CLIMATE SERVICES FOCUSED ON WATER: QUANTITY AND QUALITY

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RESUMEN

Las sinergias entre investigaciones facilitan que los tomadores de decisiones reduzcan los impactos del cambio climático en el ciclo hidrológico gracias a servicios climáticos implementados en nuestra región. Por ejemplo, CRISI-ADAPT-II está validando la adaptación al clima de acuerdo con el pronóstico estacional de los peligros relacionados con el clima, que también afectan los recursos hídricos en España, Malta, Italia y Chipre. Por otro lado, IMAGUA (Fase I y II) se centra en evaluar la disponibilidad de recursos y los riesgos relacionados con el agua. Para alimentar el modelado de los peligros climáticos, utilizamos datos de cuatro estaciones de agua y escenarios regionalizados cuantil-a-cuantil de diez modelos climáticos (ESM) del CMIP6 con la ayuda del reanálisis ERA5-Land. El excenso/defecto de agua se proyectó con el SPEI y eventos extremos sintéticos de acuerdo con 5-a-30 años de retorno. Para modelar la calidad del agua (turbidez y conductividad), este estudio empleó un método *stepwise regression* teniendo en cuenta valores diarios de temperatura media, temperatura máxima, precipitación total y humedad relativa mínima y máxima. Los resultados mostraron incrementos de temperatura de unos +2 a +4°C, lo que llevará a condiciones más extremas en la cantidad de agua, según los valores promedio proyectados de SPEI entre -1 y -2 en 2071-2100 (con extremos hasta -4) y aumentos de 10-20% en lluvia para el período de retorno de 20 años. Esta mayor variabilidad provocará también impactos en la calidad del agua, con mayor conductividad en el río Júcar, entre el +4 y +11% para 2100.

Palabras clave: CMIP6, calidad de agua, inundaciones, extremos, regionalización.

ABSTRACT

Synergies among researches are supporting stakeholders and decision makers to reduce climate change impacts on the hydrological cycle thanks to climate services implemented in the Mediterranean area. For instance, CRISI-ADAPT-II project is monitoring adaptation planning through a real-time implementation and validation according to seasonal range forecast of climate-related natural hazards, also affecting water resources in Spain, Malta, Italy and Cyprus. More focused on this issue, IMpacts of climAte chanGe on wetlands affected by groUndwAter (IMAGUA Phase I and II) is assessing water resource availability and water-related risks. To feed climate hazards modelling, we used observed data of water parameters from four stations and quantile-downscaled scenarios from ten Earth System Models of the CMIP6 project, based on the ERA5-Land reanalaysis. Water scarcity/excess was modelled by synthetic extreme events according to 5-to-30-year return periods for the historical and future periods. To model water quality (turbidity and conductivity) in the past and future scenarios, this study employs a backward stepwise regression taking into account daily values of mean temperature, maximum temperature, total rainfall and minimum and maximum relative humidity. Results showed general increases about 2-4°C in temperature, which will led to extremer conditions on water quantity, according to projected average values of SPEI between -1 and -2 in 2071-2100 (with extremes up to -4) and increases of 10-20% in rainfall for the 20-year return period. This higher variability will also cause impacts on water quality, with an increase of conductivity for the station of the Júcar River, between 4 and 11% by 2100.

Key words: CMIP6, water quality, flooding, extreme events, statistical downscaling.

1. INTRODUCTION

Water management sectors is expected to be seriously affected by climate change effects, alternating excess and scarcity extremes of water availability. Under large periods of droughts and consequent water restrictions, adaptation of the human activities (agriculture, industry, …) is already urgent, taking into account the minimum requirements of drinking water and natural environments as the ecological flow of the rivers (Forero-Ortiz et al., 2020; Gómez-Martínez et al., 2021).

Flooding and emergence response are matters of concern in important areas of the Mediterranean. In particular, pluvial floods (including sewers floods) are very susceptible to extreme rainfall (Monjo et al. 2016; Russo et al. 2020). Long rainfall events or short but intense rainstorms can cause that sewer network reaches its total capacity producing surface floods and combined sewer overflows (CSOs). On the other hand, consumption reduction during droughts usually leads to an increase in debris accumulation, generating blockages within the drainage network. Moreover, according to the RESCCUE project, the combination of storm surge and sea level rise could also reduce the efficiency of sewer weirs and spillways and increase the vulnerability of critical infrastructures and services exposed to coastal flooding (Russo et al. 2020).

