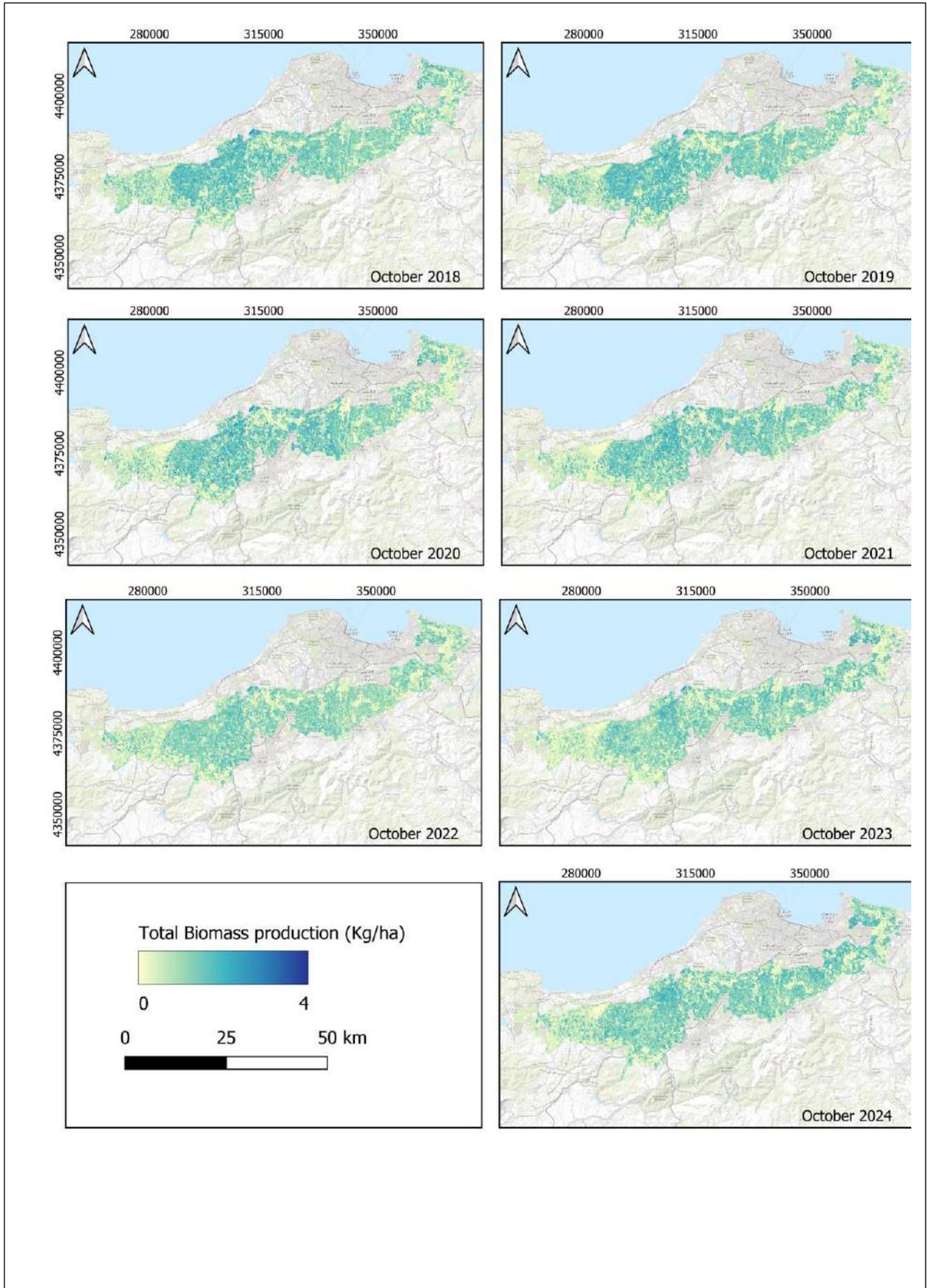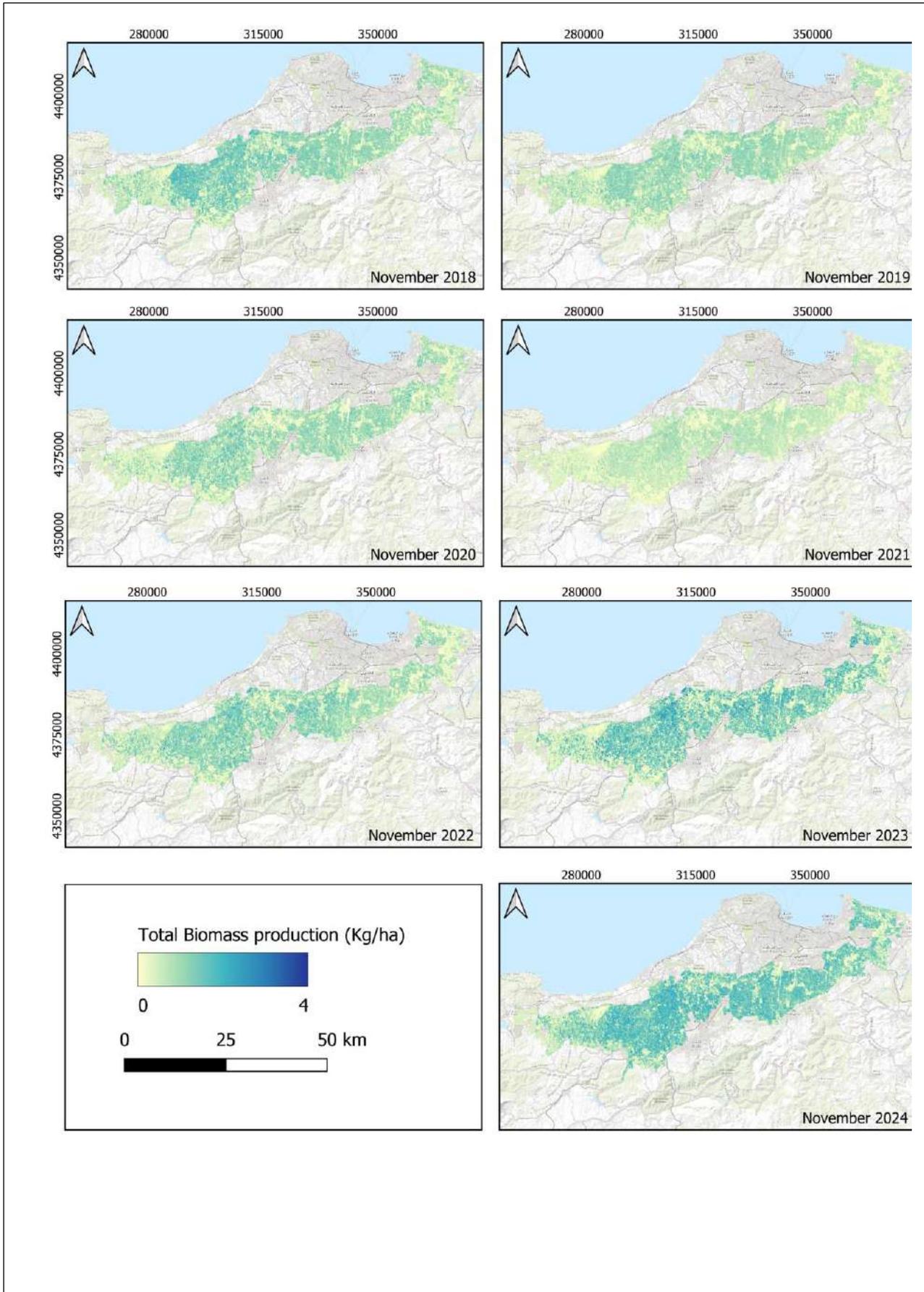
0   2

