



# CUBA    METHODOLOGIES FOR DETERMINING DISASTER RISKS AT LOCAL LEVEL

PART 1

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Risk Assessment Group of the Environment Agency (AMA),  
under the Ministry of Science, Technology and Environment (CITMA)



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PART 1



Three-meter high waves breaking on the Malecon (seafont) in Havana.

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**Main terms**

# UNDP and disaster risk assessment in Cuba

Reducing natural disasters risks is a priority in Cuba. The Country Program agreed by the Cuban government and the United Nations Development Program includes in its objectives promoting sustainable economic development, fostering population dynamics, environmental protection, climate change adaptation, food and nutrition security, and the disaster risk management approach.

The Secretary General of the United Nations, Ban Ki-moon, has called for a radical shift in development practices, emphasizing on disaster prevention and investing in disaster risk reduction as an effective method for development protection.

Likewise, the Guidelines for Cuban Economic and Social Policy considered important to prioritize studies aimed at coping with climate change and the conservation of natural resources.

Supported by its legal framework, through the Civil Defense System, Cuba has developed instruments and tools to determine disaster risks, work on their prevention and provide an effective response to natural hazards. Directive No.1, updated and improved in 2010, directs the planning, organization and preparedness of the country for disaster situations; it establishes the risk management strategy and the mandatory nature of disaster reduction studies, as starting elements for the development of economic plans and investment projects in the territories.

With this material, the Environment Agency, particularly the Risk Assessment Group, offers us the great lesson of considering vulnerable factors in reducing disaster risk. As the reader will notice, this is the methodology for conducting studies on hazard, vulnerability and risk estimation, drawn up by a group of specialists from the Ministry of Science, Technology and Environment with the participation of several scientific institutions in the country, and with the input and advice of the Civil Defense National Staff. The authors reviewed an extensive bibliography, studied documents, systematized information and conceptualized this methodology that now arises useful and beneficial, especially for local actors and decision-makers linked to the work of disaster risk prevention.

This material presents the conceptual basic information for calculating hazard and vulnerability, and estimating risks in situations of floods from heavy rains, coastal floods from sea encroachment, strong winds and severe drought. Previous studies, historical records with mapping, signaled planimetric maps, geomorphological maps, satellite images, the use of geographic information systems, and numerical and mathematical modeling for forecasting were taken into consideration, among other expertise.

We commend this book that will serve as a tool to establish the methodological guidelines in conducting studies on disaster hazard, vulnerability and risks in Cuba. It is very appropriate at a time when the mandate is advancing with sound steps towards the search for preventive solutions to the current increase in climatological disasters and the needs of adapting to climate change impacts. We trust that the dissemination of this material will serve the regional community and all those who join in the effort to reduce risks and ensure the welfare of its population.

**Mrs. Barbara Pesce-Monteiro**  
UNDP RESIDENT REPRESENTATIVE, CUBA

# General introduction

Since 1959, Cuba started developing efforts aimed at eliminating the root causes that create disaster risks in society, by developing a revolutionary process with an eminently social character that has been directed to improving the quality of life and protection of Cuban, population through a more equitable distribution of resources, the exercise of the right to education, health care, culture, work, social security, technical scientific development and building scientific capacities, all of which has resulted in the improvement of living conditions and the eradication of extreme poverty.

At the beginning of the 1960s, a strategy was envisioned for disaster reduction and the creation of a civil defense system, in which the population, knowledge and proper coordination and cooperation among all its components have been and are its main strengths. This strategy has been in continuous development and improvement, considering the new demands, achievements and shortcomings of economic and social development, progress in the field and the commitments from international agreements for disaster reduction.

In recent years, the increasing frequency and impacts of disaster hazards are affecting disaster risk conditions and obstructing sustainable development. Among these hazards are those of natural origin, mainly hydrometeorological, and those arising as a consequence of climate change, both with devastating effects on society and the environment.

Throughout the process of refining the Cuban strategy for disaster reduction, the scope of actions to assess and reduce the risks to different hazards affecting the country has been deepening. The enactment in 2005 of Directive No.1 of the President of the National Defense Council has been essential to achieve that purpose. This directive has also been improving, so that its third edition was enacted in 2010 with a strengthened legal body.

The National Civil Defense System, in its actions, has been conceptualizing and defining that for disaster reduction it is required to:

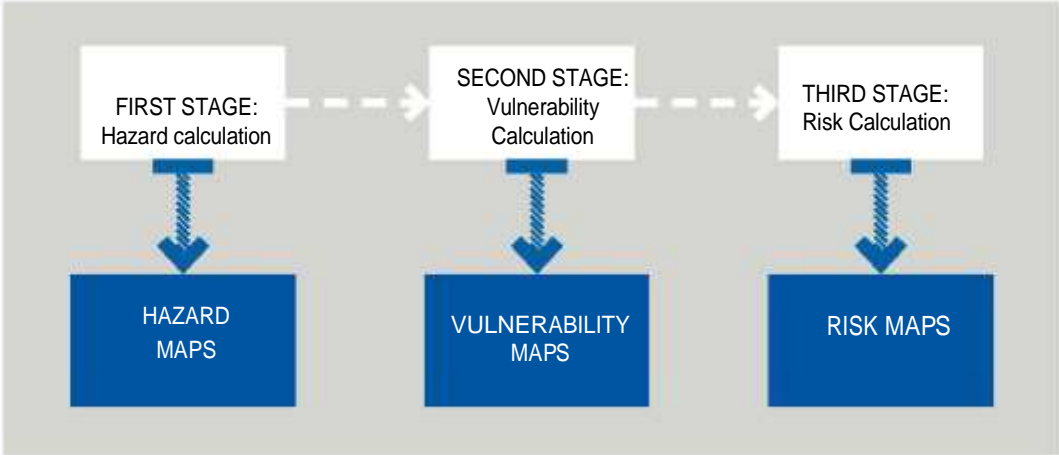
- Conduct a disaster risk reduction management, with an integrated approach encompassing economic management, social management, environmental management, and consistent with management for the sustainable development of Cuban society.
- Estimate risks, knowing the hazard and determining vulnerabilities as a key factor.
- Prioritize the stage of disaster prevention within the disaster reduction cycle.
- Evaluate the efficiency of risk management, considering first the degree of protection of the population and reducing economic losses and negative impacts on the functioning of society.
- Achieve in its action an integrated approach to disaster reduction and coping with climate change.



A tool that contributes to risk estimation and facilitates the identification of measures and decision-making for their reduction are the studies on disaster hazard, vulnerability and risks, which in Cuba are organized and coordinated by the Risk Assessment Group, under the Environment Agency of the Ministry of Science, Technology and Environment, with the participation of specialists and scientific institutions in the country, in cooperation with the Civil Defense National Staff.

