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Vulnerability and adaptation to climate change of rural inhabitants in the central coastal plain of El Salvador

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ABSTRACT: This paper develops and implements an integrated method to assess climate vulnerability in a socio-natural system by identifying and linking the natural and socio-economic factors that increase such vulnerability. With these insights, the method assists in developing effective strategies and measures to increase the system's resilience and adaptability to the adverse impacts of climate variability and change. In order to detect and address the interactions between natural and socio-economic dynamics, the climate vulnerability of the socio-natural system, later referred to as study area, is considered based on the concept of a complex adaptive system and is characterized through its natural, economic and socio-cultural local environments. A climate vulnerability index (CVI) is defined as a function dependent on 3 sub-indices, namely: climate exposure, resilience and adaptability, and the related second-order variables. The method was developed to be applied in the following steps: (1) characterization of the natural and socio-economic dynamics; (2) integrated assessment of socio-economic, environmental and climatic baseline and future conditions, through use of an indicator system, related sub-indices and the CVI; and (3) comparative analysis of current and future CVI values, to be used for guidance in adaptation efforts.

KEY WORDS: Socio-natural system · Complex adaptive system · Resilience · Adaptability

1. CONCEPTUAL AND METHODOLOGICAL APPROACH

1.1. Conceptual framework

A systemic approach was adopted, addressing the interaction and coupling between social and natural systems in the study area, which we refer to here as a socio-natural system. As such, this complex adaptive system exhibits dynamic and non-linear behavior; thus, it can reorganize itself through adaptive cycles and is able to develop functions, such as resilience and adaptability, that allow the system to recover from or resist effects of climate variability and to adapt to climate changes. The study area was delimited and characterized by natural, economic and socio-cultural environments.

The climate vulnerability of the study area was defined as a variable dependent on 3 explanatory first-order variables: climate exposure, resilience and adaptability. Climate exposure was addressed as a climate threat for the study area. Resilience indicates the capacity of the system to absorb shocks of natural or social factors and of recovering from disturbances or impacts before the system changes its structure by changing the variables and processes that control

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behavior. Adaptability is the system's ability to evolve and adapt to changes without collapsing, by feedback processes that enable it to increase its coping range and its self-organizing capacity. Explanatory second-order variables of exposure, resilience and adaptability were selected and, in turn, linked, as an interface, to the related second-order variables that characterize each of the 3 environments of the study area (Table 1).

1.2. Methodological approach

The development of the integrated climate vulnerability assessment, which was subsequently used to assist the adaptation process, involved the following general steps: (1) characterization of the study area, including the natural and social dynamics and the interaction and coupling between them; (2) integrated assessment of current climate vulnerability; (3) integrated assessment of future climate vulnerability; and (4) comparative analysis of current and future vulnerability as guidance for adaptation to climate change (UNDP 2005, p. 11–12). Participation of the local population and the counterpart organizations was very active, and included consultation processes, field surveys, climate change awareness workshops, and processes of exchange, discussion and analysis. Indigenous and local knowledge was gathered and analysed and, together with scientific knowledge, served as the basis for addressing the various issues, validations, future socioeconomic projections and planning for strategic adaptation to climate change.

To assess current and future climate vulnerability in the study area, a climate vulnerability index (CVI) was developed, as a function dependent on 3 sub-indices: climate exposure (E), resilience (R) and adaptability (A). The CVI was developed as a mathematical expression as follows:

$$\mathrm{CVI} = E\,[2 - (R + A)]/2 \quad (1)$$

with a CVI max. = 1 and a CVI min. = 0.

For each geographical area of the study area, the CVI for current and future conditions was calculated using Eq. (1). Values for R and A sub-indices were calculated by aggregating the values of the related second-order variables in the 69-indicator system (see Tables 2, 3 & 4), with the same weight attributed to each variable regardless of the environment to which it belonged. These indicators were selected to capture the main elements of the 3 environments and related dimensions, as well as the second-order variables that characterize the study area. The value of the E sub-index, also referred to as the climate threat index (CTI), was estimated by aggregating the values assigned to the quantified impacts related to the 5 meteorological indicators associated with temperature and the precipitation extremes. The relational framework for all indicators, the related variables and the CVI is outlined in Fig. 1.

Table 1. Explanatory variables of climate vulnerability. Second-order variables are interface variables

Order of variable Type of explanatory variable
First Climate exposure (E)
Second Temperature-related climate extremes Dry and wet climate extremes
E-related variables characterizing the study area
First Resilience (R)
Second Organization flexibility Mechanisms of control Structural coupling
R-related variables characterizing the study area
First Adaptability (A)
Second Potential of resources Innovation and experimentation Organization complexity
A-related variables characterizing the study area

2. CHARACTERIZATION OF THE STUDY AREA

2.1. Territory delimitation

The current configuration of the study area is the result of the combined dynamics of natural and social systems. Historical patterns of human activities have transformed and shaped current natural and social landscapes. The study area was delimited considering the interactions between local socio-cultural, economic and natural dynamics, and on the basis of 3 main criteria. Primarily, the geographical areas that were considered contained communities with organizations promoting local sustainability processes. There are about 30 000 people (6725 families) involved with such organizations which are grouped in 6 geographical areas. Secondly, the natural landscape system referred to as the 'central coastal plain'