The Mediterranean area is one of the most vulnerable regions in the world to the expected impacts of climate change, especially on the hydrological cycle (Monjo and Martin-Vide, 2016; Moutahir et al., 2017). To minimise these impacts, synergies among different projects led to climate services focused on water. For instance, the project entitled Climate Risk Information for SupportIng ADAptation Planning and operation (CRISI-ADAPT II) aimed to monitor the adaptation planning through a real-time implementation and validation according to short-term and seasonal forecasts of climate-related natural hazards, also affecting water resources (Monjo, 2021). More specifically, IMpacts of climAte chanGe on wetlands affected by groUndwAter (IMAGUA Phase I and II) aims to assess water resource availability and water-related risks. Both projects also analyze the effects of climate change on the raw water quality of the Jucar River Basin District, which mainly supplies the city of Valencia and its metropolitan area, in order to adapt drinking water treatments to new conditions and opportunities.

To facilitate the adaptation in the human activities related to water sector, statistical downscaling is essential to model the future local conditions of water quantity and quality (Ribalaygua et al., 2013; Gaitán et al., 2019; Gómez-Martínez et al. 2021). This study summarizes some of the climate services that IMAGUA and CRISI-ADAPT II provide to support decision making on water sectors in order to reduce risks and improve adaptation measures.

2. MATERIAL AND METHODS

2.1. Study area and data

The Mediterranean region is the common area for the complementarity analysis among the projects involved. As a main coordinator of this synergy, CRISI-ADAPT II supports decision making to reduce climate-related risks in four main pilot cases, representing strategic sectors: *Water management for supply, agriculture and environment* (Spain and Italy); *Flooding and emergency response* (Malta); *Energy planning* (Cyprus) and *Port infrastructures and operations* (Spain). On the other hand, IMpacts of climAte chanGe on wetlands affected by groUndwAter (IMAGUA Phase I and II) aims to assess water resource availability and water-related risks in Spain, with a special focus on the city of Valencia, set to analyze the climate change impacts on water quality in the Jucar River Basin District.

This synergistic work was applied to compare water issues of two of these pilot cases: *Flooding and Emergency response* in Malta and *Water quality* in Júcar River Basin District in Valencia. For both cases, climate drivers of ten Earth system models were used from the latest Coupled Model Intercomparison Project—Phase 6 (Table 1), which presented a good performance in mid-latitudes (Brands, 2022). Reference data of Civil Protection Department of Malta included flooding records and the related historical damage reports. To model water quality in Valencia, data have been provided by EMIVASA water monitoring stations, located at different strategic points around the city of Valencia and its metropolitan area. Daily information of turbidity (nephelometric turbidity unit, NTU) and conductivity (micro siemens/centimeter, µS/cm) was collected from four monitoring stations to assess water quality in this study: (1) El Realón, (2)–Júcar-Túria channel, (3) La Presa and (4) Túria River upstream.

CMPI6 MODELS	**Atmospheric Resolution**	**Responsible Centre**	**References**
BCC-CSM2-MR	1,125º x 1,121º	Beijing Climate Center (BCC), China Meteorological Administration, China.	Wu, T. et al. (2019)
CanESM5	2,812º x 2,790º	Canadian Centre for Climate Modeling and Analysis (CC-CMA), Canadá.	Swart, N.C. et al. (2019)
CNRM-ESM2-1	1,406º x 1,401º	CNRM (Centre National de Recherches Meteorologiques), Meteo-France, Francia.	Seferian, R. (2019)
EC-EARTH3	0,703º x 0,702º	EC-EARTH Consortium	EC-Earth Consortium. (2019)
GFDL-ESM4	1,250º x 1,000º	National Oceanic and Atmospheric Administration (NOAA), E.E.U.U.	Krasting, J.P. et al. (2018)
MPI-ESM1-2-HR	0,938º x 0,935º	Max-Planck Institute for Meteorology (MPI-M), Germany.	Von Storch, J. et al. (2017)
MRI-ESM2-0	1,125º x 1,121º	Meteorological Research Institute (MRI), Japan.	Yukimoto, S. et al. (2019)
UKESM1-0-LL	1,875º x 1,250º	Uk Met Office, Hadley Centre, United Kingdom	Good, P. et al. (2019)
NorESM2-MM	1,250º x 0,942º	Norwegian Climate Centre (NCC), Norway.	Bentsen, M. et al. (2019)
ACCESS-ESM1-5	1,875º x 1,250º	Australian Community Climate and Earth System Simulator (ACCESS), Australia	Ziehn, T. et al. (2019)