These studies constitute a process of investigation, identification, characterization, quantitative and qualitative estimation of the hazard, vulnerability of exposed elements and risks. They are carried out at local level with a view to enabling risk management. Requirements have been established for this purpose, including: the existence of methodologies; use of Geographic Information Systems and other advanced technologies available; application of an ecosystem approach by multi- and transdisciplinary experts task forces. It is a premise that the results are expressed in maps and reports in a language accessible to all actors.

The sequence for conducting the studies is expressed in the following scheme:



This publication is a compendium of methodologies for studies on hazard, vulnerability and risk of floods from heavy rains, coastal floods from sea encroachment, strong winds, drought and landslides.

These methodologies result from the work of expert groups, composed of researchers, specialists and technicians from different institutions, and they have been applied and validated by local task forces. To all of them goes our appreciation for their qualification, professionalism and high sense of dedication.

A well-deserved acknowledgment is also conveyed to the Civil Defense National Staff, for their contribution, advice, technical support and participation in the development of methodologies.

**Juana Herminia Serrano Mendez, MSc.**  
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# 1. Methodology for conducting studies on disaster hazard, vulnerability and risks of floods from heavy rains

## INTRODUCTION

A flood is the occupation by water of areas that are usually free of it, either by overflowing rivers due to heavy rainfall or snowmelt, causing extensive damage to assets or living beings that could be exposed to them. Different climate factors and hydrometeorological events can cause flooding, but man's actions have increased vulnerability by building on flood plains and riverbeds, making indiscriminate dumping in those areas, filling natural drainage networks, developing constructions that become dams and hinder runoff, among others, which combined with the increase in intensity and frequency of hydrometeorological phenomena have caused floods to become one of the hazards causing greater damage to humanity worldwide.

Heavy rains combined with physical and geographical elements in the territory, such as soil permeability and its degradation, topography, vegetation, and land use in general can cause flooding by increasing surface runoff in the basin. These floods can be brought about by rains and river overflow. The denser the drainage network, the more catastrophic these events can be.

## GENERAL OBJECTIVE:

Establish the methodological guidelines for conducting studies on disaster hazard, vulnerability and risks of floods from heavy rains.

## SPECIFIC OBJECTIVES:

1. Establish the basic procedures for collecting and organizing information and developing research to ensure a homogeneous level of measurement and analysis in all territories.
2. Calculate the risk of floods from heavy rains for different return periods.
3. Perform mapping of flood hazard from heavy rains.
4. Identify all the exposed elements, calculate vulnerability and estimate risk according to the indicators defined in this methodology, using Geographic Information Systems.

## SCOPE:

Disaster hazard, vulnerability and risk studies on floods from heavy rains are based on the analysis and evaluation of hydrographic basins, and their results are expressed at provincial, municipal and People's Council levels. The working scale is 1:25 000 or higher.

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## 1.1 MATERIALS AND METHODS

The following materials are used in hazard, vulnerability and risk studies on floods from heavy rains:

- Previous studies on this subject in the study area
- Historical flood record with its mapping
- Surface drainage network including basin limits
- Digital elevation model (DEM)
- Map of soil grouping, including soil drainage properties
- Map of degradation processes affecting water accumulation and soil saturation
- Geomorphological map, identifying low-lying areas
- Engineering-geological map (if available; it is not essential)
- Planimetric maps of towns and villages exposed in flood hazard zone
- Map of vegetation cover
- Map of slopes
- Map of karst subtype
- Land use map
- Map of unconsolidated Quaternary deposits
- Multispectral satellite images for identification of wet soils and checking results
- Data and mapping of maximum rainfall in 24 hours, for different return periods
- Map of roads (major roads or railways) exposed in the flood hazard zone
- Map showing the limits of municipalities and People's Councils

The main methods to use are:

1. **Bibliographic or document analysis:** Consultation and analysis of specialized literature, ensuring knowledge of the history and current status of the subject and identifying useful information for the work to be developed. Information will be compiled on areas that have historically been flooded in the study area, with the cartographic delimitation of the historic flood limit.
2. **Desk work:** The collected cartographic, numeric and bibliographic information will be analyzed and discussed with the local task force and experts, the multi-disciplinary and multi-sectoral composition of this task force is essential in the scrutiny of the input information to be used in the analysis, as well as in its findings and recommendations. Hazard is calculated from the multi-criteria analysis. Vulnerability is calculated by matrices through programmed calculation sheets.
3. **Fieldwork:** Field confirmation or validation of the results must be performed.

### **Using Geographic Information Systems (GIS):**

GIS will be used as a necessary tool to present all available information in digital format, with a geospatial database assigned for each thematic layer, thus guaranteeing greater mapping accuracy when performing the analyses.

GIS will be applied in calculations using map algebra and not just for cartographic support, thus also serving as a management tool and for updating results.

Figure 1.1 shows an example of a combination of the main necessary maps to obtain the flood scenario, with arrows pointing at the origin of thematic maps.