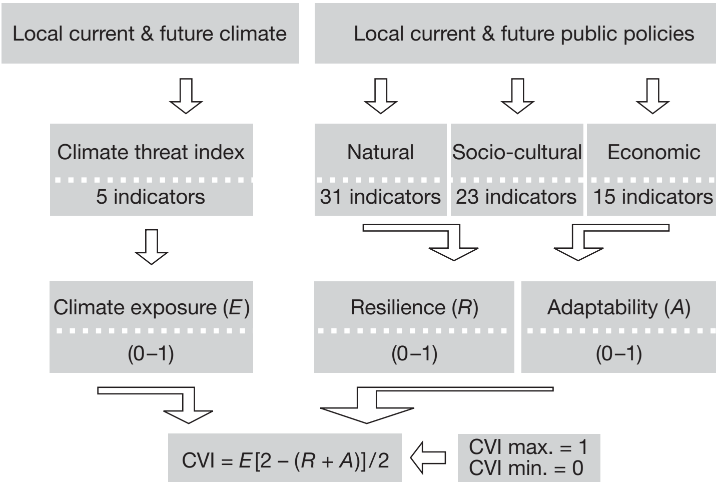

Fig. 1. Relational framework to calculate the current and future climate vulnerability index (CVI)

(Ramírez et al. 1986, p. 111–112), including agricultural valleys, volcanic bulks and massifs, was fully considered; and thirdly, river basins whose dynamics affect or are somehow linked to local human communities were also included. The study area is located in the southeastern and paracentral region of El Salvador and spreads over 1152.5 km^2 (Fig. 2). In the coastal strip there are extensive areas of medium-low and low altitudes, between 2 and 60 m above sea level (a.s.l.). To the north, the foothills of the San Vicente and Tecapa volcanoes have slopes of moderate to high altitude, between 100 and 1500 m a.s.l. The peak of the San Vicente volcano reaches 2300 m a.s.l.

2.2. Natural and social dynamics

The dynamics of the natural and social systems was addressed in an integrated manner. In terms of natural dynamics, the study area consists of 2 natural landscape systems: the central coastal plain and a recent volcanic chain, with a total of 4 major subsystems—2 coastal plains and 2 volcanic massifs, respectively. The 4 subsystems were divided into a total of 13 landscape units, including among others: bays, alluvial plains, volcanic borders, foothills, summits, outskirts of volcanic massifs, as well as mangrove swamps.

Social dynamics, understood as the set of activities of human society, include the socio-cultural and economic activities of the study area. Patterns of occupation, property and appropriation and use of local resources have been determined by the forms of social and political organization. In our analysis of social dynamics we focused on ongoing local development processes (promoted principally by 2 local counterpart organizations) aiming to support local families in improving their knowledge and taking control of the natural and social factors that strongly influence, affect or offer opportunities for local sustainability or a better quality of life.

Local organizations are already developing participatory planning processes and promoting programs and projects to harmonize economic activities with natural processes and to improve family incomes. The progressive integration into an inter-communi-

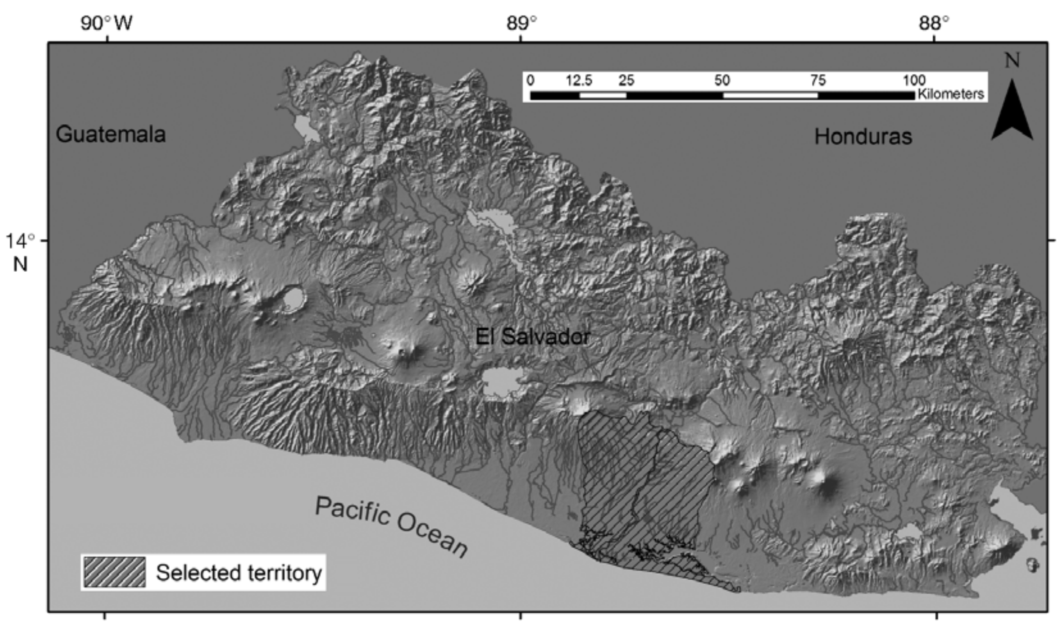

Fig. 2. Geographical location of the study area

tarian economy, eventually linked to the national economy, will generate additional benefits that can be transferred to or redistributed at the local level. In some geographical areas the above mechanisms have already been set in motion on a trial basis. The establishment and development of entrepreneurial initiatives in these pilot projects are designed in such a way that part of their profits is reinvested into new commonly shared enterprises or initiatives, including communitarian tourism resorts, aquiculture, agroforestry and cashew handicraft agro-industry.