Table 1. Information about the ten climate models belonged to the CMIP6 corresponding to the sixth report of the IPCC. Models were supplied by the Program for Climate Model Diagnosis and Intercomparison (PCMDI) archives.

Since the case studies are distributed among Portugal, Spain, Italy, Malta and Cyprus, a grid covering the whole Mediterranean area, between latitudes 30°N and 50°N and longitudes between 15°W and 40°E, has been chosen for the study. The climate variables collected from CMIP6 are wind, temperature, humidity and rainfall at a daily timescale. Moreover, ERA5-Land reanalysis (spatial resolution of 0.07°×0.07°) was used as a basis for the statistical downscaling.

2.2. Methods

2.2.a. Climate services focused on water sectors

Decision-support systems and adaptive solutions have been co-designed by technicians and local stakeholders within CRISI-ADAPT II, learning lessons from other projects such as RESCCUE and IMAGUA (I and II). This complementarity provide a set of services specialized in analysis of impacts on water management and other water-related issues, due to climate change and extreme natural variability. The main climate services are:

a) Generation of future scenarios of climate change at a local scale: daily and subdaily precipitation, temperature, wind, fog, sea level rise, waver height and storm surge (Ribalaygua et al., 2013; Russo et al. 2020; Monjo, 2021).
b) Generation of future scenarios for derived variables: Heat waves, *n*-index, fractal drought, potential evapotranspiration, Standardized Precipitation Index (SPI) and Standardized Precipitation-Evapotranspiration Index (SPEI) (Gaitán et al., 2020; Monjo et al. 2020).
c) Generation of future scenarios of hydrological variables at a local scale (flow velocity and depth in urban areas). Hydrodynamic and urban drainage models, development and calibration of 2D flooding surface models and perform of flood risk assessment including socio-economic impacts (Russo et al. 2020).
d) Application of hydrological modelling to simulate water balance in a river flow or water quality (turbidity and conductivity) in a reservoir (Gómez-Martínez 2021).
e) Operational prediction of sub-seasonal/seasonal and annual anomalies of the main climate drivers and real-time monitoring of natural hazards related to water management (Redolat, 2020; Monjo, 2021).

To better specialize this information in a GIS-based tool, the statistical downscaling method was applied to CMIP6 model outputs by using reference values obtained from the ERA5-Land reanalysis.

2.2.b. Statistical downscaling: quantile-mapping

All the climate variables (wind, temperature, humidity and rainfall) were downscaled to the ERA5-Land grid at a daily timescale. However, sub-daily rainfall was also projected for the sector of Flooding and Emergency Response, thanks to the *n*-index method (Monjo 2016, Monjo et al. 2020). Other variables such as fog and wave height requires to be obtained from model post-processing.

To obtain downscaled projections from CMIP6 model outputs, a quantile mapping was applied with respect to the reanalysis (Monjo et al. 2014). For each climate variable simulated by the CMIP6 models, the statistical downscaling was applied according to seven steps:

1) Firstly, as a reference field, a purely geo-statistical downscaling of the original Era5-Land grid (0.07°×0.07°) was performed for each variable to a 1km×1km grid, using linear stepwise regression with topological and geographical parameters (altitude, latitude, longitude and distance to the Atlantic Ocean and Mediterranean Sea), and bilinear model for the residual errors.
2) For all models and their corresponding scenarios, the average values for the study area have been calculated for the periods 1981-2010, 2021-2050 and 2071-2100 and their rate of variation between the periods 2071-2100 and 2021-2050 was considered as a criterion to sort them.
3) The model scenario with the highest rate of variation and the model scenario with the lowest rate of variation have been chosen to delimit future variations of the variables. Then, the 90th, 50th and 10th quantile scenarios were selected as representative scenarios and were named Upper, Medium and Lower, respectively.
4) For these scenarios (Upper, Medium and Lower), the empirical values corresponding to the return periods of 5, 10, 20 and 30 years for the periods 1981-2010, 2021-2050, 2046-2075 and 2071-2100 have been calculated for each grid point in the model.
5) Once the above results were obtained, an interpolation to a grid of 1km×1km was performed using the bilinear method.
6) Then, the increment or difference with respect to the same return periods of the period 1981-2010 has been calculated for each period of 30 years (2021-2050, 2046-2075 and 2071-2100) and for each return period. Relative increment (instead of absolute increment) was considered for non-Gaussian variables such as precipitation and wind speed.
7) Finally, the absolute o relative increment of each scenario and return period (step 6) was added to the reference values of each variable (step 1), obtaining climate scenarios in a 1km×1km grid.

2.2.c. Modelling of water quantity and quality

Water quantity is modelled by extreme rainfall (return periods) and droughts (SPI, SPEI). Synthetic extreme events were empirically estimated according to 5-, 10-, 20- and 30-year return periods for the historical and future periods. To model water quality (turbidity and conductivity) in the past and future scenarios, this study employed a backward stepwise regression taking into account daily values of mean temperature, maximum temperature, total rainfall and minimum and maximum relative humidity. Finally, a specific step-by-step Risk Management Process (RMP) was established for CRISI-ADAPT II project following ISO 31000:2009, with a focus on tangible and intangible impacts for current and future scenarios.

Pluvial flood hazard has been estimated combining pluvial flood depth and velocity provided by a coupled 1D-2D hydrodynamic model and specific hazard criteria related to pedestrian and vehicular stability. The 1D-2D coupled model simulates the hydrological response of the central basins of the Island of Malta, considering both surface runoff (2D model) and the existing main drainage system (1D model), implemented in the context of nation Flood Relief Project (NFRP).

The drainage system developed by the NFRP was included for the study areas, considering its capacity to drain at least an event equivalent to a return period of 5 years, following NFRP indications. The modelling of this system will reach the inlet scale, considering its drainage efficiency by implementing specific depth/flow function for every typology.

3. RESULTS

Results showed that the most significant change was found in the projected increase of conductivity for the station of the Júcar river, between 4 and 11% by 2100, respectively, under the medium (SSP2–4.5) and pessimistic (SSP5–8.5) emission scenarios. Finally, climate projections showed general increases about 2-4°C in temperature, which drive to projected average values of SPEI between -1 and -2 in 2071-2100 (with extremes up to -4) and increases of 10-20% in rainfall for the 20-year return period.

Concerning the support of decision making, an advanced version of the CRISI-ADAPTII tool (Fig. 1) was implemented for the sector of Flooding & Emergency Response, and Malta Civil Protection received training sessions to apply an adjusted version for the operational use (under weather and seasonal forecasts).

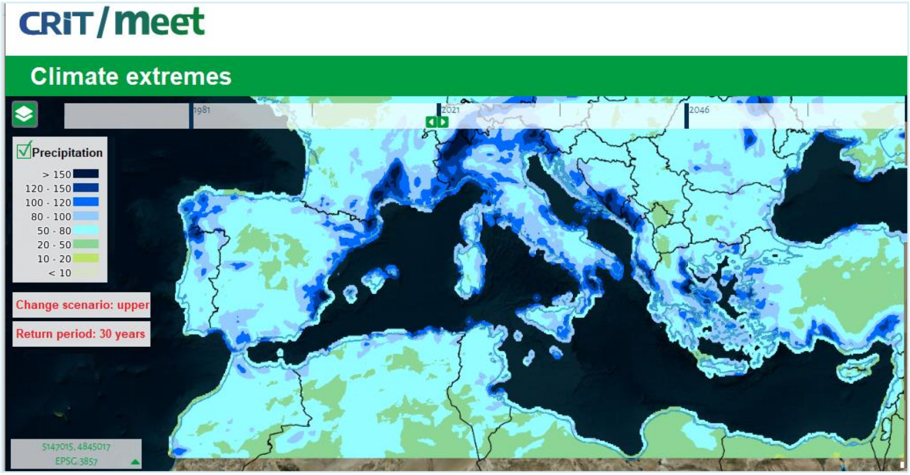

Fig. 1. Maximum daily precipitation for a return period of 30 years under the upper scenario projected for 2021-2050 period. Source: https://tool.crisi-adapt2.eu/clima-extremo/?visible_layers=878328272,878328277