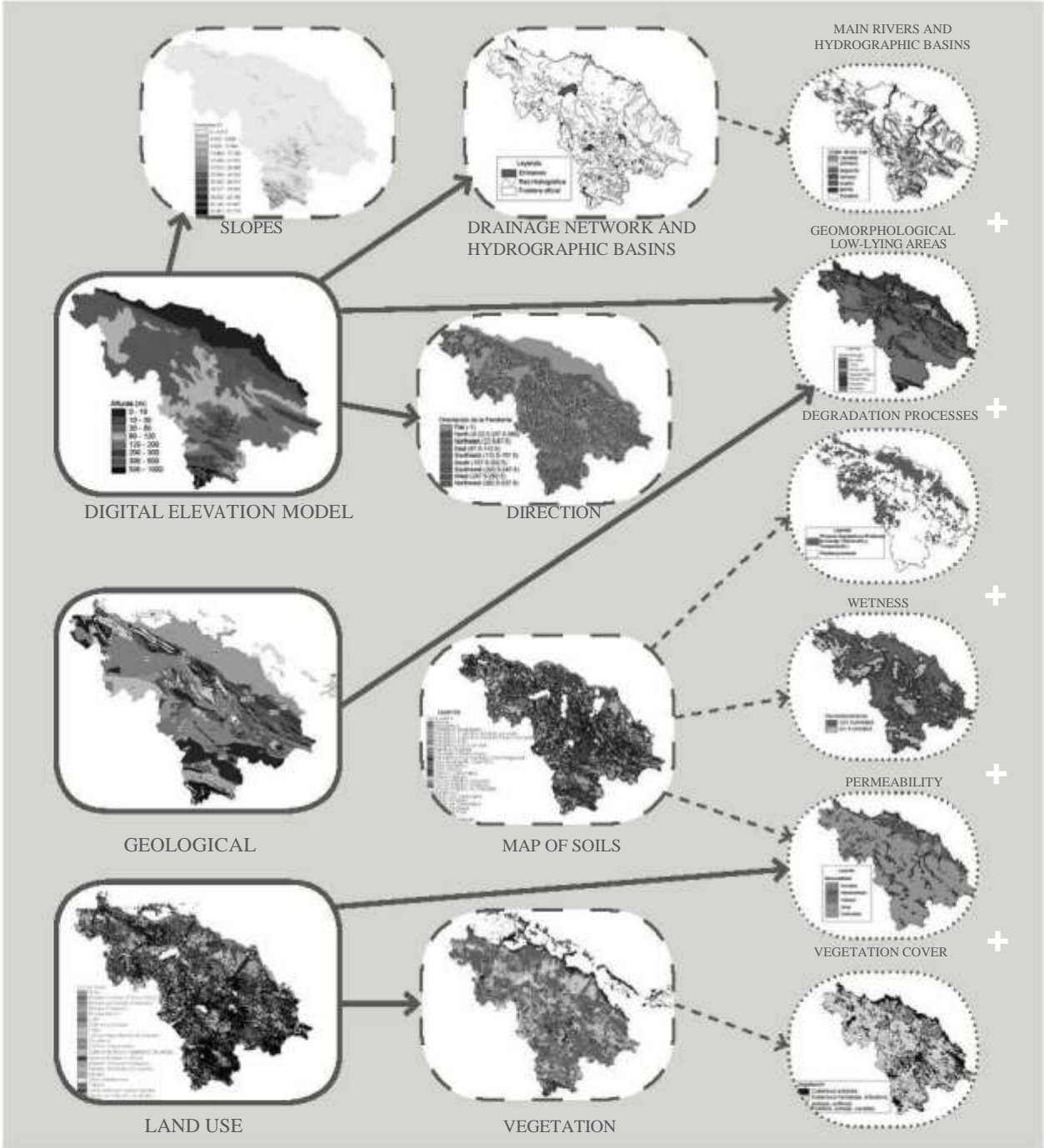


Figure 1.1: Combination of key maps necessary to obtain flood-prone zones, example from Villa Clara province.

## 1.2 HAZARD CALCULATION

When hazard calculation is done, it provides answers in probabilistic terms to the questions:

### ***Where, how and when will the event occur?***

To answer the question as to where the event will occur, it is necessary to characterize the site that is susceptible to flooding, that means to obtain the map of hazard scenario.

As regards when the event will take place, it is answered with the frequency of occurrence of the event or its return period. In this case, the frequency or return period of the triggering element can be used, which for flooding is rain.

And finally, the question on how the event will occur is responded with intensity values or the severity that could be expected should flooding occur, which are generated from combining the severity of susceptibility to hazard and rain intensity that can cause it.

### **1.2.1 DETERMINATION OF AREAS SUSCEPTIBLE TO FLOODING OR HAZARD SCENARIO**

Multicriteria modeling is applied to obtain the hazard scenario or areas susceptible to flooding. The recommended criteria are as follows:

#### ***– Topographic criteria***

As topographic criteria, for the delimitation of floodplain it will be used the hypsometric map generated from the digital elevation model, selecting thereof the height of maximum flood, defined from the river to the isoline that identifies the maximum flood value historically reported.

Besides, areas of topographic depressions where there are water flows with soft slopes are further considered.

#### ***– Criteria for considering soil permeability***

The layers corresponding to maps of soil grouping and soil degradation processes are considered relevant for the analysis. This includes the mapping of impermeable soils, in both non-developed and little developed areas.

#### ***– Geomorphological criteria***

By interpreting relief forms, the geomorphological map allows defining whether relief is karstified or not. This is an important criterion to consider, because floods have very different behaviors in each case.

Non-karstified reliefs are more prone to floodings, since they are composed of cracked rocks with low permeability. In karstified rocks that are highly permeable, flood duration is shorter because a rapid process of rainwater percolation into the aquifer occurs.



River relief forms are distinguished in the geomorphological map. In the case of riverbed, the permanent or low water channel, the apparent bed and flood plains or planes are recognized at the mouth of rivers, deltas, estuaries and marshes. Lowest relief areas are differentiated; in the karstified relief there are karst topography depressions, such as dolinas, poljes and uvalas; and in the non-karstified, the lowest areas in general, which by their morphology allow for water accumulation. Lacustrine forms are also recognized as highly susceptible to flooding, due to their characteristics of being low and impermeable relief forms.

**– Criteria for considering karst influence**

It will be evaluated according to the subtype of karst:

- Karst covered by swamps and marshes
- Karst covered by potential deposits when there are very deep soils (> 100 cm and sometimes over 10 meters deep) and usually with soils that have no direct genetic association with limestones
- Karst covered by a thin layer of soil
- Uncovered and half-uncovered karst

**– Criteria for considering the influence of vegetation**

When facing flood peaks, with the onset of heavy rains, infiltration and runoff may vary depending on the vegetation cover, mainly in hydro-regulatory belts that correspond to the first flooding plane. A forest cover will allow for a retardant hydroprotection action, even anti-erosion, when facing the heavy rain phenomenon.

The type of vegetation will be taken as a criterion of susceptibility to flood (tree, shrub or herbaceous), as reflected in **Table 1.1**, and in the case of forest, density and the main component species are taken into account.

TABLE 1.1: VEGETATION CRITERIA	
Types of vegetation cover	Susceptibility to flooding
Tree cover (forests)	reduced susceptibility
Herbaceous and shrub cover (scrub and secondary herbaceous communities), crops and orchards	increased susceptibility

Floods also respond to slope direction and inclination, that is, to the vegetation percent existing on the slope and its tilt in degrees, considering that the greater the vegetation presence, the lower the runoff. Therefore, the possibility of the occurrence of flooding in river flows also becomes less likely.

**– Criteria for engineering-geological consideration**

The engineering - geological map provides information on soil type, the relation to the type of underlying lithology and rock grain size and porosity conditions.

These combined factors characterize whether an area is more or less permeable or impermeable. To sum up, this characterizes the distribution and duration of flooding, the area it can occupy and how long it takes to drain by rivers or percolate into the aquifer.

**– Criterion of soil wetness index from the use of satellite images**

This index is an indirect indicator of the degree of soil permeability. Soils with high wetness index indicate areas with low permeability, and thus have lower infiltration. Soils with low wetness index have higher permeability values, and therefore equally high water infiltration into the aquifer. This index is interpreted through the capacities provided by the interpretation of multispectral satellite images, where certain bands do allow this recognition.

**– Documentary criteria**

Verification through field trips and historical documentary records that allow corroborating the data obtained from the desk work interpretation; in this case, surveys are conducted or the limits reached by flood waters are photographed. Following this criterion, verification mainly includes the height reached by flood waters, their spatial distribution and behavior on the affected surface basin, defining flood directions and areas of origin.