Relevant social and economic transformations have occurred within the study area, which have modified the role of local actors. For instance, the fundamental modification of land property regulations in 1992 which included legal allocation of land plots and housing among local inhabitants as part of the peace agreement assented to in El Salvador after a 10 yr war, significantly affected the ways of organizing and developing the local economic and social activities. However, lacking of credit and technical support, local inhabitants had to organize locally to collectively manage environmental and socioeconomic threats, impacts and challenges. Likewise, for a sizable segment of the local population, there is currently significant potential for the use and control of environmental services and natural resources to support consumption and productive activities. Both mangrove ecosystems and secondary terrestrial forests are relevant in the supply of animals and plant products, as well as for the food security and income of local families. Forests also serve as barriers against floods and river swells and provide a habitat for a great variety of native and migratory species.

3. INTEGRATED ASSESSMENT OF CURRENT CLIMATE VULNERABILITY

Baseline conditions of the socio-cultural, economic and natural environments were set for 2004, and were numerically estimated through the 69-indicator system. These indicators were grouped together with first-order variables or dimensions for each environment and then assigned a level (5 categories, from very high to very low) according to their level of contribution to resilience or adaptability. Depending on the indicator's level and related numerical value, its contribution could either increase or decrease the CVI value. For each environment, values for resilience and adaptability variables were calculated and further aggregated to determine the consolidated values for the resilience and adaptability indices.

3.1. Current socio-cultural environment

The socio-cultural environment is addressed considering the basic social organization of local inhabitants. It is characterized by 3 dimensions: (1) normative, (2) cultural and (3) psycho-social (which encompasses social patterns of human behavior). Such dimensions were reflected in 23 selected indicators (Table 2). Baseline conditions were numerically estimated through those indicators for 2004.

Of the values assigned to indicators, the cultural dimension was the one that contributed the most to resilience and adaptability in the whole study area. This was due to existing local initiatives, which have shown foresight in the harmonization between human activities and natural processes and the preservation and appraisal of indigenous and local knowledge and culture, particularly in connection with agricultural systems, technologies and practices and human health. The precarious quality of life, territorial dysfunctionalities (e.g.: ineffectiveness or lack of basic services and land planning) and low organizational flexibility, as well as the lack of municipal regulations regarding sustainable land management, constitute the basic factors determining the high contribution of the psycho-social and normative dimensions to the current level of vulnerability of the study area.

3.2. Current economic environment

The local economic environment refers to the geographic space in which local people develop economic activities, either of family or entrepreneurial nature. It also refers to the space in which goods and services are produced, circulated and consumed, and the generated wealth is distributed. Three dimensions were identified to characterize the local economic environment: (1) production, (2) circulation and (3) consumption and income distribution, which were reflected in 15 selected indicators (Table 3) and further categorized based on their assigned numerical values.

According to the indicators' values, there is a local economic potential, since most of the families own land plots and organize productive and social activities in community partnership. The main current barriers for economic dynamism have been the lack of financial capital, physical infrastructure and equipment to support productive investments and economic activities. Likewise, local poverty has been exacerbated by the lack of successive public policies that consider the needs or the priorities of a rural economy — e.g. the strengthening of human capacities to develop and adopt appropriate environmentally friendly agricultural systems, technologies and practices, or the pro-

Table 2. Variables and indicators characterizing the socio-cultural environment

First-order Second-order variables	Indicators
Normative	
Local counterparts	
Organization flexibility	No. of levels that participate in the strategic or operational decisions
Organization scope	No. of geographic levels for local development work
Organization nature	No. of thematic areas for local development work
Alliances to promote local sustainability	No. of municipalities supporting the work of counterpart organizations Counterparts' level of participation in alliances
Normative framework to promote local sustainability	No. of public entities and projects within the study area No. of participating non-government entities and projects No. of municipal contributing ordinances
Cultural	
Endogenous sustainability processes	Endogenous level of the counterparts' development plans and programs Endogenous level of the counterparts' development projects Local counterparts' geographic influence on the promotion of endogenous local sustainability
Harmony with environment	Contribution of local activities to conservation of the environment
Historical, cultural and territorial identity	Frequency of locally organized socio-cultural events Contribution of historical commemorations to strengthening identity No. of locally promoted sustainable tourism initiatives
Psycho-social	
Quality of life	Income level of the local population Level of access to basic services Level of access to natural resources for local food security Level of access to credit, technical assistance and training
Territorial functionality[a]	Level of access to transport Level of access to communications
Safety[b]	Effectiveness of local/national flood early-warning systems Delinquency level within the study area

[a]Dimension that has to do with the mechanisms that regulate internal and external interactions of socio-natural systems and optimize their functioning, e.g. social infrastructure contributes to fulfillment of social functions

[b]Dimension that contributes to fulfillment of psycho-social functions

motion of entrepreneurial ventures that could activate the economy, generate employment and make feasible the redistribution of national revenue to improve and disperse local wealth. Although, currently, the local economy is focused on traditional family-economy schemes, there are some innovative entrepreneurial ventures that combine individual and partnership property schemes.

