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Climate Change Impacts on Flood Events and Its Consequences on Human in Deba River

Mendizabal, M.[1*], Sepúlveda, J.[2] and Torp, P.[3]

[1]Tecnalia Research & Innovation, Parque Tecnológico de Bizkaia, Edificio 700, 48160 DERIO (Bizkaia), Spain

[2] Engineering School, University of he Basque Country, Gasteiz, Spain

[3]DHI, Department of Urban and River Hydraulics, Ventura Rodriguez 8, 1ºD, 28008, Madrid, Spain

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ABSTRACT: The scientific community agrees that climate change is one of the greatest challenges that our society will have to face this century. Indeed, the fourth report from the Intergovernmental Panel on Climate Change (IPPC) confirms the certitude of this phenomenon and its impacts, which can range from droughts to floods, health problems and food shortages. The principal objective of this paper is to assess the impact of climate change on flood events and its consequences on human. This point is necessary to define and evaluate different adaptation options. Even taking into account the medium greenhouse emission scenario, according to the results, it is expected that extreme precipitation will increase during the twenty century, although there is an uncertainty in the percentage due to the climatic models. It is expected an increase in peak discharge between 14±9 and 15±8 for 3 models and for the period 2001-2040 with a return period exceeding 40 years. For the period 2041-2080 there is more uncertainty, it is expected an increase between 12±8 and 19±10 for 2 models. According to the results, changes in flood event are expected with its associated uncertainty and new flood zones are detected with greater hazard to people.

Key words: Flood, Climate change, Human health, Heavy precipitation, Impacts

INTRODUCTION

The European Commission's White Paper on adaptation to climate change (2009) endorses the need to incorporate adaptation-related aspects into our policies on the basis of solid economic and scientific analysis. Thus, the manner in which each policy area should be reoriented in order to facilitate adaptation should be analysed, an action that will, on occasions, require further funding. The fourth report of the Intergovernmental Panel on Climate Change (IPCC) (Adger *et al.*, 2007) defines climate change adaptation measures as changes to decision-making in order to increase the resilience, or reduce the vulnerability, in the face of future projected climate change. According to the scenarios developed by the IPCC changes in the water cycle are likely to increase the risk of floods. Projections under the IPCC IS92a scenario (similar to SRES A1B) (IPCC, 1992) and two GCMs (Lehner *et al.*, 2006) indicate that the risk of floods increases in northern, central and eastern Europe (IPCC, 2007). Increase in intense short-duration precipitation in most of Europe is likely to lead to increased risk of flash floods (EEA, 2004). Today's 100-year floods occur more frequently in northern and north-eastern Europe (Sweden, Finland, northern Russia), in Ireland, in central and eastern Europe (Poland, Alpine rivers), in Atlantic parts of southern Europe (Spain, Portugal), and less frequently in large parts of southern Europe (Lehner *et al.*, 2006).

However, for the Iberian Peninsula there is no consensus on the changes in extreme precipitation for 2070–2100. On the one hand, Semmler & Jacob (2004) predicted a decrease of 50% in extreme rainfall within return periods of 10 and 20 yr, compared to 1961–1990. However, Goubanova & Li (2007) found an increase of 10–20% for extreme rainfall (30 yr return period) by the 21st century, in comparison to the period 1970–1999. The location of the Iberian Peninsula within a transitional climate regime between oceanic temperate and the dry subtropical climate (Barry & Chorley 2003) makes it difficult to predict future rainfall over the area. Moreover, focusing in the area of the Basque Country (north of Spain) recent studies estimate a 10% increase in extreme rainfall throughout

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*Corresponding author E-mail: maddalen.mendizabal@tecnalia.com the 21st century, under A1B scenario, extracted from the ENSEMBLES project (Niehörster *et al.,* 2008) (Moncho, 2009; Chust *et al.,* 2011). Increasing flood risk from climate change could be magnified by increases in impermeable surface due to urbanisation (de Roo *et al.,* 2003) and modified by changes in vegetation cover (Robinson *et al.,* 2003) in small catchments. The increasing volume of floods and peak discharge would make it more difficult for reservoirs to store high runoff and prevent floods. Although the North of Spain has an Atlantic climate, in general sense with frequent and abundant rainfall, mild winters and cool summers, the floods are characterized as Mediterranean's one, flash floods. The rivers are short and fast flowing. That is because of the proximity to the sea of the mountains they birth (Marco, 1995). This coupled with the inadequate management of land and the consequences of the climate change affects on natural and human systems causing tangible and intangible effects.