**Table 1.2** shows the evaluation of different thematic layers used, with a maximum value of 10 points in total. Considering the criteria for selecting the maximum flood limit, each layer should be subdivided, giving each subdivision a progressive score, depending on its influence on susceptibility to reach the corresponding maximum score.

Thematic layers	Maximum Value
Rivers of orders 3, 4, 5 and 6	2.0
Geomorphology	1.7
Slope inclination	1.2
Soil permeability	1.7
Soil degradation processes	1.2
Map of vegetation cover	0.6
Soil wetness	0.6
Unconsolidated Quaternary deposits	1.0

River order	Classification	Assigned value (Score)
Of 6° order	Collection	2.0
Of 5° order	Collection	1.9
Of 4° order	Collection	1.5
Of 3° order	Collection	1.0
Of 1° to 2°	Runoff	0.1



Relief forms	Assigned value (Score)
First flood plane	1.7
Low areas of non-karstified relief	1.5
Second flood plane	1.2
Third flood plane	0.5
Karstified relief	0.1

Relief forms	Assigned value (Score)
From 0 to 5	1.2
From 5 to 10	0.9
Greater than 10	0.5

Soil type	Assigned value (Score)
Vertisol	1.7
Hydromorphic	1.5
Fluvisol	1.0
Histosol	0.8
Other types with gleization	0.5
Other soils	0.2

Degradation Processes	Assigned value (Score)
Drainage problems	1.2
Hydromorphy	1.2
Compaction	0.5

Type of vegetation cover	Assigned value (Score)
Herbaceous and shrub cover (scrub and secondary herbaceous communities), crops and orchards	0.6
Tree cover (forests)	0.0

Wetness index	Assigned value (Score)
With wetness	0.6
Without wetness	0.1

Types of deposits	Assigned value (Score)
Alluvial	1.0
Marshy and lacustrine	0.8

Polygons resulting from the combination and calculation with the layers will be classified according to the following flood susceptibility ranges:

- (0.1 – 3.3) Low**
- (3.4 – 6.6) Medium**
- (6.7 – 10) High**

Risk scenarios are confirmed through field trips and historical documentary records, which allow corroboration of the data obtained from desk interpretation. In this case, surveys are conducted or the limits reached by flood waters are photographed. Following this criterion, verification mainly includes the height reached by flood waters, their spatial distribution and behavior on the affected surface basin, defining flood directions and areas of origin.

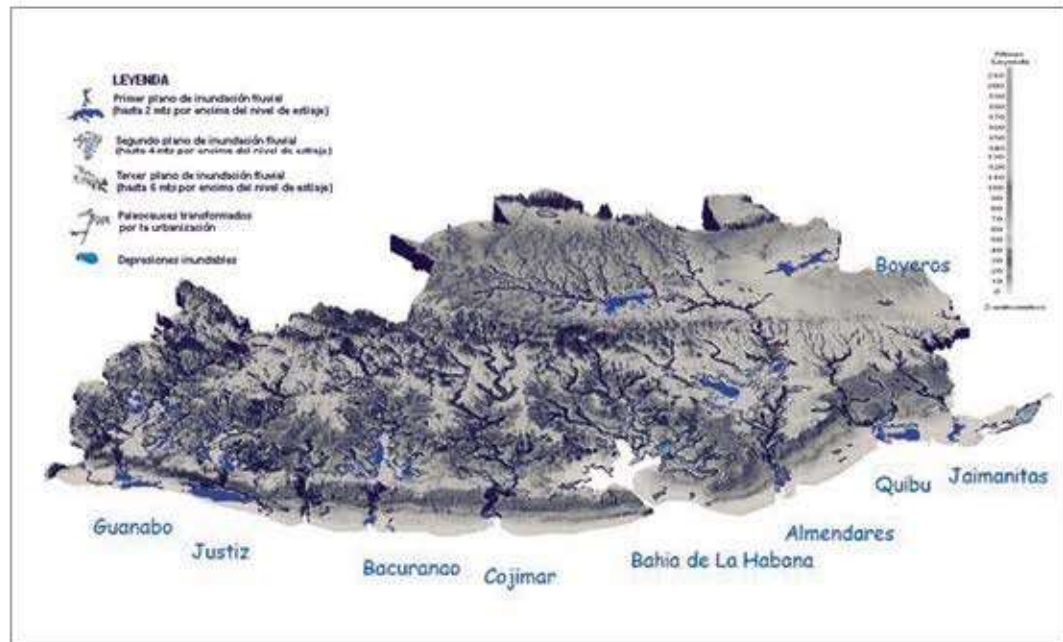


Figure 1.2: 3D Graphic output of the digital elevation model and flood-prone areas in Havana.

### 1.2.2 CALCULATION OF HAZARD INTENSITY AND RETURN PERIOD

For floods to occur, besides area susceptibility explained in the previous section, the rainfall external factor should be present.

Given these conditions, it can be formulated that the assessment of flood hazard intensity (*PI*) combines susceptibility factors from the hazard scenario (*FS*) and the triggering factor (*FII*), which are heavy rains and it is expressed as follows:

$$PI = f(FS, FII)$$

Where

**PI** — intensity of the hazard of flood from heavy rains

**FS** — susceptibility factor (susceptible areas) according to the abovementioned ranges

**FII** — triggering factor, given the level of daily maximum rainfall in 24 hours

### **FII RAINFALL TRIGGERING POTENTIAL**

To determine the triggering factor (**FII**), the maximum rainfall isohyet maps are calculated in 24 hours for different return periods **T**.

This factor is determined from the statistical treatment of data recorded by rainfall stations located in the study region and its surroundings, taking the values of daily maximum rainfall in 24 hours.

The following formula is used to calculate different returns periods, according to the model of the World Meteorological Organization.

$$X_t = X_{media} + DS * K$$

Where

**X<sub>t</sub>** — Maximum rainfall in 24 hours with a return period **t** at the rainfall station in question

**X<sub>media</sub>** — maximum rainfall average in 24 hours in the rain gauge in question

**DS** — standard deviation of that average

**K** — coefficient tabulated in the Manual of Applied Climatology, Page 130, by Felipe Fernandez Garcia.

T years	K
5	0.89
10	1.58
15	1.96
20	2.30
50	3.09
100	3.73

That is, for a rainfall station with rainfall records of **T years**, it is necessary to look for the maximum rainfall in 24 hours in all those years, calculate the average and standard deviation of those values, add the **X<sub>media</sub>** with the result from multiplying the standard deviation by the coefficient **K** tabulated above, and that allows estimating the maximum rainfall in 24 hours at the station in question with a return period of **T years**.