0   25   50 km

October 2024
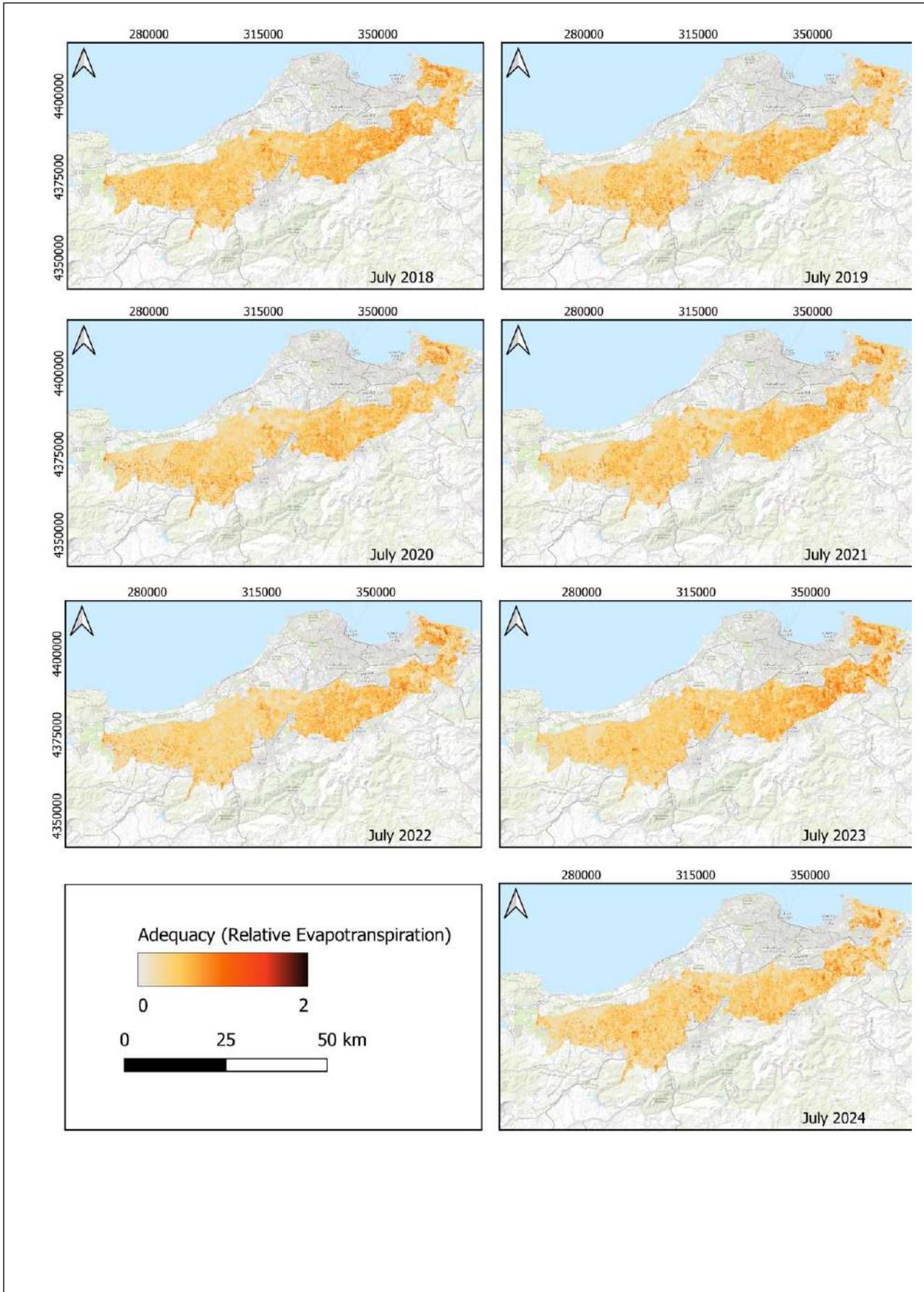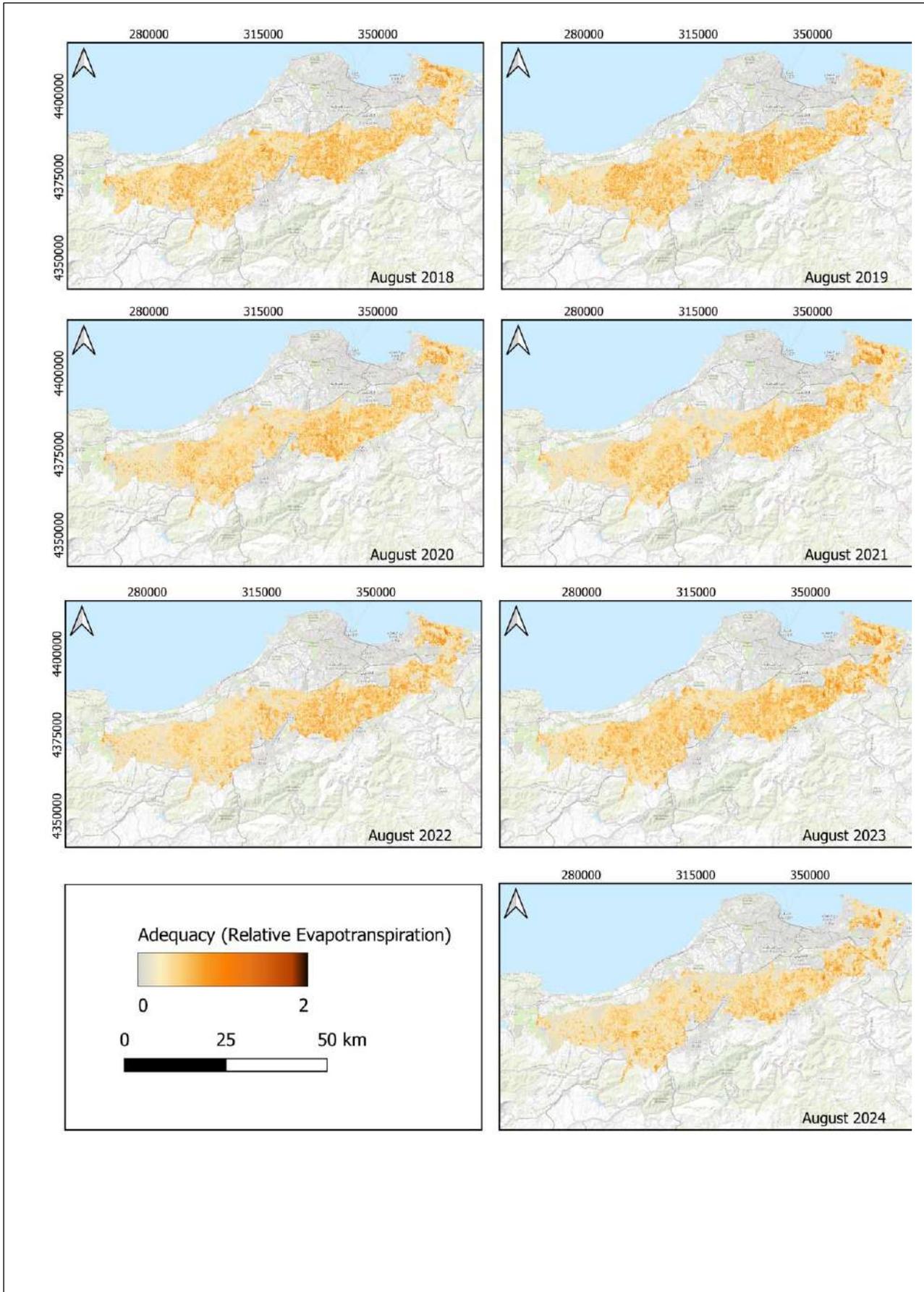