In this context, the regional government has developed "the Basque Plan to Combat Climate Change (2008-2012) (PLCC)", which is intended "to ensure that by 2020 the Autonomous Community of the Basque Country has taken irreversible steps to consolidate a carbon-indepoendent socio-economic model, thereby minimising the regions´vulnerability to climate change". This plan proposes the following main priotity: "to act against climate change and prepare the region for its consequences".

The work here presented aims to contribute to the understanding of regional climate change over the Basque Country area by exploring the most recent regional climate projections over the area. The precipitation is analysed using a set of regional climate model outputs from the EU-FP6 ENSEMBLES project at 25x25 km horizontal resolution. Current bias correction method and the assessment of impact of extreme precipitation on flood events and its consequences on human is also presented. This point is necessary to define and evaluate different adaptation options. As well as evaluate the adaptation measures in terms of their ability to lower the vulnerability of water resources to climate change.

MATERIALS & METHODS

The main objective of this paper is to evaluate and assess the climate change effects on flood events in Deba river basin and analyse its consequences on human systems (Basque Country, north of Spain) (Fig. 1). Deba river basin placed in the occidental side of the Basque Country area, covers an area with complex terrain of about 534 km^2.It includes important rural and urban populations: high industrial activities support water ecosystem services; while central-low part of the basin is densely populated (with more than 135000 inhabitants). The main stream, Deba river, is 55 km long and includes 14 tributaries (short and fast flowing). Five meteorological stations are selected from the basin with a common daily data period (from 1986 to 2000). Additionally, tere are four gauging stations installed recording daily discharge data sice 1987. The runoff is dominated by rainfall.The vegetation has heterogeneous spatial distribution: forest cover 54% of the total area, scrubs and pasture cover 40% (22% each category), pavement or built areas counts about 5%. More than a half of the area is represented by the cambisol and mostly appears in the upper-medium part of the basin.

In order to fulfil this objective five actions are defined: (1) regional precipitation projections and calibration with local station; (2) hydrological-hydraulic model description and calibration with observation data; (3) runoff simulation introducing regional climate model data; (4) assess changes in flood prone area; (5) assess changes in hazard to people (in terms of flood depth and velocity).

(1) Regional precipitation projections and calibration with local station

For this study four Regional Climate Model (RCM) included in the EU-FP6 ENSEMBLES project (Hewitt, 2005) were selected: DMI-HIRHAM, CNRM-ARPEGE, EHTZ-CLM, and KNMI-RACMO. These climatic models considered for the study have a good coverage for the Basque Country. In the ENSEMBLES project simulations run under the IPCC A1B climate scenario and the period 1961-2100.

The A1B scenario, assumes the increase of the emissions during the first half of the present century which turns to decrease in the mid of the century due to more efficient technologies usage (Nakicenovic *et al.,* 2000).

Model data were compared with observed data provided by the Spanish National Meteorological Agency (AEMET).Five observatories covering the basin were selected fulfilling the criteria: observatories must give good coverage to the study area; they contain missing values under the threshold (8%) and provide enough data during the control period. A reconstruction of the series was applied by linear regression between best correlated stations.

A bias correction of the RCM outputs has been realized. Thus, the main purpose of this study is the projections at local scale. The series of the RCM outputs and the observations (defined hereafter as references) have been standardized on a daily based