With these results, a division into three rainfall intervals is performed for each province, taking a rainfall minimum and maximum cumulative value for the territory, to generate the following table:

TABLE 1.11: CLASSIFICATION OF THE RAINFALL FACTOR	
Rainfall intervals in 24 hours (mm)	Assigned value
Set the interval with the maximum rainfall value for the territory as higher limit	4
Define an intermediate interval	3
Set the minimum interval from 100 mm	2

*Note: The first column of the table is completed depending on the rainfall intervals registered in the different territories.*

For hazard mapping, layers of susceptibility factors or hazard occurrence scenario and the triggering factor layer, which in this case corresponds to the isohyet maps, are combined using GIS. The maximum daily rainfall occurred in 24 hours is considered. That is, for each return period a rainfall map is obtained that will relate to the hazard occurrence scenario. The multiplication of layers is carried out considering the ranges and weights set for the hazard scenario layer above and **Table 1.11** on the classification of the Rainfall Factor. Resulting from such combination, the following ranges are defined for classifying hazard intensity for the corresponding to rainfall return periods.

- (0.2 – 13.3) Low Hazard**
- (13.3 – 26.6) Medio Hazard**
- (26.6 – 40.0) High Hazard**



Figure 1.3: Zaza River flood at the height of Zaza del Medio settlement due to the heavy rains in 2002, Sancti Spiritus.

To test the results, alternatively, some empirical working methods can be used at basin closing points; their main advantage is that they require little data and calculations are easy. The data used for their application come from cross-sections documented on the field and characterizing the morphology of riverbeds. For that purpose, the flood return periods or likelihood of occurrence are estimated, starting from the hypothesis that the knowledge of flows that occur in the area due to rainfall and the maximum flow that can run through the riverbed, given its characteristics, allow calculating in which sections floods will occur and with what likelihood of occurrence.

This method establishes the use of the rational formula for calculating the maximum flow running through a riverbed (Gonzalez, 1996):

$$Q = \frac{C * I_p * A}{3.6} * K$$

Where

$Q$  — peak flow in  $\text{m}^3/\text{s}$

$C$  — dimensionless maximum runoff coefficient

$I_p$  — mean maximum intensity (mm/h) for a duration equal to the basin concentration time  $t$  (min)

$A$  — basin area in  $\text{km}^2$

$K$  — uniformity coefficient (Témez, 1991)

The basin concentration time is calculated, which means the time it takes for rainfall water to run through the riverbed. This parameter is obtained to define the uniformity coefficient  $K$  required for the application of the maximum flow equation, according to California.

$$t_c = 58 \left[ \frac{(L_r)^3}{\Delta H} \right]^{0.385}$$

Where

$t_c$  — basin concentration time (min)

$L_r$  — length of the main river (km)

$\Delta H$  — slope of the river from its source (m)

The uniformity coefficient ( $K$ ) is then calculated

$$K = 1 + \frac{t_c^{1.25}}{t_c^{1.25} + 14}$$

Where

$t_c$  — basin concentration time

Once these parameters are calculated, rainfall intensities for different return periods or likelihood are determined, using the parameters of the curves described by the rain gauges neighboring the area. The mathematical expression to calculate  $I_p$  is as follows:

$$I_p = \frac{A}{(t_c + B)^n}$$

Where  $A$ ,  $B$ ,  $n$  are coefficients

$t_c$  — basin concentration time (min)

$I_p$  — mean maximum intensity (mm/h) for a duration equal to  $t_c$  (min)

TABLE 1.12: EXAMPLE OF RETURN PERIODS AND VALUE OF COEFFICIENTS FOR DIFFERENT LIKELIHOOD LEVELS

Likelihood (%)	Return periods (years)	A	B	n
50	2	5682.1	48.5	0.99
20	5	6813.63	45.0	0.99
10	10	7486.78	43.0	1.00
4	25	8873.41	43.0	1.01
2	50	9455.71	41.5	1.01
1	100	10118.95	40.5	1.01
0.1	1000	13135.37	40.0	1.02

The values of the coefficients  $A$ ,  $B$  and  $n$  for different likelihood levels should be taken from the curves of intensity and duration frequency of rain gauges located in the territory under study.

To calculate  $Q_p$  of 1%, the runoff coefficient ( $C$ ) is selected from the table of Basso (Gonzalez, 1996) considering how this coefficient varies depending on terrain slope, soil and vegetation. With this selected coefficient and with  $K$ ,  $A$ ,  $I_p$  substituted in the rational formula,  $Q_{1\%}$  is calculated. Then, from this  $Q_{1\%}$  the remaining  $Q_p$  are calculated using the following relationships.

$$\begin{aligned}
 Q_{0,1\%} &= 2,09 * Q_{1\%} \\
 Q_{3\%} &= 0,8 * Q_{1\%} \\
 Q_{4\%} &= 0,61 * Q_{1\%} \\
 Q_{10\%} &= 0,43 * Q_{1\%} \\
 Q_{20\%} &= 0,29 * Q_{1\%} \\
 Q_{50\%} &= 0,19 * Q_{1\%}
 \end{aligned}$$

According to recommendations by Aleksee (1962) for Cuba, the calculation of all likely maximum flows is performed for each likelihood level, varying the  $I_p$  and  $C$  for each calculation likelihood according to the methodology by Francis (1996).

To know the volume of water flowing through riverbeds and compare it with estimated flows, according to rainfall that occurred in this area, the areas of river cross-sections is calculated according to field documents; and then they are multiplied by river flow speed. This is expressed as follows (Cooke *et al*, 1990; Derruau 1978):

$$Q = V * A = V * W * H$$

Where

$V$  — flow velocity (m/s)

$Q$  — flow (m<sup>3</sup>/s)

$A$  — riverbed area ( $m^2$ )

$W$  — riverbed width

$H$  — depth (m)

$$V = H^{0.167} * (H * Y)^{\frac{1}{2}} * \frac{1}{N}$$

Where

$H$  — depth (m)

$Y$  — slope of the river stretch (m/m)

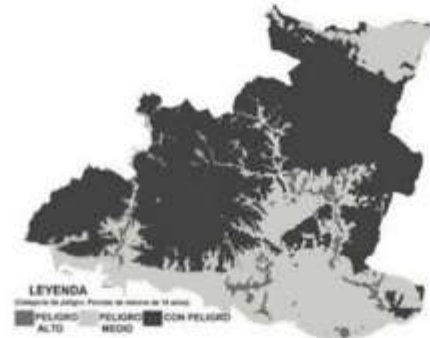
$N$  — coefficient characterizing the roughness of the stretch

After obtaining the flows generated by rainfall and those that can run through the valley of river overflow, they are compared to conclude whether or not flooding will occur. Another element used is to compare the hydrological area and the geometric area:

- If  $A_g > A_h$ , the stretch shows no overflow problems.
- If  $A_g < A_h$ , the stretch shows overflow problems.