3.3. Current natural environment

3.3.1. Local environmental quality

The dynamics of natural systems are strongly influenced by socio-economic dynamics, the latter being able to determine a structural coupling or decoupling between both systems. Thus, 2 dimensions were identified to characterize the natural environment: (1) natural and (2) socio-natural, which were reflected in 31 selected indicators (Table 4). Natural landscapes and ecosystems were addressed under the natural dimension, whereas the socio-natural dimension refers to local natural resources and environmental management schemes. Values were assigned to these indicators to determine baseline conditions, including some local climate-related indicators (mean flow of river water and seasonal moisture content of the soil), which are closely related to local flood dynamics.

A comparative analysis of the natural and socio-natural dimensions showed that, in most geographical areas of the study area, the contribution to resilience and adaptability of the natural dimension was higher due to the relevant contribution of the essential environmental functions that enable local sustainability. Whereas the lower contribution of the socio-natural dimension is mainly reflected in, on the one hand, the structural decoupling between existing land management patterns and natural dynamics, and on the other, the prevailing natural dynamics that generate relevant adverse impacts in the study area, such as river floods, tide surges and salinization of soil and water. Thus, under current baseline conditions, local inhabitants are maladapted to current climate variations, including extreme events, due to their very low coping ranges to climate variability.

Table 3. Variables and indicators characterizing the economic environment

First-order variables or dimensions Second-order variables	Indicators
Production	
Production organization	No. of local agricultural activities Basic grain planted area Diversity of livelihoods associated with local survival strategies Relative efficiency in the agriculture or livestock productive activities
Technological level	Percent people with access to technical assistance for production Percent producers with innovative methods and technology Percent producers using irrigation in productive activities Technological response in the agriculture/livestock sector to local temperature Technological response in the agriculture/livestock sector to local precipitation
Circulation	
Access to resources	Percent income from activities other than agriculture or livestock Percent people who own the land for agriculture or livestock Percent people who have access to credit for economic activities
Distribution and consumption	
Access to markets	Access to local human settlements and land plots No. of markets available and accessible for what is locally produced Percent of market-oriented production

3.3.2. Local climate baseline

For the characterization of local climate, observations from meteorological stations with information on the variables precipitation and temperature were considered. The best records were for the 1970s, since the information available afterwards was scarce and referred only to precipitation. Most of the local meteorological stations had short time series and usually showed discontinuities. The data used were from meteorological stations within or close to the study area; these were grouped into 3 categories according to the number of observations, type and quality of records, and time series horizons.

The study area's climate is mainly influenced by the adjacent waters of the Pacific Ocean and by the meteorological systems associated with the Inter-Tropical Convergence Zone (ITCZ) and easterly waves. It is also frequently influenced by migratory tropical hurricane systems and is highly vulnerable to the annual occurrence of floods and droughts, the latter due either to the North Atlantic Tropical Ocean cold conditions or to El Niño years. Annual mean precipitation oscillates between 1500 mm, in the coastal strip, up to 1700 mm northward. Every year during the rainy season, which occurs from May to October, 5 to 15 consecutive dry-day periods occur, which are referred to as midsummer drought. The annual cycle of precipitation over the southern part of Mexico and Central America exhibits a bimodal distribution, with maximum values during June and September and a relative minimum during July and August. As regards extreme temperatures within the study area, the highest temperatures occur during the day at ~14:00 h, while the lowest temperatures occur at ~05:00 h. Annual mean maximum temperatures vary from 31°C on the low coastal fringe to 36°C upstream of the Lempa River. The annual mean minimum temperatures decrease inland, varying from 23°C along the sea–land boundary to 21°C north of the study area. The warmest months are March and April, reaching 34.6°C in the lowlands, whereas the lowest temperatures occur in December or January, reaching 20.1°C in the highlands. Sea to land breezes regulate local climate and, in the morning, produce an onshore breeze that contributes to humidity, rain generation and air freshening in the study area.