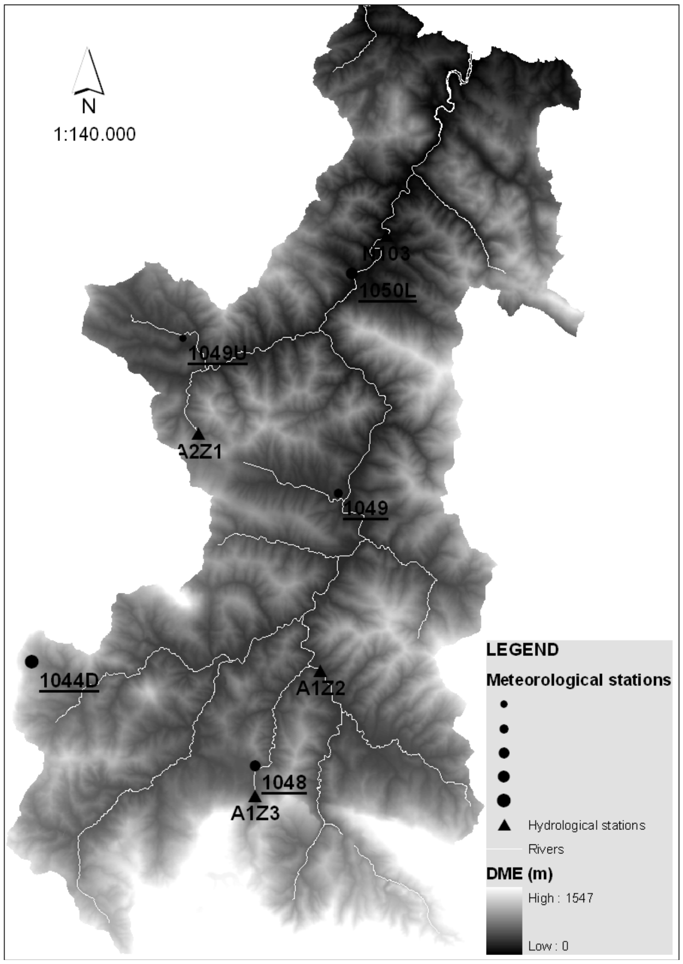

Fig. 1. Digital Model Elevation of the Deba basin including the location of the meteorological and hydrological stations. The meteorological station point size represent the amount of annual rainfall

frequency to extract the statistics of each month. The aim is to compare the model and the reference series. The standardization and the bias correction method have been undertaken by using cumulative probability of daily precipitation records (quantile mapping). However, the commonly used probability distributions (Gamma, GEV, Exponential, Pareto, etc.) have not fitted well to the whole spectrum of precipitation and it is necessary to use other alternative. It was observed that the empirical return period of the data is better adjusted to an alternative model (Moncho *et al.,* 2012).

(2)Hydrological-hydraulic model description and calibration with observation data

MikeShe-Mike11 hydrological and hydraulic coupled modelling tool is used. It consists in a physically distributed and process-based model. The temporal resolution of the model is 1 day and the spatial resolution, 490 x 490 meter pixel to the entire zone and 5 meters to the flood plain area. For the flood simulation Mike21 is used which simulate better the water velocity on the flood prone area than MikeShe-Mike11. Therefore, with this model, river runoff is simulated at daily time steps for the present and future precipitations.

The calibration and validation of the model is applied for periods in which observations and runoff data are available (1987 to 2000). MikeShe has an automatic calibration method where a coefficient of determination (R) and Nash Stcliffe (NS) is calculated. The calibration is done through estimation by comparing the measured and simulated daily flow for a state variable in the model and the entire time period of evaluation. NS indicates how well the observed values versus simulated fits 1:1 relation (in this study 0.72 for calibration period and 0.74 for validation period). R indicates the strength of the relationship between observed and simulated data ((in this study 0.87 for calibration period and 0.88 for validation period).

(3) Runoff simulation introducing regional climate model data

To evaluate the basin hydrological response to climate change, MikeSHE-Mike11 hydrological-hydraulic coupled model is forced by projected climatic variables. The main objective is to evaluate the shifts in magnitude of runoff. To answer this question comparison is made between present day discharge (reference period) and the hydrological response to precipitation projections.

(4) Assess changes in flood prone area

The main goal is to obtain the flood prone area and the velocity and water level in flooded zones caused by future precipitation and stream flow conditions to finally obtain the hazard to people maps.

For this purpose, it is used as input the precipitation and stream flow projection before the urban area (1050L precipitation station and N103 gauging station). As output it is obtained the flood analysis at the urban area under climate change conditions: it is calculated the changes on flood prone area and on severity of the event and it is calculated the hazard to people.