For calculating the geometric area, the water depths  $h_1$  and  $h_2$  are determined for the flood area, to know the flood height.

**Figures 1.4** and **1.5**, on the right, show examples of hazard maps for floods from heavy rains in a province and a municipality.



**Figure 1.4:** Hazard of floods from heavy rains in a province. Return period 10 years (150- 600 mm of rain in 24 hours)



**Figure 1.5:** Hazard of floods from heavy rains in a municipality.

### 1.3 VULNERABILITY CALCULATION

For vulnerability calculation, it is required to compile information on assets, population, animals, crops, protected areas and fragile ecosystems exposed to the flood hazard. It is necessary to use socio-economic, agricultural and ecological information, as well as information on housing, critical facilities and lifelines exposed in flood hazard areas. All information must be georeferenced for its cartographic expression.

Vulnerability ( $V$ ) is expressed, from the mathematical point of view, as a limited number between zero (0) and one (1). This implies that for an event of a given intensity,  $V$  takes the value 0 when the damage is null and 1 if the damage is total.

Value judgments for determining vulnerability must be made in workshops by criteria of experts and specialists from the task forces and territories, in a multi-disciplinary and multisectorial manner.

In this study, vulnerability types taken into account are: structural, non-structural, functional, social, ecological and economic.

The calculation is based on the use of matrices, with the help of spreadsheets.

### 1.3.1 STRUCTURAL VULNERABILITY

The resistive capacity of housing buildings to the destructive forces of floods will be analyzed.

For the calculation, the factor damage to the building (*Dc*) is considered, indicating the quality of housing depending on hazard intensity and location factors.

*Dc* damage factor can be evaluated with different gradations as without damage, with substantial or severe damage, giving it different weights in the overall equation. This damage factor, whether increased or not by location elements, will also have a weight. It will add a weight value to the total for structural vulnerability.

Structural vulnerability is calculated according to the following formula:

$$Ves = Dc + Location\ factors$$

Where

*Dc* — factor of damage to buildings

*Location factors* — value expressing the influence of soil impermeability or not due to urbanization, the influence of slope and height of the site where the building is located. This indicator can add a maximum weight of 3.

Soil permeability is assigned the following weights:

Soil permeability	Weights
Uncovered zones of permeable lithology	0.0
Partially covered zones of permeable lithology	0.5
Impermeable zones	1.0

Slope refers to the inclination surrounding the housing. It may take as a reference the slopes of the People's Council. If the housing is surrounded by steep slopes, or if there are settlements on the lower slope of a mountain, they will be affected when rapid runoffs occur.

The influence of slope is assigned the following weights:

Slope	Weights
Low (<10 degrees)	0.0
Medium (10 – 15 degrees)	0.5
High (>15 degrees)	1.0



Height is analyzed as the coefficient given by the percentage of the exposed area with elevation below the average height of the People's Council. The influence of terrain height, referring to the site where the building is located, is assigned the following weights:

Terrain height	Weights
Above mean height of the People's Council	0.0
Half the height of the flood area is below the mean height of the People's Council	0.5
All the height of the flood area is below the mean height of the People's Council	1.0

$Dc_n$  is expressed by the equation:

$$Dc_n = \sum (f_i * p_{ji}) + AET$$

Where

$Dc_n$  — potential damage that may suffer the buildings of a particular type, when facing an event of a given intensity in a People's Council  $n$

$f_i$  — fraction of housings or facilities of  $i$ -th type within a People's council

$p_{ji}$  — value expressing a weight of potential damage that may suffer the facility of  $i$ -th type due to the impact of an event of  $j$ -th intensity

$AET$  — damage due to the technical condition of the building, considering the predominant technical status in the People's Council

To assess the damages to which buildings are exposed, an  $f$  factor should be distinguished, which expresses the fraction or percent of buildings belonging to a given type, the total of facilities in the People's Council, for example, if there is a total of 1200 buildings in the Council and 700 of them are type I, then  $fI$  equals 700 divided by 1200,  $fI = 0,58$ , that is 58% of houses in the People's Council are type I.

When evaluating  $p_{ji}$ , three intervals of rainfall intensity are considered and weights to assign are indicated, depending on the type of building and rainfall.

Rainfall Range (mm/24h)	BUILDING TYPE				
	I	II	III	IV	V
100 – 200	0	0	2	6	8
200-300	0	2	6	8	10
Over 300	2	6	8	10	12

To evaluate  $AET$ :

$AET=0$  if the predominant status in the People's Council is good

$AET=2$  if the predominant status in the People's Council is regular

$AET=5$  if the predominant status in the People's Council is bad.

This way, structural vulnerability  $V_{es}$  has a weight of 20.

### 1.3.2 NONSTRUCTURAL VULNERABILITY



Figure 1.6: Flooding caused by Hurricane Ike in 2008, central region of Cuba.

Damages that may suffer the lifelines in the territory, such as roads, gas supply, communications, power grid, pylons and underground electrical networks should be assessed for flood hazard, as well as the status of the drainage system and sewerage networks.

The structural and nonstructural vulnerabilities express the exposure factors, i.e., they will allow assessing the degree of exposure of the studied territory to the influence of hazards.

To assess nonstructural vulnerability  $V_{nes}$ , which may reach a maximum of 10 points, the following exposure indicators will be considered:

TABLE 1.13: CLASSIFICATION OF SCORES ACCORDING TO EXPOSURE INDICATOS	
Indicator	Assigned value (Score)
State of drainage and sewerage networks	5
Damaged or obstructed roads	3
Other damaged lifelines (power, gas and communications networks)	2
<b>Total</b>	<b>10</b>

- State of drainage and sewerage networks: evaluate the percent of the drainage and sewerage networks in the affected area that are blocked, damaged or missing.

State of drainage and sewerage networks (%)	Weights
100% affected	5
50% affected	2.5
0% affected	0

- Damaged or obstructed roads: assess the percent of roads in the affected area that were damaged or obstructed.

Damaged or obstructed roads(%)	Weights
100% affected	3
50% affected	1.5
0% affected	0

- Other damaged lifelines: underground electricity grids, gas and communications are evaluated.

Other damaged lifelines (%)	Weights
100% affected	2
50% affected	1
0% affected	0

### 1.3.3 FUNCTIONAL VULNERABILITY

In this analysis, the influence of structural and nonstructural vulnerability will be discussed as related to the stability or stoppage of production and services, for each type of event of a given category. Vulnerability analysis allows realizing the status of **response preparedness factors**.