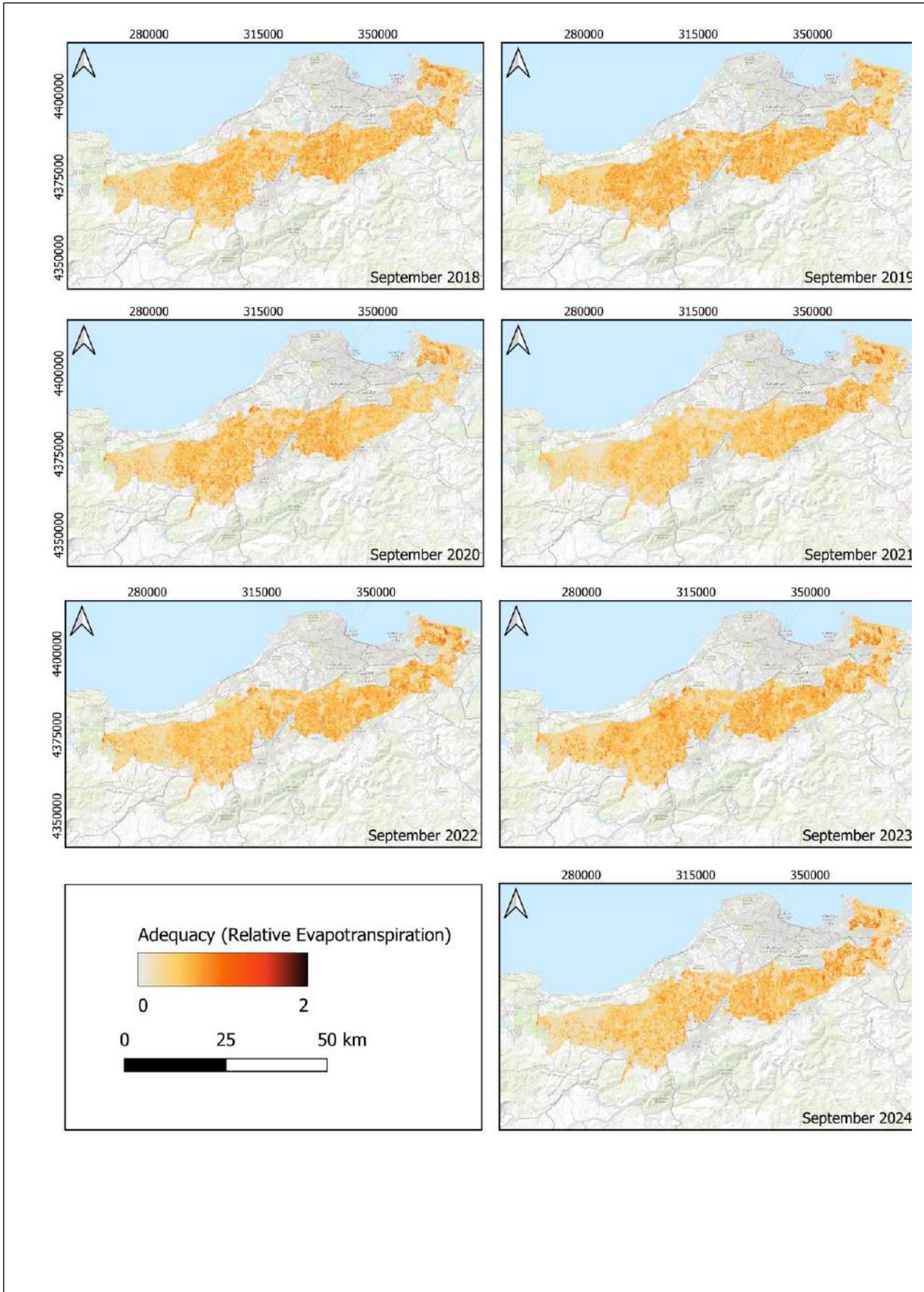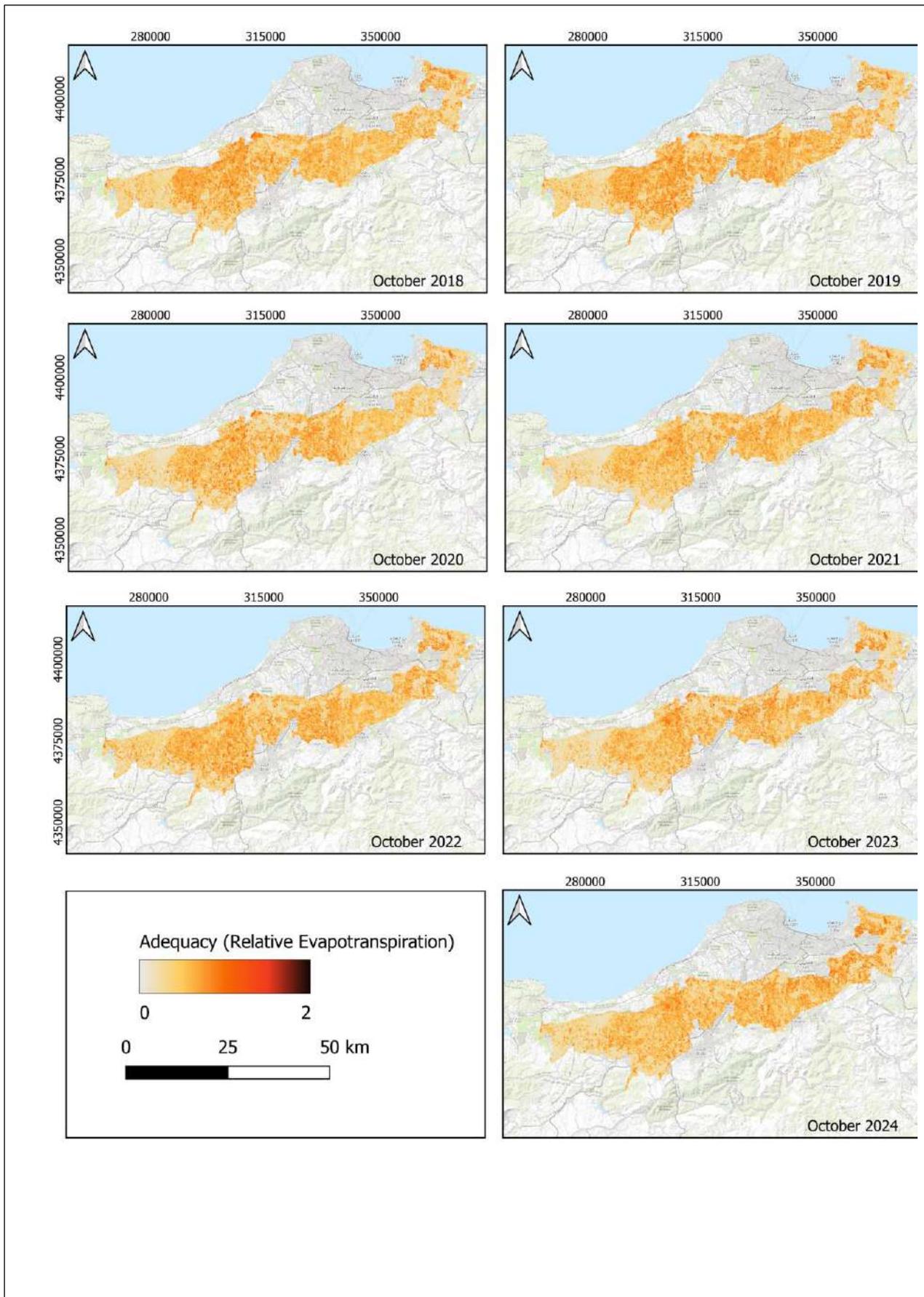
ANNEX No 23