3.4. Current local climate threats and impacts

The definition and calculation of a CTI allowed us to identify local climate threats and impacts on baseline and future conditions in the study area. Available data from local meteorological stations were not useful as they did not comply with the minimum quality and quantity standards required. Accordingly, annual records of maximum and minimum temperature and precipitation for the baseline period from 1961 to 1990 were used to assign values to the CTI-related indicators. These data were acquired from the San Miguel-UES meteorological station, which is located close to the study area (13° 26.4′ N, 88° 07.6′ W) and was selected according to the following criteria: (1) level of representativeness for the study area, according to principal component analysis; (2) 30 yr or more of availability of daily precipitation records for 1961 to 1990; (3) availability of precipitation records updated to the year

Table 4. Variables and indicators characterizing the natural environment. Soil agrological potential: soil fertility in relation to crops

First-order Second-order variables	Indicators
Natural	
Essential environmental functions	Soil sedimentation and erosion
	Rivers and creeks that have changed their course
	Susceptibility to seismic and geomorphological activity
	Flow of river water in local streams
	Seasonal moisture content of soil
	Soil agrological potential
	Number of different ecosystems
	Relative amount of plant and animal species
	Habitat loss threat
	Proportion of land consisting of environmental corridors and natural areas
Functions supporting human activities	Availability of plants and forest products for human and livestock food, and for sale
	Availability of energy-related forest species for family use, production and sale
	Availability of aquatic and marine species for local consumption and fishing
	Level of scenic beauty for human welfare and tourism
	Availability of forest species for local consumption and sale
	Availability of river rocks and sand
	Availability of water for family use
	Availability of water for local productive activities
	Forest contribution to flood mitigation
Socio-natural	
Environmental influence and prevalence	Flood frequency
	Soil permeability and drainage capacity
	Soil salinity
	Availability of, and access to, underground water
Capacity for management & transformation of the environment	Conflict between potential and actual land use
	Influence of hydroelectric dams on flood dynamics
	Level of deforestation
	Air pollution due to the use of aerial sugar cane ripening agents
	Soil pollution due to fertilizers, pesticides and waste
	Level of exploitation of local land, aquatic and marine species
	Contribution of protection works to flood mitigation
	Protection of the existing natural areas

2005; and (4) availability of ≥30 yr of maximum and minimum temperature records.

The CTI was constructed on the basis of 5 meteorological indicators associated with temperature and precipitation extremes, including extreme wet and dry climate events, namely: (1) recurrence of extremely dry years, (2) recurrence of extremely rainy years, (3) maximum number of consecutive days with ≥40 mm of daily rainfall, (4) recurrence of dry periods ≥11 d (representative of moderate to severe drought) in July and August, and (5) increase in the annual mean maximum temperature during extremely dry years. As for Indicators 1 and 5 of the CTI, the occurrence of an extremely dry year (mean annual precipitation 10% below average levels) does not necessarily imply an increase in the annual mean maximum temperature. When an extremely dry year is determined by a decrease in rainy season mean precipitation of 11% or more below average levels (accompanied by the highest temperatures of the year), the annual mean maximum temperature increases. Whereas if an extremely dry year is determined by a decrease in dry season mean precipitation of 34% or more below average levels (accompanied by the lowest temperatures of the year) the annual mean maximum temperature does not necessarily increase.

After defining and calculating the behavioral range for each of the 5 meteorological indicators for the period from 1961 to 1990, using a statistical downscaling model (SDSM), the level of threat associated with each one was defined by identifying the impacts on the productive, hydrological processes. Specific criteria allowed the categorization of the impacts and the subsequent quantification of the levels of threat. The current value for the CTI was calculated as a simple average of the calculated values of the 2 sub-indices, namely: (1) levels of climate threat on productive activities and (2) levels of climate threat on the hydrological processes. The small size of the study area allowed the calculation of a single CTI value, since all the geographical areas, including the human communities considered in the present study, are located in 2 agricultural valleys within the coastal plain covered by the study area, where local climate is very similar.

With regards to productive activities, the greatest climate exposure is determined by the recurrence of extremely dry years, the maximum number of consecutive days with ≥40 mm of daily rainfall and the recurrence of dry periods ≥11 d in July and August. Variations in temperature are also noted to constitute a threat to production, especially when accompanied by a midsummer drought during the rainy season. With recurrence of extremely dry years, droughts and the adverse affects of flooding are heightened, thereby triggering a decrease in yields from agricultural and livestock activities. The recurrence of dry periods ≥11 d in July and August has an increasingly adverse effect as midsummer droughts become more intense, which affects the harvest from the May sowing and creates problems for activities associated with the August sowing period. The increase in annual maximum temperature during an extremely dry year increases evapotranspiration and, therefore, the water demand for crops, especially during the dry season.

The hydrological processes are mainly affected by the recurrence of extremely wet or dry years. As water balance depends on the rain volume rather than the number of rainy days, the decrease in rainy days during extremely dry years, as well as the maximum number of consecutive days with ≥40 mm of daily rainfall and the recurrence of dry periods ≥11 d in July and August, produce low-level impacts on local hydrology. Increases in temperature also have negative effects on the water balance, as a result of the increase in evapotranspiration as well as the loss of vegetative land cover in the study area, which exacerbates the negative impacts associated with local water scarcity.

4. INTEGRATED ASSESSMENT OF FUTURE CLIMATE VULNERABILITY

4.1. Future socio-economic and environmental scenarios

The development of future socio-economic and environmental scenarios included 4 steps: (1) analysis of current national macro-policies and related key indicators or driving forces, (2) integrated analysis of the dynamics generated by the projected national macro-policies and related key indicators by 2015, (3) definition of the local expression of national macro-policies for the 3 local environments and their related dimensions by 2015, and (4) definition and validation of the local socio-economic and environmental scenario by 2015, on the basis of the future values calculated for the 69-indicator system and related dimensions, which would contribute to increase, decrease, or maintenance of the baseline values of R and A indices and, in turn, of the CVI under future conditions.