To assess the functional vulnerability  $V_f$  that in the worst case scenario adds 20 points, the following response preparedness elements are added:

Indicator	Assigned value (Score)
Availability of power generator sets	4
Preparedness of the health-care system for disaster events	4
Shelter capacity for evacuees	4
Access to remote areas	4
Reserve of basic supplies (water, food, fuel)	4
<b>Total</b>	<b>20</b>

- Availability of power generator sets

Availability of power generator sets (%)	Weights
0% availability	4
50% availability	2
100% availability	0

- Preparedness of the health-care system for disaster events

Preparedness of the health-care system for disaster events (%)	Weights
0% prepared	4
50% prepared	2
100% prepared	0

- Shelter capacity for evacuees.

Shelter capacity for evacuees (%)	Weights
0% sheltered	4
50% sheltered	2
100% sheltered	0

- Access to remote areas.

Access to remote areas (%)	Weights
0% access	4
50% access	2
100% access	0

- Reserve of basic supplies (water, food, fuel).

Reserve of basic supplies (water, food, fuel) (%)	Weights
0% reserve	4
50% reserve	2
100% reserve	0

### 1.3.4 SOCIAL VULNERABILITY

To assess the social vulnerability  $V_s$  the following **social factors** are considered, adding up a total of 20 points:

Indicator	Assigned value (Score)
Affected population (population density)	10
Hazard perception by the population and decision-makers	2
Existence of unhealthy neighborhoods or slums	2
Preparedness of the population and decision-makers	3
Presence of solid wastes on the streets	3
<b>Total</b>	<b>20</b>

- Affected population (*AP*)

$$AP = \text{Affected population} / \text{total population of CP}$$

Affected population	Weights
< 0.25	0
0.26 – 0.50	2
0.51 – 0.75	5
0.75 – 0.90	7
1.0	10

- Hazard perception by the population and decision-makers

Hazard perception by the population and decision-makers	Weights
Low	3
Medium	1.5
High	0.0

- Existence of unhealthy neighborhoods or slums

Existence of unhealthy neighborhoods or slums (%)	Weights
0%	0
50%	1
100%	2

- Preparedness of the population and decision-makers

Preparedness of the population and decision-makers (%)	Weights
0% prepared	3
50% prepared	1.5
100% prepared	0

- Presence of solid wastes on the streets

Presence of solid wastes on the streets (%)	Weights
0% presence of wastes	0
50% presence of wastes	1
100% presence of wastes	2

### 1.3.5 ECOLOGICAL VULNERABILITY

The indicators to assess are the following, and they make a total of 10 points:

- Fragile ecosystems or ecologically sensitive areas that may be affected.

Indicator	Weights
0% damaged	0
50% damaged	2.5
100% damaged	5

- Protected areas (PAs) that may suffer impacts.

Indicator	Weights
0% damaged	0
50% damaged	2.5
100% damaged	5

### 1.3.6 ECONOMIC VULNERABILITY

Economic factors are evaluated, taking into account industrial zones, crop areas and animals in flood areas, the implementation level of vulnerability reduction budget and what it accounts for in response costs. In this case the maximum total value is 20 points.

Indicator	Weights
Implementation level of vulnerability reduction budget	4
Industrial zones in risk areas	4
Response costs accounted for	4
Extent of crop lands in risk areas	4
Number of animals in risk areas	4

Finally, the total vulnerability to a particular hazard for the People's Council is the sum of all its vulnerabilities, calculated independently, i.e.:

$$Vt = V_e + V_{ne} + V_F + V_s + V_{ec} + V_{ecn}$$



Figure 1.7: Floods triggered by tropical storm Noel in 2007, Cauto River Basin, in eastern Cuba.

Where

$V_e$  — structural vulnerability

$V_{ne}$  — nonstructural vulnerability

$V_F$  — functional vulnerability

$V_s$  — social vulnerability

$V_{ec}$  — ecological vulnerability

$V_{ecn}$  — economic vulnerability

The cartographic output will result from a GIS project, including classification attributes, total number of exposed people, total number of exposed housings, building types, housing conditions and all information related to each element in the different vulnerabilities.

#### **Vulnerability ranges**

**(0 – 33) Low Vulnerability**

**(34 – 66) Medium Vulnerability**

**(67 – 100) High Vulnerability**

This value is divided by 100 to narrow the value between 0 and 1, and is reported in decimals.

### **1.4 RISK ESTIMATION**

Risk is evaluated from the equation:

$$R = \sum_{i=1}^n V_i * P_i$$

Where

$R$  — risk of occurrence for flooding

$V_i$  — total vulnerability to a hazard intensity  $i$

$P_i$  — Likelihood of occurrence of a hazard intensity  $i$

Resulting risk classification according to the following intervals:

**(0 – 0.33) Low Risk**  
**(0.34 – 0.66) Medium Risk**  
**(0.67 – 1.0) High Risk**

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Penetración del mar en el Malecón de La Habana, consecuencia del paso de un frente frío en 2010

Sea encroachment in Havana's Malecon (seafont) caused by a cold front in 2010

## 2. Methodology for conducting studies on disaster hazard, vulnerability and risks of coastal floods from sea encroachment

### INTRODUCTION

The main coastal problems in Cuba, according to Alcolado (2003), are related to impacts on biodiversity, coastal erosion, loss of beach quality, pollution, depletion of fishery resources, inadequate land use, rising sea level and coastal floods from sea encroachment due to extreme hydrometeorological events.

The current increase in frequency and destructive force of extreme hydrometeorological events, and their main destructive elements that are sea encroachment, heavy rains, strong winds and the potential for technological and health-related disasters, including real threats of a biological attack determine the need for improving the political, social, economic and environmental approach to risk management and the need for risk assessment in the country.

### GENERAL OBJECTIVE:

Establish the methodological guidelines for conducting studies on disaster hazard, vulnerability and risks of coastal floods from sea encroachment across the country.

### SPECIFIC OBJECTIVES:

- Establish the main procedures to organize information and research, and ensure a homogeneous level of measurement and analysis in all territories, from national to local levels.
- Calculate coastal flood risk for different return periods.
- Conduct hazard mapping of coastal floods in GIS
- Identify all exposed elements and determine vulnerabilities according to the indicators defined in this guideline, using GIS and field data.
- Obtain the risks for municipalities and People's Councils for analysis and comparison with others within the country, and their GIS mapping
- Prepare a technical report including the results and cartographic output for each unit of analysis.

### SCOPE:

Studies of disaster hazard, vulnerability and risks of coastal floods from sea encroachment are performed to determine the vulnerabilities and risks of the elements exposed to the impact of various hazard scenarios. Results will be provided at provincial level with outputs at municipal and People's Council levels. In the case of coastal floods, the study will be conducted by municipalities. Working scale is 1:25 000 or higher for detailed case studies.