(5) Assess changes in hazard to people (in terms of flood depth and velocity)

Ramsbottom et al. (2003) and Penning-Rowsell et al. (2005) have proposed a semiquantitative equation to relate the flood hazard to people to depth and velocity of the water as well as the amount of debris that is in the water:

$HR=h(v+0.5)+DF$

Where,
HR is the (flood) hazard rating
h is the water depth (m)
v is the water velocity (m/s)
and DF is 0-1 score described the likelihood of debris (Table 1).

From the above flood hazard index, the level of hazard to people can be estimated and then categorized as: low (HR=0-0.75) that is caution (flood zone with shallow flowing water or deep standing water), moderate (HR=0.75-1.25) that means dangerous for some i.e. children and old people (flood zone with deep or fast flowing water), significant (HR=1.25-2.5) that is dangerous for most people (flood zone with 1 meter deep and fast flowing water, 1.5 m/s), or extreme (HR>2.5) that means dangerous for all (flood zone with deep higher than 1 meter and fast flowing water, higher than 1.5 m/s) (Ramsbottom *et al.*, 2003; HR Wallingford, 2006).

RESULTS & DISCUSSION

Even taking into account the medium greenhouse emission scenario, it is expected that extreme precipitation (percentile 0.99) will increase during the twenty century, although there is an uncertainty in the percentage due to the climatic models. The expected changes have a spatial variability depending on local characteristic (orography, distance to the coast, vegetation, etc.). One of the location do not presents significant change for most of the models (1049U) (Table 2). For most extreme models (CNRM, EHTZ and HIRHAM) it is expected an increase of 29±2% (1044D), 26±3% (1049) and 23±7% (1050L) (Fig. 2) for a return period exceeding 40 years and for the 2001-2040 period. For the less extreme model (KNMI) it is not expected significant changes for 1049 and 1049U stations and for the 2001-2040 period. However, for the 2041-2080 period the results change. For the most extreme model (CNRM) it is expected that extreme precipitation increases between 10% and 34%, the highest increases are for 1050L (Fig. 3) and 1044D stations. For this period the less extreme model is HIRHAM and it is expected less increase than the period before (except 1049U).

Changes in precipitation in first order impact discharges. It is expected an increase in peak discharge (percentile 0.99) between 14±9% and 15±8% for 3 models and for the period 2001-2040 with a return period exceeding 40 years, for N103 station (located before the urban area). For the period 2041-2080 there is more uncertainty, it is expected an increase between 12±8% and 19±10% for 2 models with a return period exceeding 40 years. For the other 2 models the increase is not significant with the same return period (Table 3).

Table 1. Guidance on debris factors for different flood depths, velocities and dominant land uses

Depths	Pasture/Arable	Woodland	Urban
0 to 0.25 m	0	0	0
0.25 to 0.75 m	0	0.5	1
d>0.75 m and/or v>2	0.5	1	1

Ref: FD2321/TR1 (HR Wallingford, 2006)

Table 2. Change in precipitation (C) (%) and the error (E) (%) for each climatic model (EHTZ, CNRM, KNMI, and HIRHAM), each meteorological station (1050L, 1049, 1049U, 1048 and 1044D) and different return periods (RP)