Pluvial issues were post-processed by GIS technology to develop infographics and appropriate maps, which can be adopted as a starting point for future in-depth analysis. (Fig. 2). The platform stands out for its constant updating capacity, which translates into improving the quality and reliability of information on vulnerability and risk in the territory, thanks to the management of vulnerable elements and their climate sensitivity (resilience). Moreover, the system offers the possibility of providing information from web services (WMS-OGC) in accordance with the European INSPIRE directive, and its data model is fully adaptable to the needs of each end user.

Finally, the obtained results are presented as a specific flood risk assessment of climate change, suggesting a development strategy to fulfil European Directives indications to prone flood areas but more generic to expand Malta's flooding issues knowledge and to increase urban resiliency to face with Climate Change potential consequences.

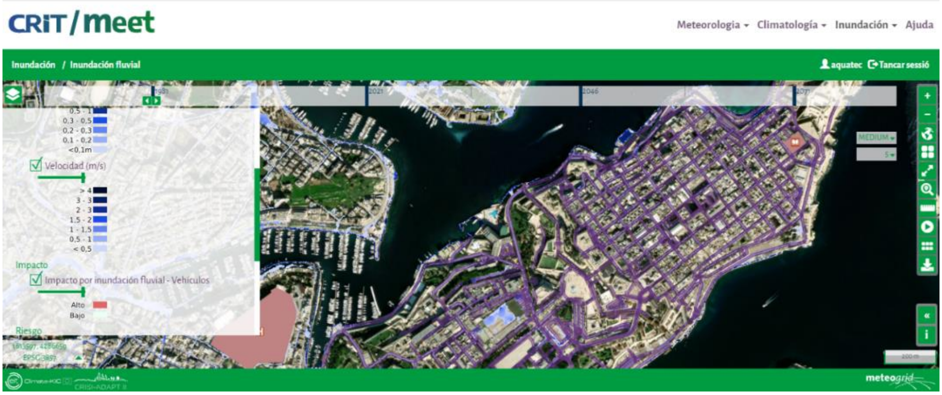

Fig. 2. Screenshot of the CRISI-ADAPT-II tool for the Malta study case, related to flooding and emergency response.

4. DISCUSSIONS AND CONCLUSIONS

Our results shown the possible consequence of no action to face climate change regarding the exacerbation of pluvial flooding. Despite the novel approach adopted for this case study, further investigation is necessary to deepen the knowledge of the hydrological equilibrium of Malta's mayor basins as well as the rest of the catchments.

Possible development must be focused on infrastructural cascading effects analysis produced by climate-related hazards which could offer a strategic starting point to increase Malta's flood resilience. Suggestions for preliminary implementation will naturally follow this step, with particular attention to the cost-benefit analysis of such proposed measures.

For the Malta case study, risk assessment process was applied for current (Baseline) and future scenarios (Business as Usual). Risk treatment, concerning the definition and analysis of the capacity of selected measures and strategies to increase the resilience of the island with respect to the occurrence of flooding events has been not undertaken. Although risk reduction analysis was out of the scope of this project, it could be object of future works and collaborations among the CRISI-ADAPT II project partners and local actors involved in this study.

Concerning water quality issues, climate services may respond to the need of quantifying these impacts on the availability of water resources, guaranteeing that the purification treatments are resilient to climate change,

Improving and adapting the quality and reliability of the results provided by the use of these kinds of tools will allow water managers to better fit and plan their investment programs to improve this kind of resilience of the water resources systems to better respond to the impact of climate change. Thus, through the joint analysis of the evolution of temperature, turbidity, conductivity and available resources along time, water managers will identify the necessary additional treatments for purification or treatment processes, or necessary catchment works, in order to face water scarcity periods and the consequent quality problems.

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