ANNEX No 24

ANNEX No 26

January 2018

January 2019

January 2020

January 2021

January 2022

January 2023

Relative Water Deficit

0   -1   1   50 km

January 2024

ANNEX No 28

Relative Water Deficit

-1   1

0   25   50 km

ANNEX No 29

Relative Water Deficit

-1   1

0   25   50 km
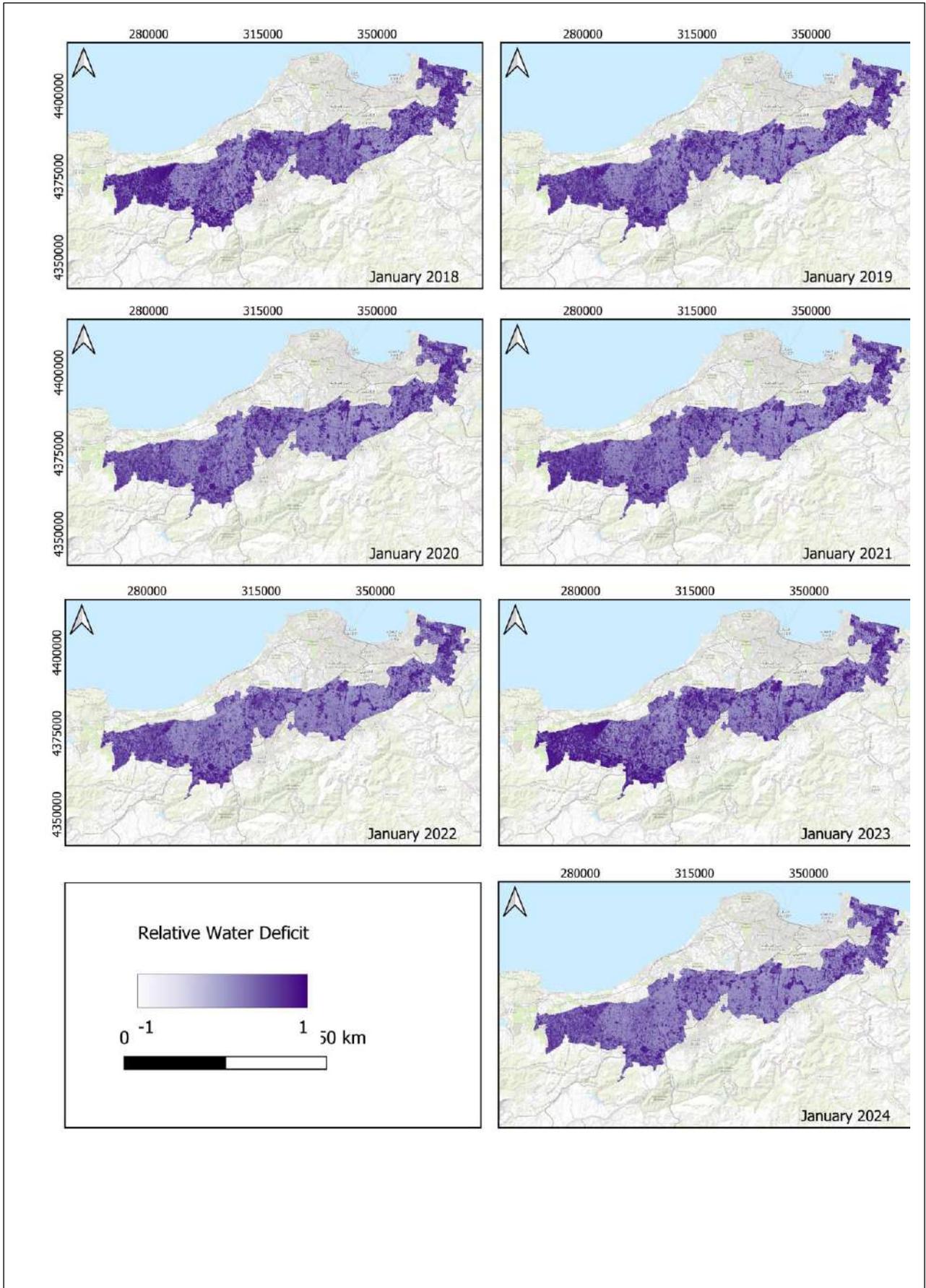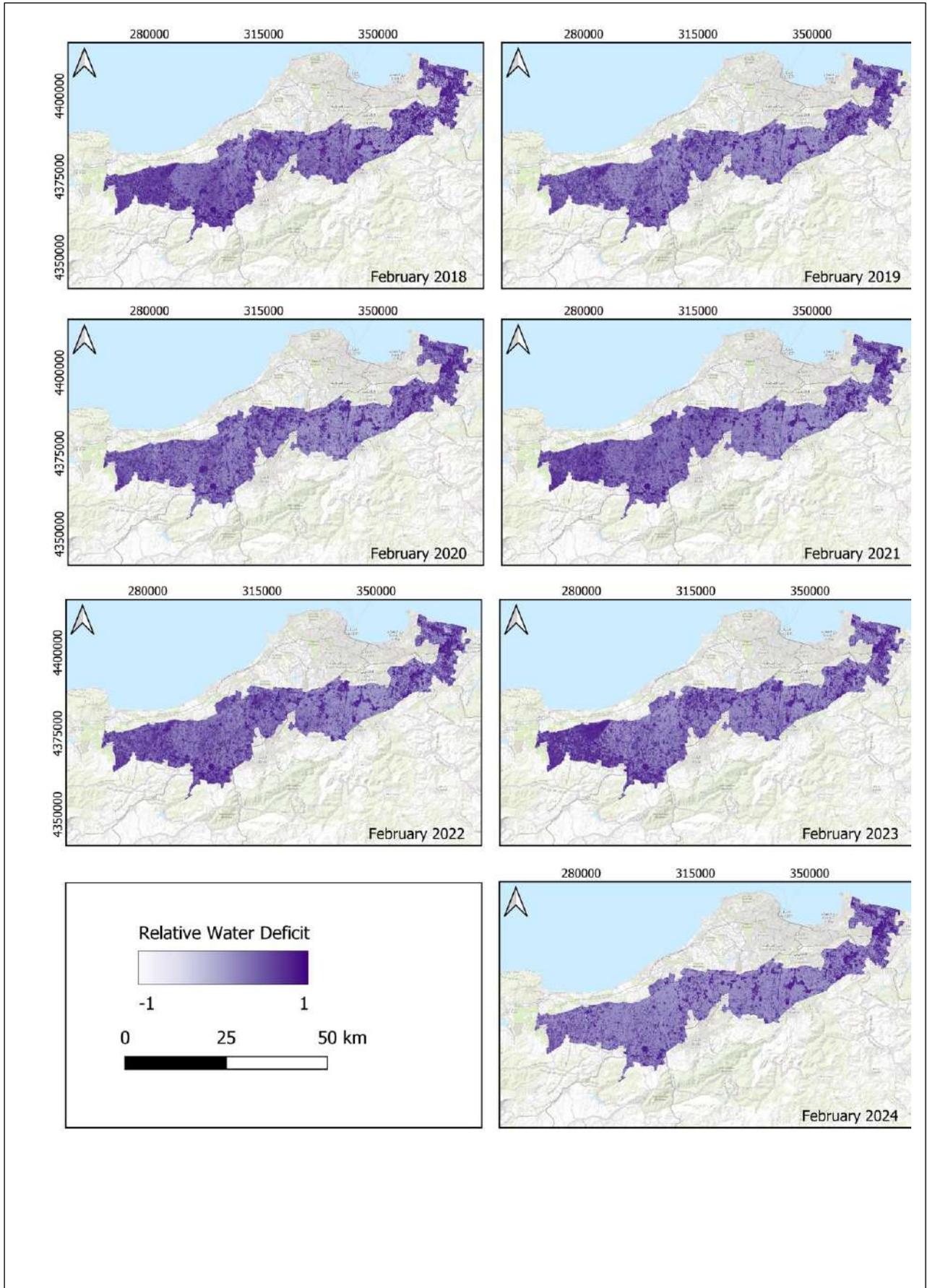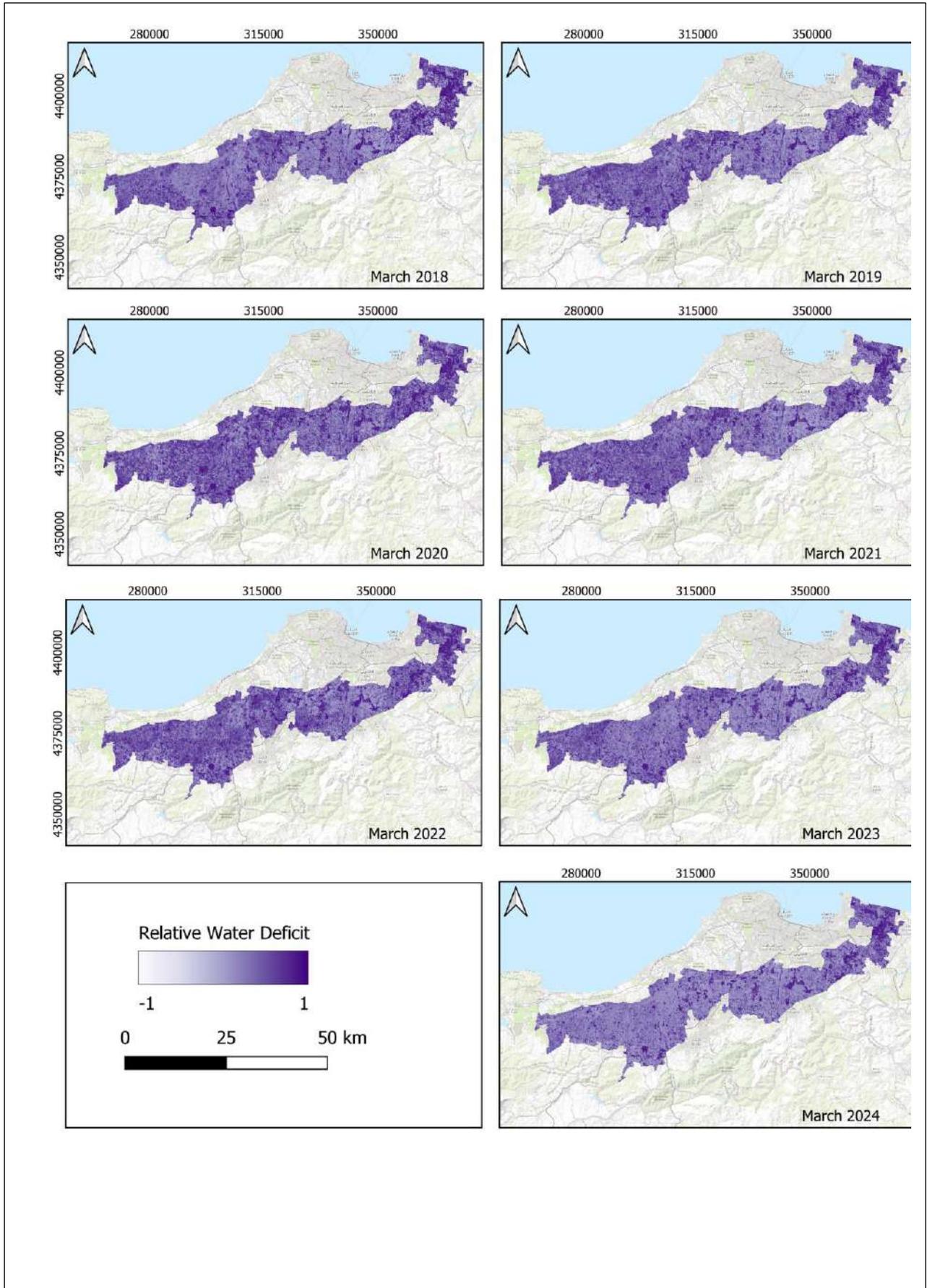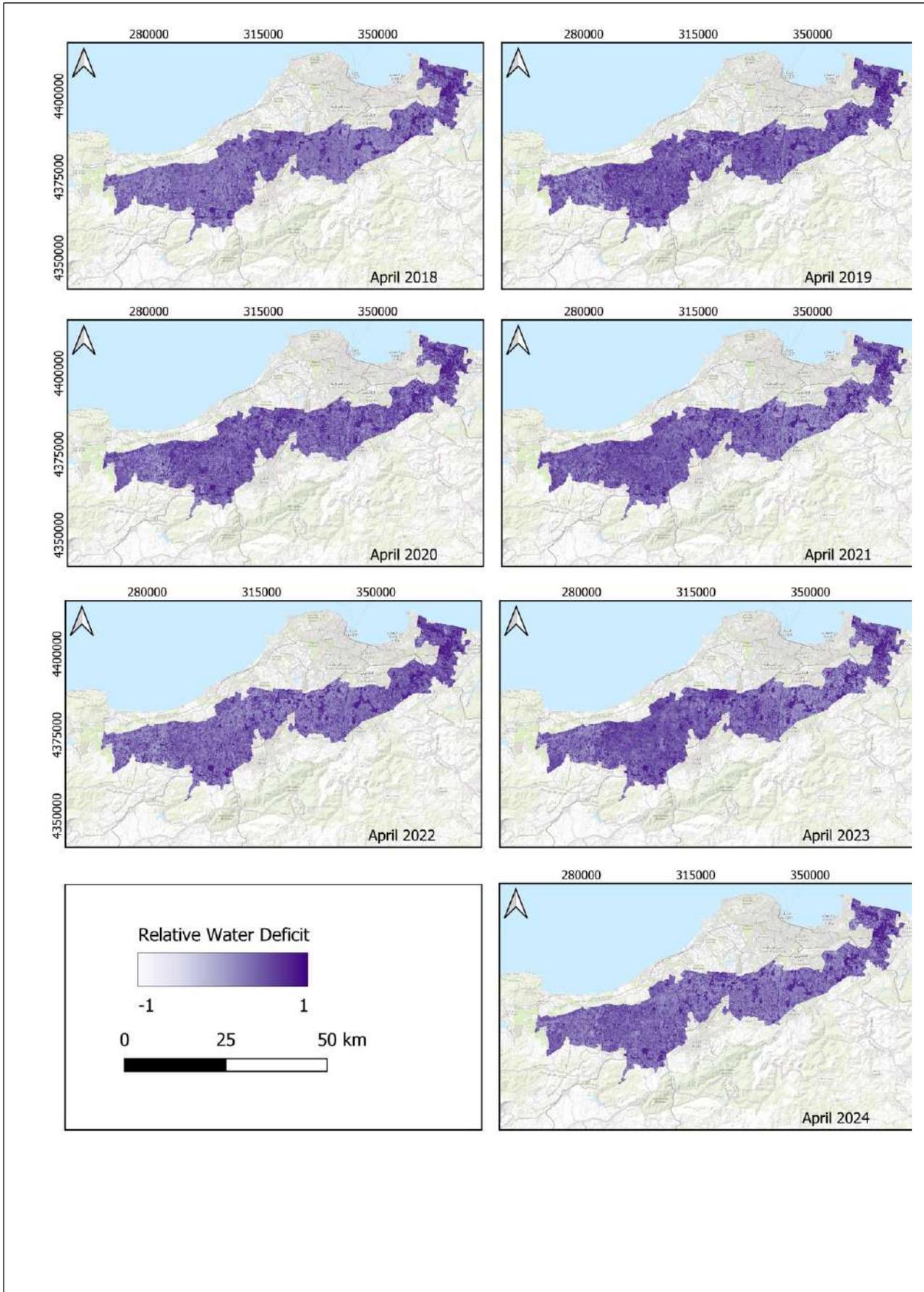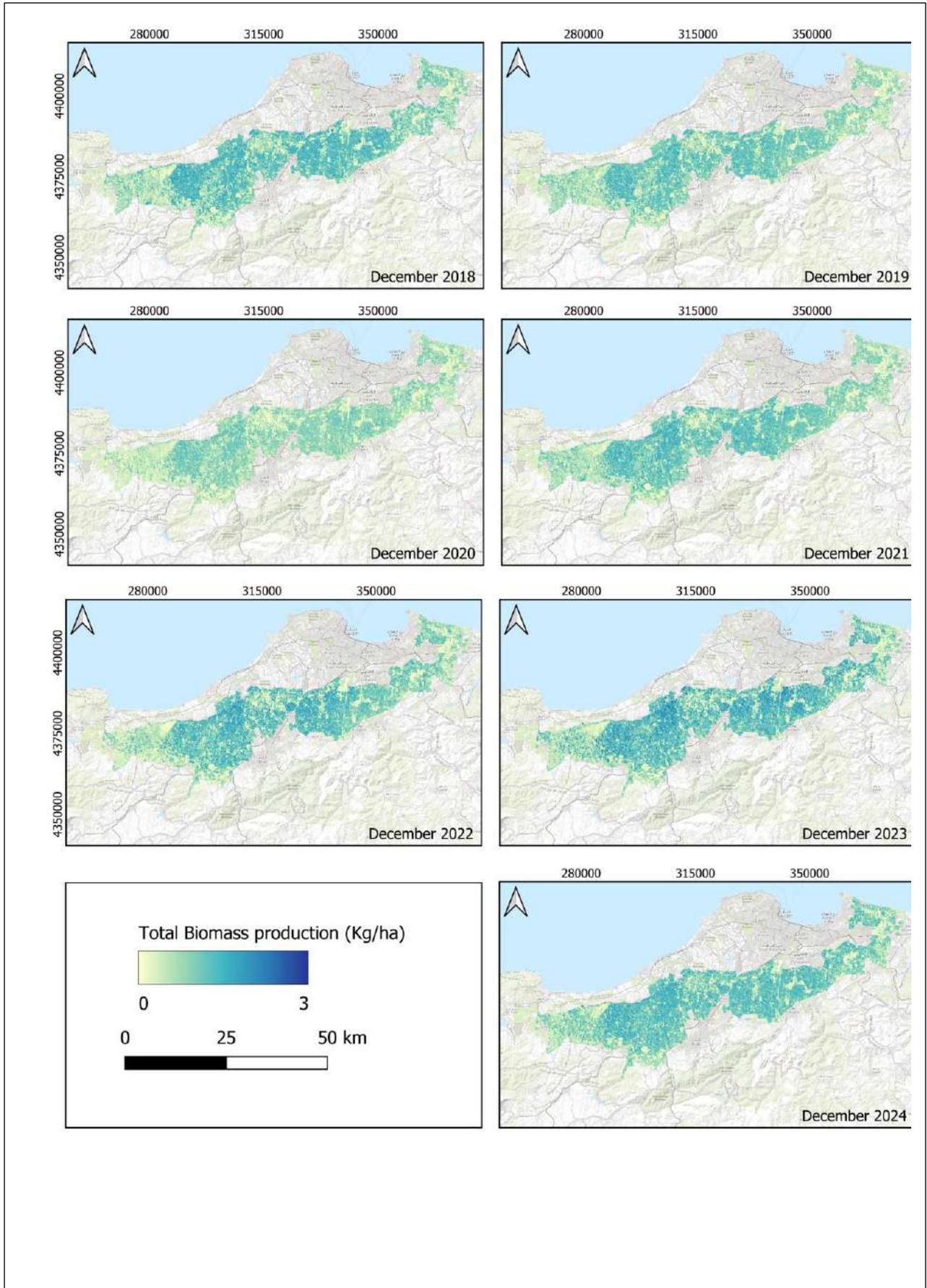
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