STATION / RP	EHTZ				CNRM				KNMI				HIRHAM			
	2040		2080		2040		2080		2040		2080		2040		2080	
1050L	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E
10	8,1	4,0	14,5	4,3	12,8	4,4	18,0	4,3	9,6	2,4	12,4	2,4	-0,2	2,1	3,4	2,1
40	11,7	6,4	26,8	7,3	22,6	7,4	26,5	7,2	14,0	3,6	14,6	3,6	0,6	3,0	7,0	3,1
100	14,2	8,7	35,6	10,3	29,6	10,5	32,5	10,0	17,0	4,8	16,0	4,7	1,1	3,9	9,4	4,0
1049																
10	10,1	3,2	6,6	3,3	8,5	2,9	10,1	2,8	1,9	3,2	12,5	3,3	15,8	2,1	6,4	2,1
40	14,9	4,5	13,3	4,5	13,2	3,9	11,7	3,7	1,9	4,5	14,6	4,6	26,3	2,9	10,5	2,7
100	18,1	5,5	17,9	5,7	16,3	4,7	12,8	4,5	1,8	5,6	16,0	5,9	33,7	3,5	13,2	3,3
1049U																
10	14,7	3,8	8,8	3,9	0,3	2,2	8,7	2,2	1,1	2,6	3,0	2,6	0,4	1,2	-2,1	1,1
40	19,0	5,2	16,9	5,6	0,4	2,9	10,0	2,9	0,8	3,6	0,9	3,5	1,2	1,6	-3,3	1,5
100	22,0	6,5	22,6	7,1	0,6	3,5	10,9	3,5	0,6	4,5	-0,5	4,3	1,8	1,9	-4,2	1,9
1048																
10	0,0	2,3	-1,3	2,3	-4,4	1,7	8,2	1,8	5,7	1,4	26,1	1,4	10,4	2,1	6,1	2,1
40	-0,9	3,1	0,3	3,3	-6,2	2,2	10,5	2,3	7,2	1,9	35,7	2,0	16,4	2,7	10,3	2,7
100	-1,4	3,9	1,3	4,1	-7,3	2,6	12,1	2,8	8,3	2,3	42,5	2,6	20,6	3,2	13,2	3,1
1044D																
10	18,7	4,2	7,0	4,2	18,0	1,9	24,2	1,9	16,1	2,3	31,6	2,4	18,4	1,7	4,5	1,6
40	26,5	6,3	15,1	6,4	27,5	2,8	34,4	2,8	22,1	3,5	43,4	3,7	28,9	2,2	8,2	2,1
100	32,0	8,3	20,8	8,5	34,2	3,6	41,6	3,6	26,3	4,6	51,8	5,0	36,3	2,6	10,7	2,5

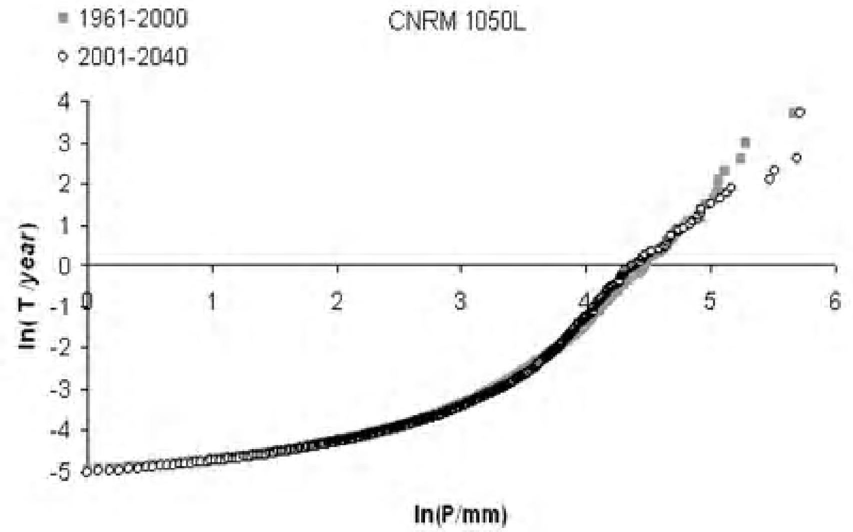

Fig. 2. Precipitation return period with respect to the period of reference (1961-2040 period), logarithm (mm). 1050L stations located before the urban area, CNRM climate model