Future dynamics related to national macro-policies were developed through projection to 2015 of current and projected governmental plans and programs, taking into consideration the future impacts that the whole set of national and local policies — mainly public programs, projects and actions — would likely produce. Salvadoran governmental institutions have projected future public policies and programs to 2015, in order to facilitate monitoring and compliance with the Millennium Development Goals (MDG) set by the United Nations. These policies and programs included future trends based on the related key indicators or driving forces (Umaña 2000).

4.2. Future local climate scenarios

4.2.1. Observed recent climate trends in Central America

In a recent study (Aguilar et al. 2005) addressing the trends in observed climate extremes in the Central and northern South American region, changes in extreme temperatures and precipitation were identified and analyzed. The study indicates that extreme temperatures and the oscillation between them appear to be changing in the region and that warming is becoming more intense in the boreal summer and autumn. The total amounts of rain show no significant increase, but the intensities indicate a significantly increasing trend.

Furthermore, the results of a national study referring to the baseline period from 1961 to 1990 (Centella et al. 2000a), identified a remarkable increase in annual mean temperature. The estimated values of linear trends indicated a warming process of approximately 0.04°C yr^{-1}; thus, annual mean temperature rose about 1.2°C during the 30 yr baseline period. The warmest decade of the specified period was 1980 to 1989; the 3 warmest years during the same period were 1987, 1990 and 1983, with anomalies of up to 1.1, 0.8 and 0.7°C, respectively.

4.2.2. Future climate change scenarios for Central America and El Salvador

Future climate change scenarios for Central America and El Salvador: Regional and national climate change scenarios are based on greenhouse gas (GHG) emission and concentration levels as the basic climate sensitivity forcing. Thus, when assessing climate change impacts and vulnerability, many uncertainties should be considered, namely: uncertainties related either to future GHG emissions, global climate sensitivity and global circulation patterns, or to natural climate variability, etc.

According to the projections of nine atmosphere-ocean general circulation models (GFDL_R30_c, CSIRO Mk2, HadCM3, ECHAM4 / OPYC, CSM 1.3, CCSR / NIES2, MRI2, CGCM2 and DOE PCM), regarding 2 socioeconomic scenarios to quantify projected climate change and associated uncertainties, the mean global temperature is expected to increase by 1.3 to 4.5°C under a medium-high emissions scenario (IPCC A2 scenario) and by 0.9 to 3.4°C under a medium-low emissions scenario (IPCC B2 scenario) by the end of the 21st century (2071 to 2100), in comparison to temperatures in the period from 1961 to 1990 (IPCC 2001).

The future climate change patterns in northern Central America, including El Salvador, project annual mean temperature increases of 0.3°C by 2010 to 1.2°C by 2050. By 2050, for any month of the year, temperature increases would be slightly higher under the B2 scenario, whereas, beyond 2050, temperature increases would be higher under the A2 scenario: from 1.8°C (B2) to 2.2°C (A2) by 2075 and from 2.3°C (B2) to 3.3°C (A2) by 2100 (IMN-MINAE-CRRH 2006).

According to another national study on climate scenarios for El Salvador (Centella et al. 2000b), the annual mean temperature is expected to increase 0.8 to 1.1°C by 2020 and 2.5 to 3.7°C by 2100. For precipitation, the results are less certain and include ranges of between −11.3 and 3.5% by 2020 and −36.6 to 11.1% by 2100. Although magnitude changes are observed, the projected monthly rainfall pattern is similar to that in the baseline period. A relative reduction of the total volume of rainfall in July and August is expected, which would be associated with the yearly occurrence of midsummer droughts. With regards to the sea level rise (SLR), a national study (Monterrosa 2000), which has been quoted in other climate reports (IPCC 2007), projected and assessed a rise of 13 to 110 cm using incremental scenarios, which would have adverse impacts on the people and coastal systems of the Salvadoran coastal plain in the future.

Local climate scenarios for the study area were developed using the 3 following 30 yr periods: 1961–1990, 2006–2035 and 2070–2099. In order to develop local climate change scenarios for maximum and minimum temperatures and rainfall, a SDSM was used, which involves relations between macro-scale and surface observations. The basic hypothesis of the SDSM is that relations established for current climate will remain under future climate change conditions. The data used were selected from daily records of the San Miguel-UES meteorological station, located northeast of the study area. Mean changes for the 30 yr period from 2006 to 2030 were then used to calculate the future CTI. Inter-decadal and inter-annual variations were not assessed due to the lack of relevant data.

Data of both the United States' National Center of Environmental Prediction (NCEP) reanalysis model and the SDSM under A2 and B2 scenarios, with current forcing, satisfactorily reproduced the current observed mean minimum, absolute minimum and mean maximum temperatures. Other parameters, such as the absolute maximum temperature, daily temperature ≥38° and monthly mean rainfall, were overestimated. Daily rainfall ≥40 mm was underestimated, although, in all cases, the monthly distribution pattern was well reproduced.