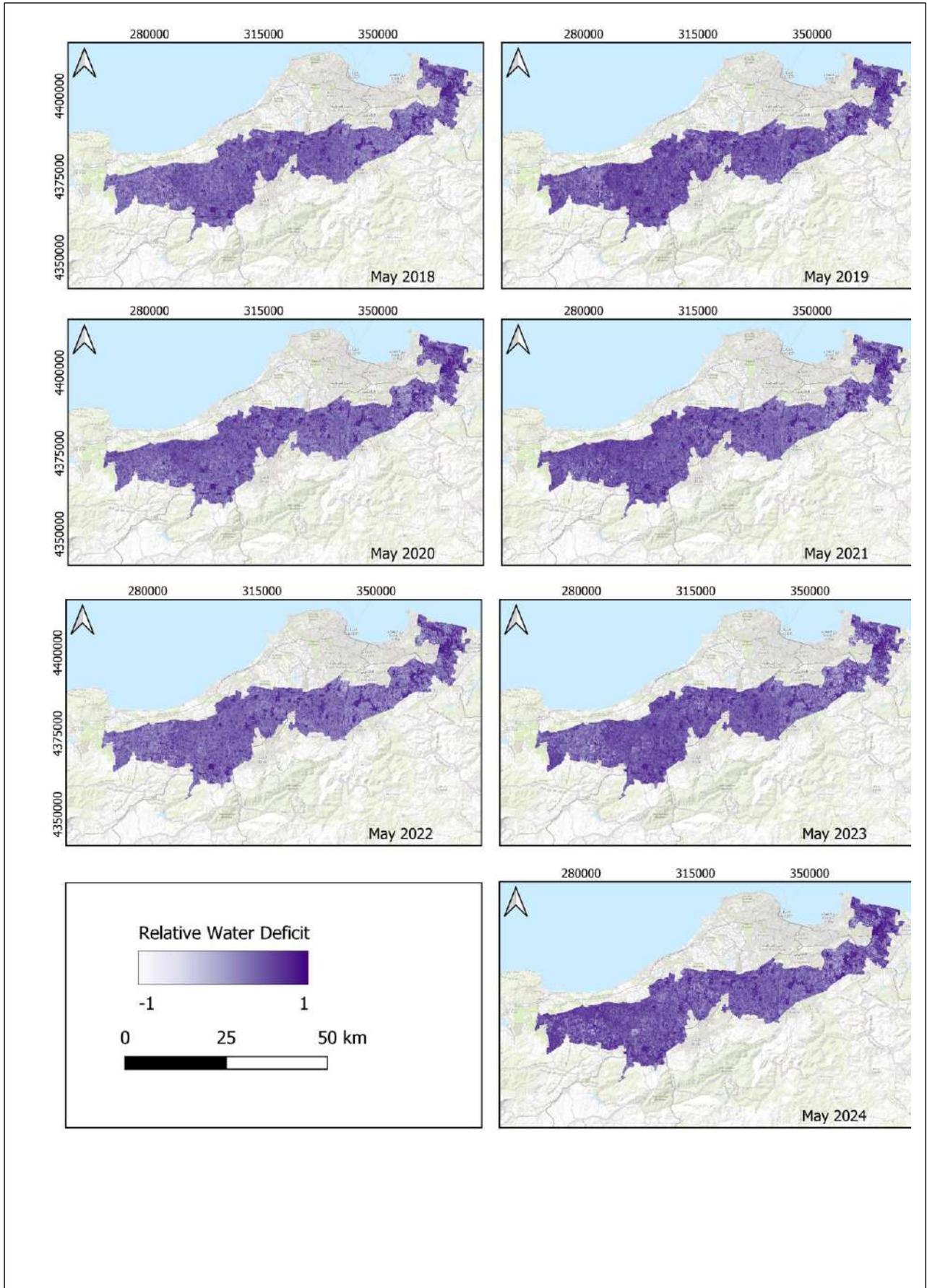
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ANNEX No 32
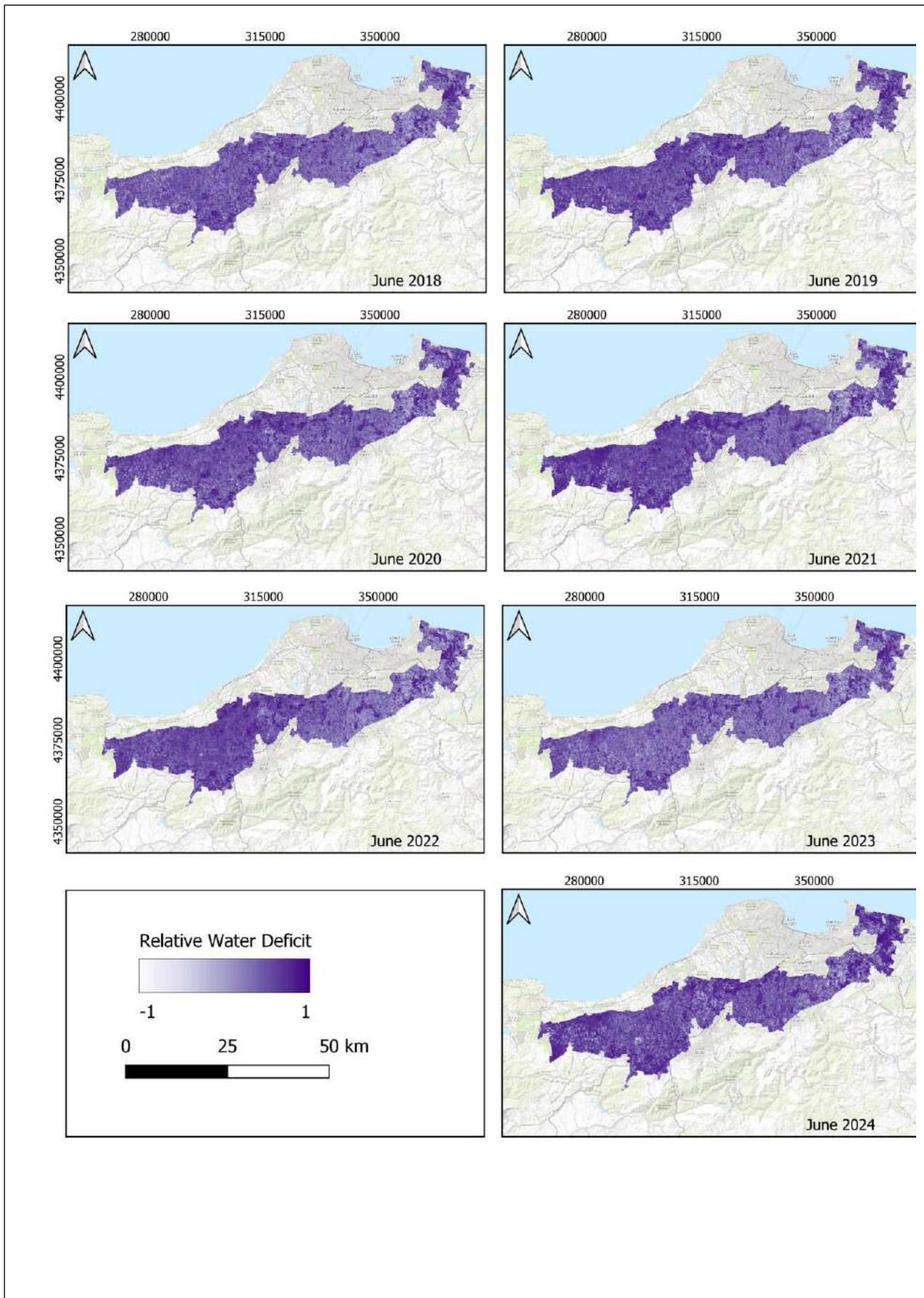
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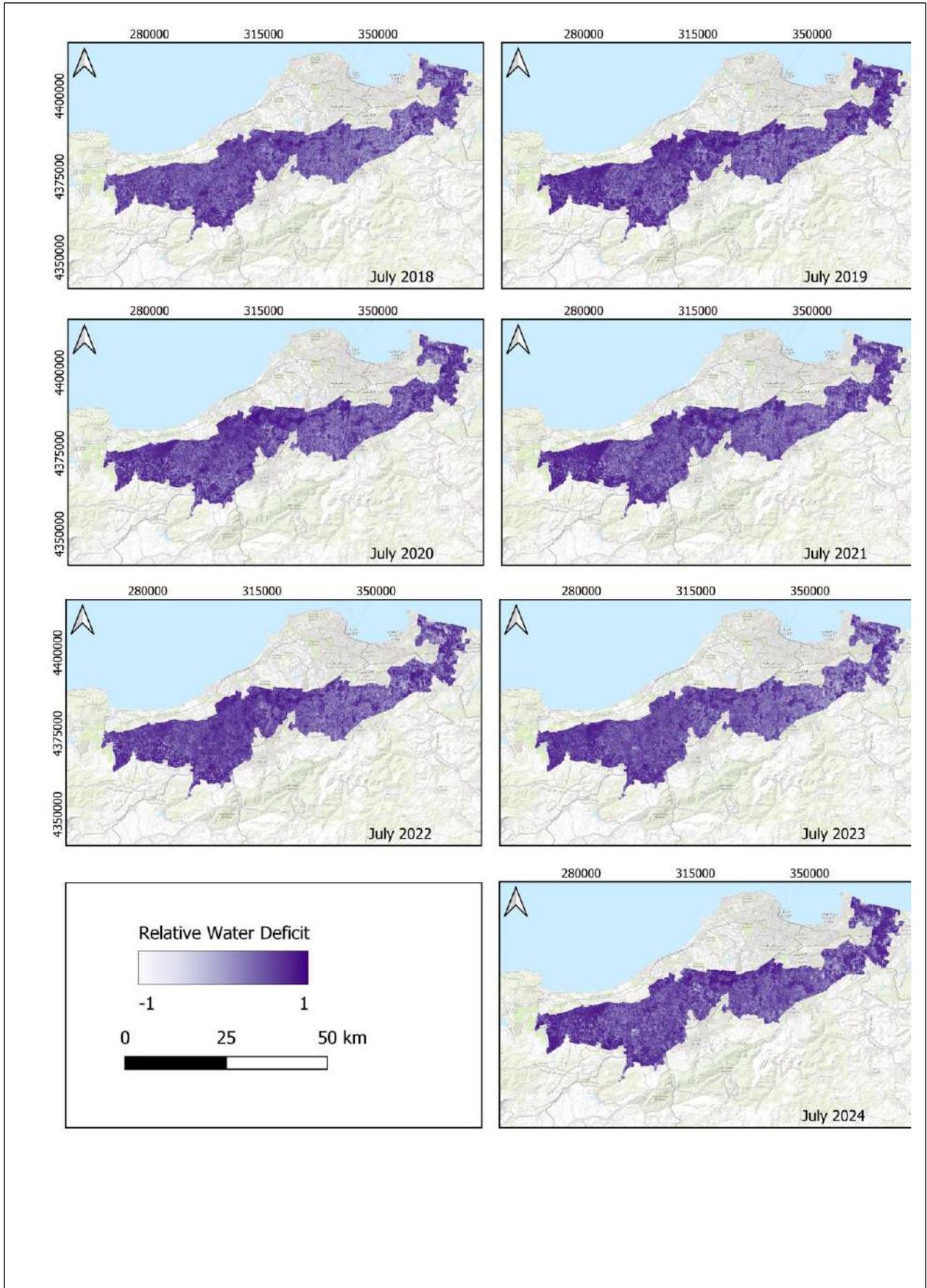
ANNEX No 34