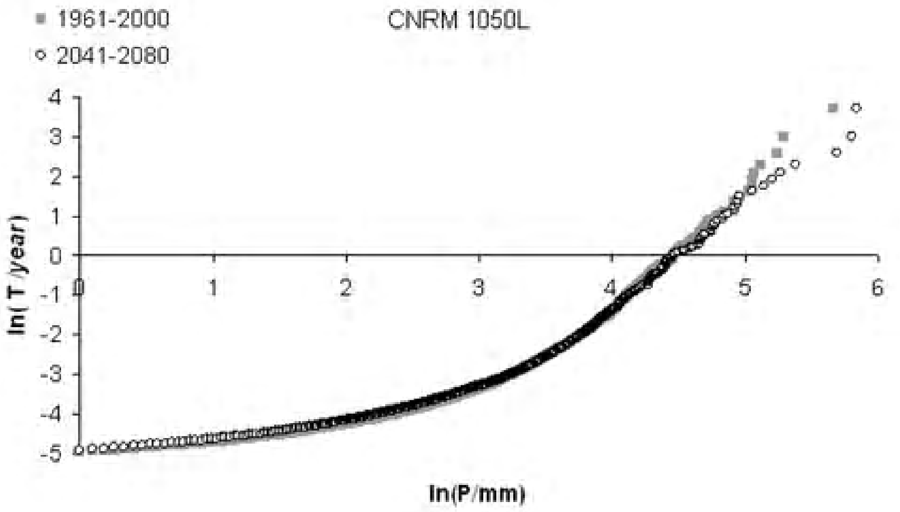

Fig. 3. Precipitation return period with respect to the period of reference (2040-2080 period), logarithm (mm). 1050L stations located before the urban area, CNRM climate model

Table 3. Change in discharge (C) (%) and the error (E) (%) for each climatic model (EHTZ, CNRM, KNMI, and HIRHAM) and different return periods (RP) for the station N103, located before the urban area

STATION /RP	EHTZ				CNRM				KNMI				HIRHAM			
	2040		2080		2040		2080		2040		2080		2040		2080	
N103	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E
10	12	6	10	6	12	7	10	7	-15	6	15	7	8	6	3	6
40	15	8	12	8	15	10	11	10	-18	10	19	10	14	9	6	9
100	17	10	14	10	17	12	12	12	-19	12	22	13	18	11	7	11

In order to analyze changes in flood-prone area and natural phenomena severity, precipitation and flow projection are used as inputs before the urban area. Changes in flood event are expected with its associated uncertainty. According to the results, new flood zones are detected with greater hazard to people. It is difficult for people to walk in flooded areas where the hazard factor is 1 and almost certainly fall when this factor exceeds 1.4 (Ramsbottom *et al.*, 2003; HR Wallingford., 2006). In the study area, several areas are detected with this range of hazard.

For CNRM model, one of the model with extremes results, it is expected an increase in the flood prone area and in the severity of the phenomena for both periods (2001-2040 and 2041-2080) (Fig. 4a, b). In general sense, the lowest return period (10 years) do not change a lot its extend (%1.1), the medium return period (40 years) decrease increase more (5.5%) and the highest return period (100 years) increase significantly the extend (82.3%), for the first period.

The situation for the future period is different (2041-2080). For the lowest return period it is expected a little increase of the flood extend (2%), the medium return period decrease the extend (-1.3%) and the highest return period increase the flood area extend but not as much as for the first period (38%).

In the Deba river basin, the municipal area of Deba will have a 12% and 7% increase in extend for significant and extreme hazards and a 11% and 12% decrease in extend for low and moderate hazards (CNRM model, compared the period 2001-2041 with respect the reference period, 1961-2000) (Table 4). Further, there are new areas with significant and extreme hazards (Fig.5a, b). This new areas are residential buildings and roads. It is considered difficult for the people to walk with a hazard rate up to 1 and the people are going to fall down when the rate is higher than1.4 (Ramsbottom *et al.*, 2003). That means that the vulnerability of those areas classified us significant and extreme hazard is very high.