Under scenario A2, by 2020, the average annual mean minimum temperature would increase by 0.2°C and, by 2085, it would increase by an additional 0.2°C. Under scenario B2, the annual mean minimum temperature would increase by 0.2°C and would remain constant until 2085. Under scenario A2, the annual mean maximum temperature is expected to increase 0.3°C by 2020 and 0.5°C by 2085. A greater increase in annual mean maximum temperatures is expected than in annual mean minimum temperatures. In general, projections show that precipitation will decrease during the rainy season from May to October. The projected rain increase during April in both A2 and B2 scenarios and in all time horizons could be a false signal due to an early onset of the rainy season. This could cause a delay of May rains, which would be more evident under scenario B2.

4.3. Future local threats and impacts related to climate change

4.3.1. Calculation of future CTI

Local downscaled climate scenarios projected for the 30 yr period from 2006 to 2035, generated parameters and criteria that served as the basis for projecting future values of the 5 CTI indicators, using the SDSM, as well as climate records for the specified period and A2 scenario outcomes. Baseline precipitation scenarios for the 30 yr period from 1961 to 1990, as well as future precipitation scenarios (2006 to 2035) under A2, were assessed thorough statistical analysis, specifically monthly rain distribution, in order to infer future inter-monthly precipitation behavior by 2020.

The same criteria used for the climate baseline period to estimate impacts on productive activity and environmental quality were used for projecting future climate impacts and quantifying the future CTI value by 2020. However, taking into account uncertainties related to future climate scenarios, future CTI values are just indicative numbers reflecting the possible direction of future climate trends in the study area.

4.3.2. Future local impacts related to climate change

Future CTI values reflected that current climate impacts would be worsened by the combined effect of temperature increases and the occurrence of prolonged dry periods during the rainy season. Hydrological dynamics and environmental quality would be negatively affected, especially by the higher probability of recurrence of extremely rainy years and the occurrence of extremely dry years. Evapotranspiration would increase; thus, water availability would not be able to fulfill the needs of humans, animals, or crops. Floods would likely cause the deterioration or destruction of facilities and equipment, such as mills, electrical power infrastructure, plant nurseries, irrigation equipment, aquaculture pumps and pools, fences and stables. Sedimentation and the collapse of existing drainage and dam systems would increase. Furthermore, pathways, footpaths, bridges, sewage systems and wharves would deteriorate or collapse. A predicted higher incidence of fires and pest infestations could contribute to accelerated land-use change in forested areas, thus increase fragmentation of forests, and floods would undermine the plinth of mangroves causing their deterioration or reduction. Development and behavior anomalies of indigenous and migratory species are expected, as well as loss of and disturbances in habitat. According to a national study (Monterrosa 2000), using incremental SLR future scenarios, there would be many adverse impacts on coastal people, infrastructure, ecosystems and sectors, including land loss ranging from 10 to 27.6% of the total coastal plain area, and an increase in soil sedimentation, salinization and erosion in coastal low lands — as well as in aquifers — due to the combined effect of more frequent floods and higher tides.

5. COMPARATIVE ANALYSIS OF THE CURRENT AND FUTURE CVI VALUES

Current and future CVI values for 2004 and 2015, respectively, were calculated for each of the 6 areas within the study area. As CVI values approach 1, vulnerability levels heighten, and as CVI values approach 0, vulnerability levels decrease. Although, CTI values were projected for 2020, the values obtained were used in calculations to year 2015, in order to assure consistency with the time horizon adopted for the socio-economic and environmental scenarios. The CVI integrates values calculated for the variables resilience and adaptability related to the whole study area, which result from the consolidated values of these 2 variables for each of the 3 local environments. Current and future values of the CVI and of its 3 explanatory variables or sub-indices are shown by geographical area in Table 5. Even though, in the whole territory, the future CVI values were elevated in comparison to values in 2004, increases were small, probably due to the significant increases in the values of the resilience and adaptability indices, which, to some extent, could reflect the positive effects of existing and projected local sustainability efforts and be considered autonomous adaptation.

Since the future climate exposure sub-index (E) is the same for the whole study area, future CVI variations would mainly be influenced by the future values of adaptability and resilience in each geographical area.

For future adaptability (Table 6), the socio-cultural environment would contribute the most to improvement by 2015, mainly due to plans and projects that have been locally designed and promoted to consolidate and improve social organization, through participatory local planning and the implementation of

Table 5. Current and future values of the climate vulnerability index and its explanatory variables, by geographical area. 1: Microregión Económico Social; 2: Iniciativa para el Desarollo Económico y Social; 3: Sistema Económico y Social; 4: San Juan del Gozo; 5: San Marcos Lempa; 6: Tierra Blanca