ANNEX No 35

ANNEX No 36

ANNEX No 37

ANNEX No 38

ANNEX No 39

Total Biomass production (Kg/ha)

ANNEX No 40

February 2018

February 2019

February 2020

February 2021

February 2022

February 2023

Total Biomass production (Kg/ha)

0   4

0   25   50 km

February 2024

ANNEX No 41

Total Biomass production (Kg/ha)

March 2018
March 2019
March 2020
March 2021
March 2022
March 2023
March 2024

ANNEX No 41

ANNEX No 42

Total Biomass production (Kg/ha)
Band 1 (Gray)

ANNEX No 43

Total Biomass production (Kg/ha)

ANNEX No 44

Total Biomass production (Kg/ha)

0   7

0   25   50 km

ANNEX No 45

Total Biomass production (Kg/ha)

0   7

0   25   50 km

ANNEX No 46

Total Biomass production (Kg/ha)

ANNEX No

Total Biomass production (Kg/ha)

ANNEX No

Total Biomass production (Kg/ha)

0   4

0   25   50 km

ANNEX No

Total Biomass production (Kg/ha)

0   4

0   25   50 km

ANNEX No

Total Biomass production (Kg/ha)

0   3

0   25   50 km

ANNEX No

Water Biomass Productivity

ANNEX No

February 2018

February 2019

February 2020

February 2021
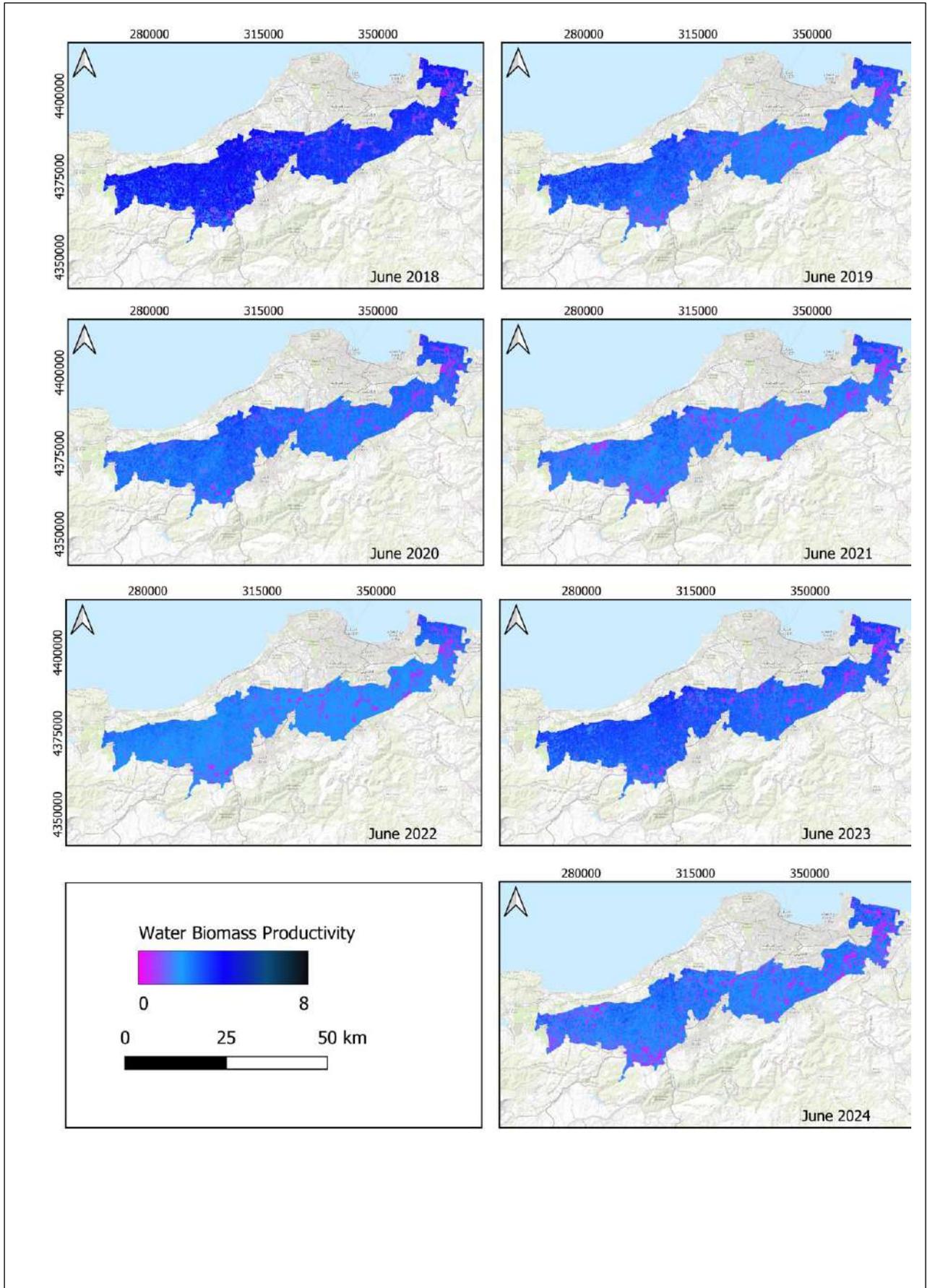
February 2022

February 2023

Water Biomass Productivity

0   12

0   25   50 km

February 2024

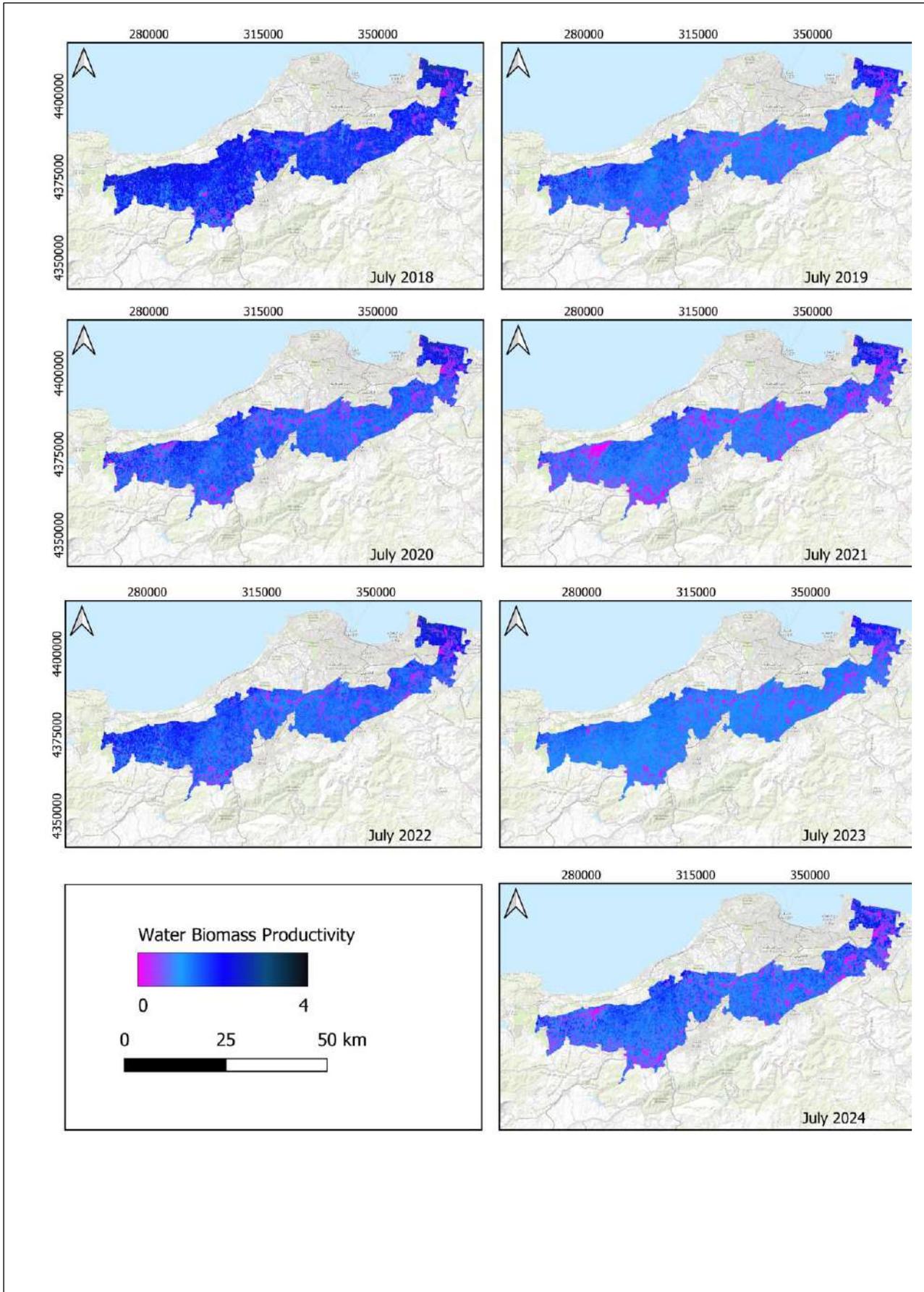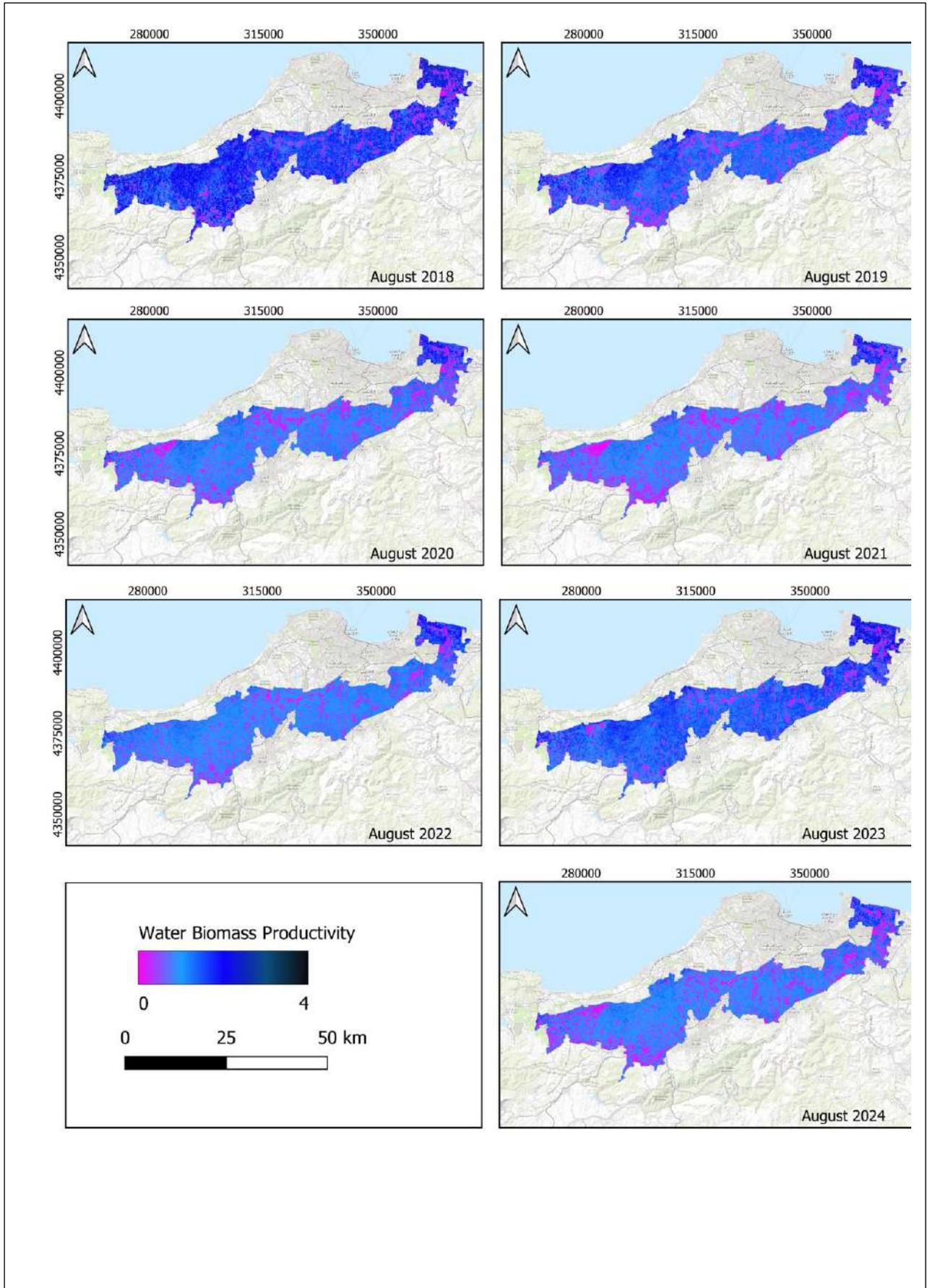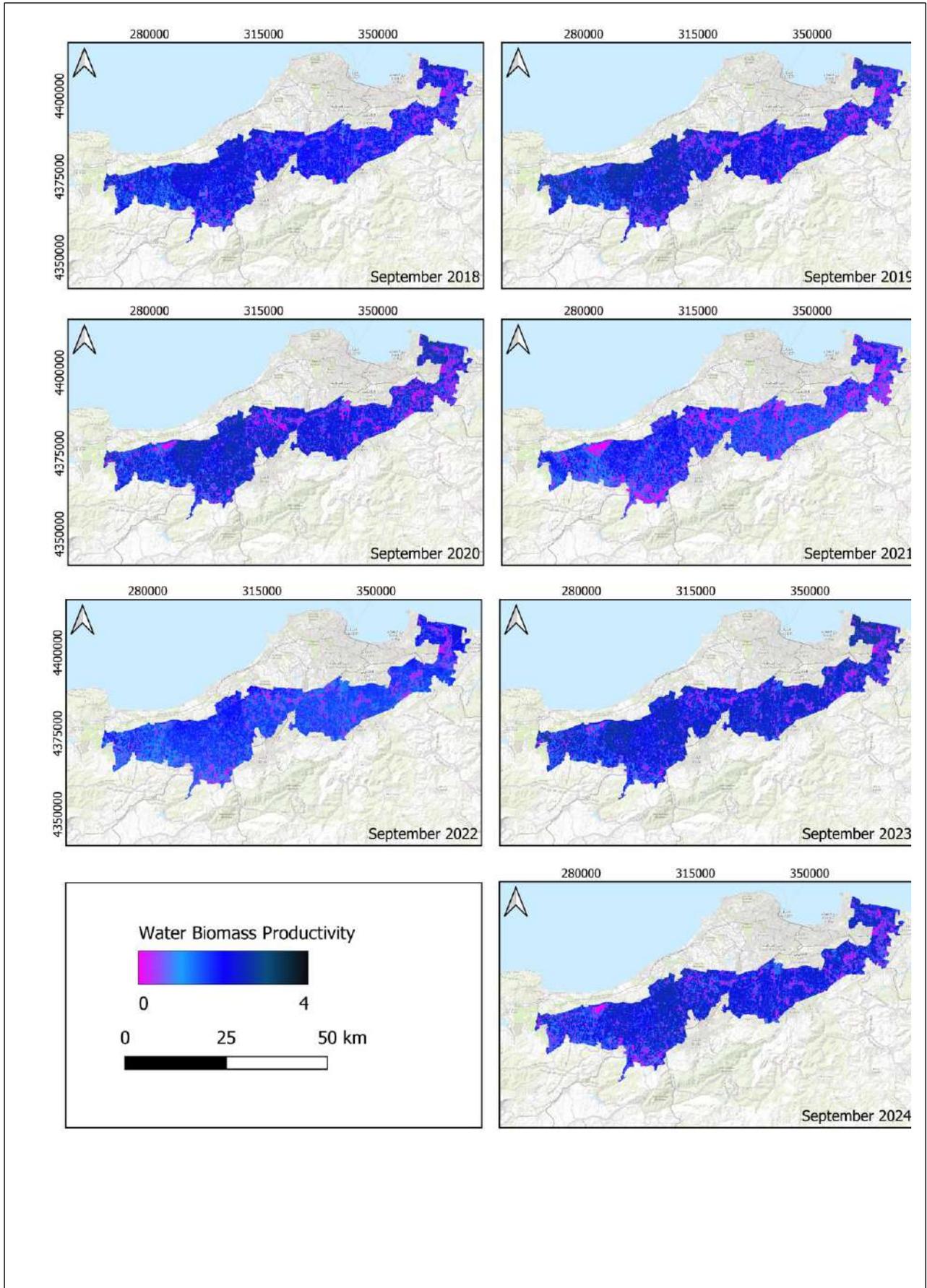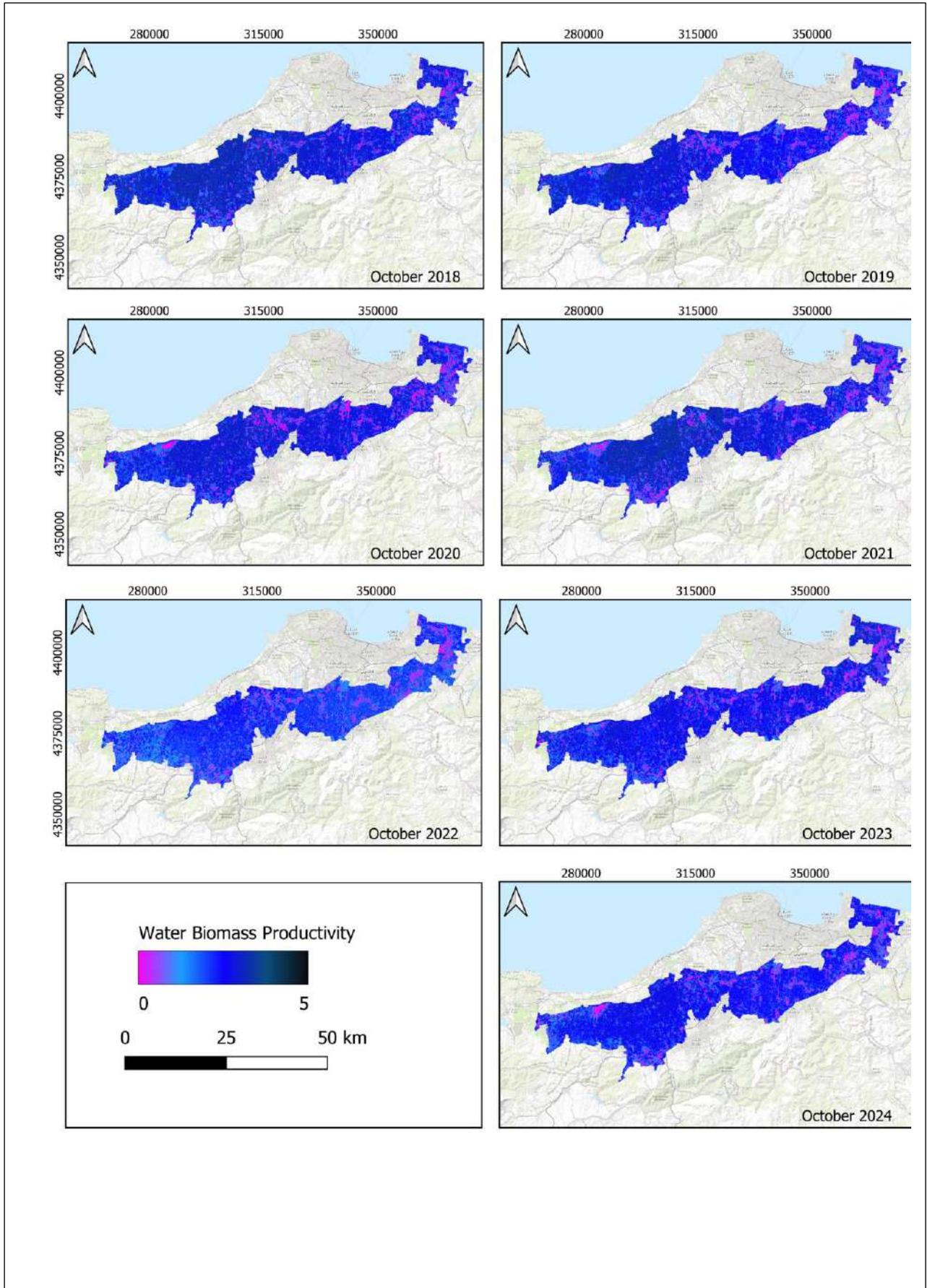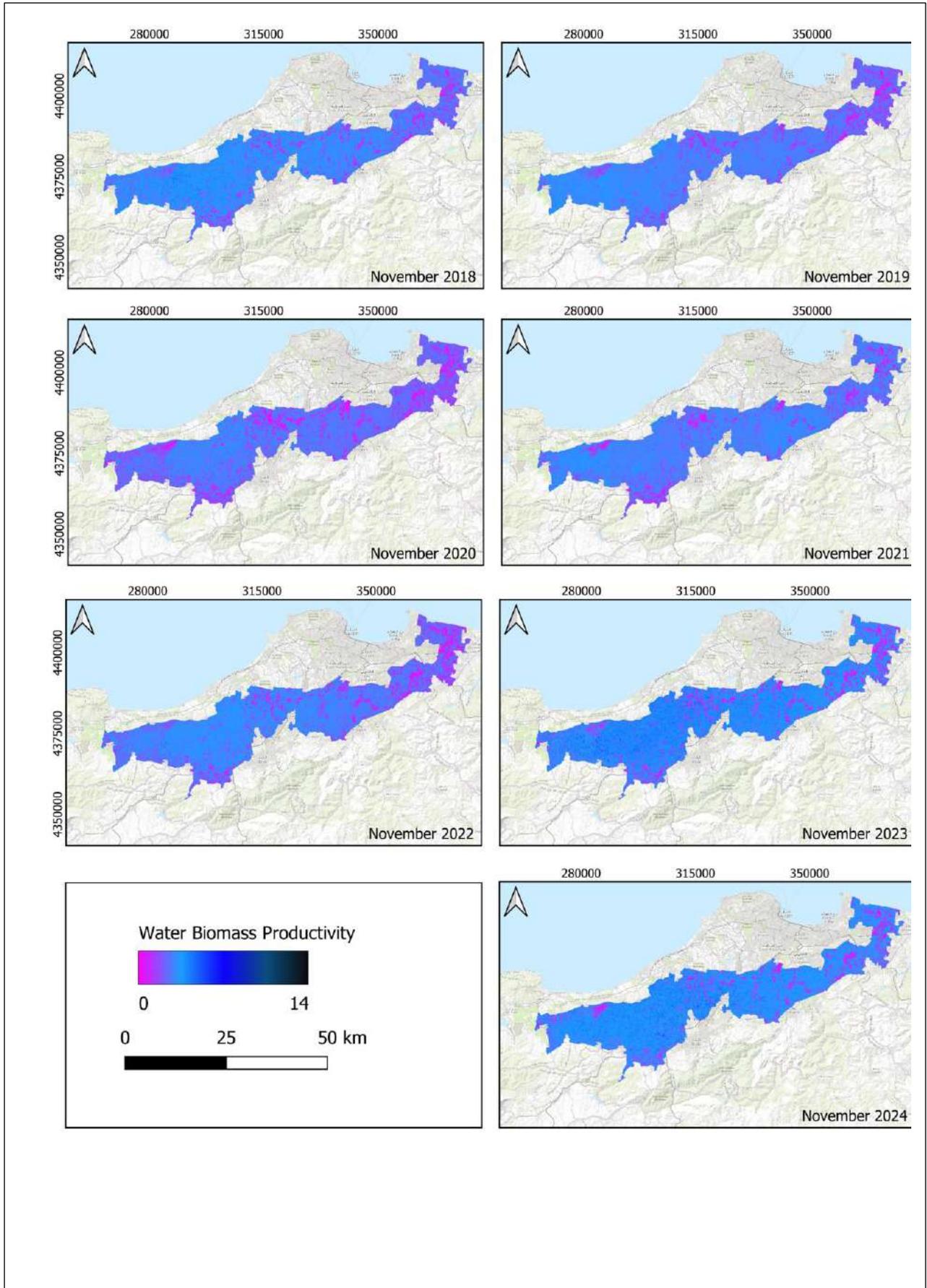ANNEX No

ANNEX No

ANNEX No

ANNEX No

ANNEX No

July 2018

July 2019

July 2020

July 2021

July 2022

July 2023

Water Biomass Productivity

0   4

0   25   50 km

July 2024

ANNEX No

Water Biomass Productivity maps for August 2018, 2019, 2020, 2021, 2022, 2023, and 2024.

ANNEX No

September 2018

September 2019

September 2020

September 2021

September 2022

September 2023

Water Biomass Productivity

0   4

0   25   50 km

September 2024

ANNEX No

ANNEX No

ANNEX No

Water Biomass Productivity