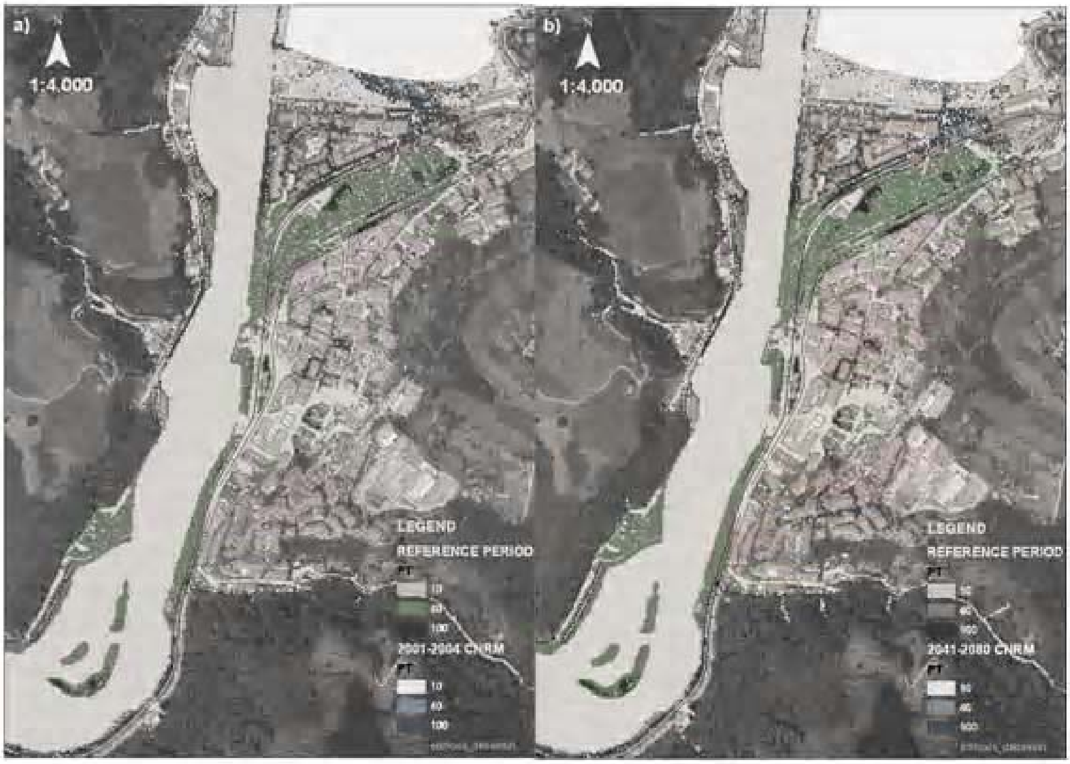

Fig. 4. a) Flood extend map. Actual (reference period, 1961-200) and future (with CC, 2001-2040). CNRM model. b) Flood extend map. Actual (reference period, 1961-2000) and future (with CC, 2041-2080). CNRM model

Fig. 5 a). Hazard to people data for 100 year events under past conditions (reference period, 1961-2000). b) Hazard to people data for 100 year events under future conditions (reference period, 2001-2040). CNRM model

Table 4. Hazard to people extend area (Ha) for the reference period (1961-2000) and future (2001-2040), for 100 year events under CC (CNRM model)

PT100	Reference Period	CNRM 2040	
HR	**Extend (Ha)**	**Extend (Ha)**	**Changes (%)**
None	0,15	0,17	12,87
Low	7,64	6,78	-11,23
Moderate	4,35	3,85	-11,58
Significant	5,48	6,15	12,28
Extreme	39,13	42,00	7,34
	56,75	58,95	3,88

CONCLUSION

According to the first available results, the expected precipitation and discharge changes in percentage have a variability depending the climatic model, the period analyzed and the spatial characteristics of the basin.

The discharges shows changes according the variability mentioned before but the most important conclusion of the study is that the extreme precipitation have more influence on flood processes than the discharge before the town. The low capacity of the system to absorb and control the precipitation is the cause of the fast basin's response. So the precipitation has an immediate influence in the river. Therefore it is important to have a good knowledge about the expected changes in extreme precipitation due to climate change and its consequences in the discharge and in the flood processes, even this kind the studies have an uncertainty associated.

This increase in precipitation has consequences in hazard to people. The expected climatic effects are increases in the severity of the hazard more than increases in extend of the flood prone area. There are new areas with high hazard probability that are residential buildings and roads. That means that the vulnerability of those areas is very high. And it is necessary to start defining adaptation strategies and measures to minimize the impacts.

This type of research plays an important role in defining adaptation strategies that are necessary due to the expected impacts on peak discharge and its consequences in flood hazard and human health at local scale. In this context, the results become the tools to define and evaluate different adaptation options that are already implemented or are conceivable according to current scientific knowledge. So the models become tools for evaluating adaptation measures in terms of their ability to reduce the vulnerability of the basin to the effects of climate change.

The idea of adapting to the potential effects of climate change has therefore gained ground in climate policies. The future work consist in how the political sphere must define an adaptation strategy at regional and local scale using impact studies which have an associated uncertainty.

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