Area	Resilience		Adaptability		Climate exposure		Climate vulnerability	
	Current	Future	Current	Future	Current	Future	Current	Future
West Bank								
1	0.586	0.619	0.514	0.559	0.475	0.543	0.214	0.223
2	0.592	0.611	0.544	0.579	0.475	0.543	0.205	0.220
3	0.530	0.622	0.556	0.588	0.475	0.543	0.217	0.214
East Bank								
4	0.465	0.546	0.554	0.562	0.475	0.543	0.233	0.242
5	0.509	0.626	0.591	0.584	0.475	0.543	0.214	0.214
6	0.544	0.633	0.578	0.570	0.475	0.543	0.209	0.216

Table 6. Contribution of each environment to current and future adaptability and resilience, by geographical area (area numbers as in Table 5)

	Local environment					
	Socio-cultural		Economic		Natural	
	Current	Future	Current	Future	Current	Future
Adaptability						
West Bank						
1	0.576	0.754	0.521	0.589	0.446	0.335
2	0.549	0.749	0.625	0.572	0.460	0.415
3	0.638	0.790	0.625	0.606	0.406	0.368
Mean	0.587	0.764	0.590	0.589	0.437	0.373
East Bank						
4	0.544	0.769	0.604	0.556	0.513	0.361
5	0.648	0.797	0.625	0.572	0.500	0.381
6	0.610	0.779	0.604	0.556	0.520	0.375
Mean	0.601	0.782	0.611	0.561	0.511	0.372
Resilience						
West Bank						
1	0.671	0.778	0.625	0.625	0.461	0.453
2	0.718	0.773	0.708	0.708	0.352	0.352
3	0.556	0.847	0.667	0.667	0.367	0.352
Mean	0.648	0.799	0.667	0.667	0.393	0.385
East Bank						
4	0.486	0.676	0.542	0.625	0.367	0.336
5	0.477	0.667	0.667	0.875	0.383	0.336
6	0.528	0.648	0.667	0.875	0.438	0.375
Mean	0.497	0.664	0.625	0.792	0.396	0.349

development initiatives. As well, there would be improvements in road infrastructure, partly financed by municipal budgets.

Resilience of the socio-cultural environment is projected to increase in the whole territory by 2015, and would continue to contribute most to the climate resilience of the whole study area. This is due to initiatives in strategic planning promoted by local organizations, including strengthening of local capacities and opportunities for development, improvement of local flood early-warning systems, and preservation and promotion of indigenous and local knowledge on climate-resilient agricultural systems, technologies and practices. Territorial identity would be enhanced through the appraisal and dissemination of local culture, history and natural dynamics. As for social and economic alliances and networks, they would be consolidated and broadened to include local, sectoral, national and regional levels.

The contribution of the economic environment in future adaptability would decline, especially in all of the East Bank areas, due to the lack of technical assistance, credit, technological transfer and research from public administrations, as well as the stagnation or deterioration of rural family incomes. However, a positive contribution from this environment to future adaptability can be expected due to stabilization of the land market. Future values of the economic environment are expected to remain constant in the West Bank areas, while they are expected to improve in the East Bank areas, due, above all, to local productive capabilities. In addition, improvement can be expected due to local endogenous efforts to diversify economic and agricultural activities and improve productive efficiency, including the use of appropriate species and varieties to adequately cope with climate variability.

The natural environment would contribute least to future adaptability, due to further environmental deterioration and the lack of land planning and management. These processes would adversely affect performance of essential environmental functions that support human activity and life at the local level. As under baseline conditions, the lowest future resilience values (Table 6) would be in the natural environment, and future values would be even lower than those under baseline conditions. This environment would notably contribute to the increase in the future CVI value by 2015, which is probably due to the lack of local control over environmental quality and natural resources management.

As a general feature for the whole territory, future CVI levels would continue in a low rank category to 2015. It is worth noting that projected socio-economic and environmental scenarios were 'business as usual', as they included ongoing and planned local processes and measures, with some autonomous adaptation measures; this would explain the relatively high values of projected resilience and adaptability sub-indices. If these efforts were not to be assumed by local actors, the future positive contribution of the 3 environments to resilience and adaptability would be significantly lower, and, thus, the future CVI value would be higher. The future socio-economic and environmental scenario was only intended to indicate the direction of socio-economic and environmental trends if planned national and local policies and practices continue into the future within the same current policy framework.

An alternative and more optimistic future scenario would include and address sustainability concerns, including adaptation to climate change, to reduce climate vulnerability and the adverse impacts of climate change. The implementation of an adaptation strategy to climate change would add to the already ongoing local efforts to promote and implement autonomous sustainability. An adaptation strategy could be formulated based on the results of the comparative analysis of current and future climate vulnerability.

6. CONCLUSIONS

The proposed method makes integrated assessments of climate vulnerability feasible, since it incorporates and articulates natural and social dynamics of the selected system, which is characterized through its natural, socio-cultural and economic environments. A system of variables and indicators is defined to represent the specific dynamics of each of the 3 specified environments. In addition, the method enables the identification and further monitoring of the relevant factors that determine climate vulnerability, through the establishment of an interface between the second-order variables that characterize the selected system and those associated with the first-order explanatory variables of climate vulnerability: resilience and adaptability. The values of the indicator system should be modified, as part of an adaptation strategy, in order to increase climate resilience and adaptability and, thus, to reduce vulnerability to current and future climate-related impacts.

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