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## 2.1 MATERIALS AND METHODS

For hazard studies on coastal floods, it is taken into account:

1. Analysis of the maps needed for the study.
2. Calculation of return periods for the occurrence of these events from historical data on wind, extreme wave and extreme weather conditions that generated them.
3. Numerical modeling of surge and wave and inland cartography.
4. Mapping the maximum limit of coastal floods from sea encroachment using Geographic Information Systems.
5. Analysis of the results of vulnerabilities identified from the analyzed indicators.
6. Analysis of existing baseline studies on topics related to hazard, vulnerability and risk studies under Directive No. 1.

Essential maps for the study:

- Digital Elevation Model at scale 1:25 000 or higher in digital format (GRID), in GIS, which are used for mapping inland flooding caused by different hydrometeorological events.
- Bathymetry map or data on the study area in GIS, used for generating the calculation grid in the wave model.
- Map of contour lines and heights, used to make corrections to DEM; if necessary, they can be developed by the group of experts.
- Geomorphological map.
- Map with the coastline, used to determine the boundary of emerged land.
- Map of mangrove forests, used to identify those places having a protective barrier against waves.
- Map of Soil Grouping and degradation processes used to determine the infiltration capacity of potentially flooded areas.
- Maps of towns and villages, to determine the affected settlements.
- Road map to identify blocked access roads for evacuation plans.
- Map of the limits of People's Councils or municipalities under study.
- Satellite imagery as support and for verification of results.
- Previous studies on this subject.
- Multispectral satellite imagery. (Landsat TM 30 meters per pixel resolution), Quick-bird, Aster, Spot, GeoEye1, etc.
- Google Earth images as support in case of not having the above.

## 2.2 CALCULATION OF COASTAL FLOOD HAZARD

Coastal floods occur as a result of waves generated by meteorological conditions (cold fronts, southern winds and tropical cyclones). They take place because of the combination of sea level rise by wave and surge.

Coastal floods will be affected to a greater or lesser extent by these effects, depending on the submarine slope (whether it is sharp or soft) and the configuration of the coast (beach, cliff or rocky).

The calculation is performed separately, as shown in the following diagram:



The analysis can be done for all intensities of tropical cyclones, from category 1 to category 5 (as established by the Saffir-Simpson scale), as well as for wave generated by other events from their real-time simulation. It can also be performed for past events and based on return periods, considering various impact directions.

Sometimes it is challenging to obtain the necessary information, due to lack of qualified technical staff to undertake research and difficult access to information sources. In such cases, known extreme events can be selected to evaluate all vulnerabilities and risk.

### ***Numerical surge modeling***

Surge is constituted by a long gravitational wave, with scale length similar to the size of those generated by tropical cyclones, with a few hours duration and affecting 200 km coasts on average.

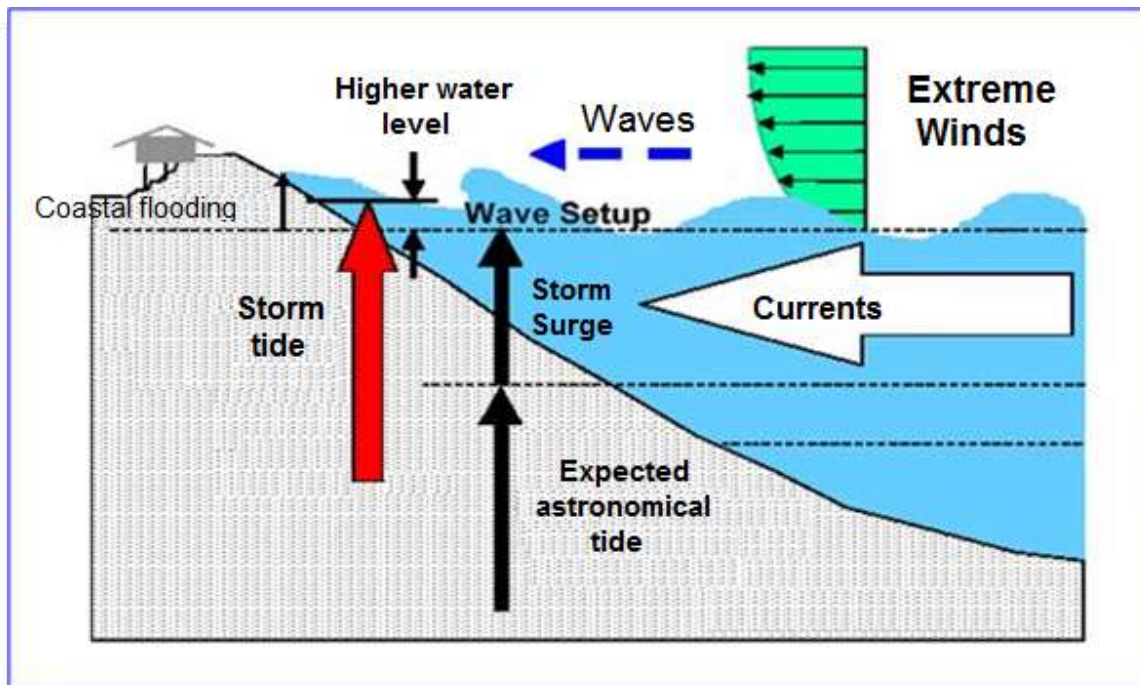


Figure 2.1: Components of Storm Tide. Source: WMO (2006) Observations and forecasts of storm tides. Works- hop Topic Reports. Sixth WMO International Workshop on Tropical Cyclone (IWTC-VI). Report Series TMRP No. 72. San José, Costa Rica, 21-30 November 2006.

In turn, there is another term associated with surge that is called storm tide. This is the combined effect of surge, astronomical tide, and in recent years it has been agreed to include in it the effects of mean sea level rise by wave setup breaking on the coastline (Wagenseil, 2000 and WMO, 2006) (**Figure 2.1**).

Given the height reached by the surge and the extent of flooding inland, they play a key role: the size, travel speed, return periods for each point, time on the island or continental shelf, angle of incidence between the path of the cyclone and the coast, maximum wind speed, radius of maximum winds and central pressure. Bathymetry, topography and coast configuration, buildings and facilities on the coast and vegetation also have an influence on this process.

The spatial characteristic of the ocean bottom is the most important factor in surge wave amplification. The largest of such waves originate in regions with extensive, shallow shelves, thereby contributing to coastal morphology. The type of coastline and inland slope play a significant role in this aspect. Tropical cyclone databases belonging to INSMET were used, as well as those from the Tropical Forecasting Center of the National Hurricane Center in the United States (1851 to 2005) (Landsea *et al.*, 2005.), which are online at the website <http://www.nhc.noaa.gov/pastall.shtml>. These were processed with the softwares "Eye of the Storm" and "HURREVAC".

Numerical surge modeling is done using the MONSAC 3.1 High Resolution Numerical Model (Perez Parrado *et al.*, 2005) and its corresponding bathymetric database. The calculation of Extreme Regimes is performed by the Method of Peak Frequencies (Martín *et al.*, 1990; Martín and Martínez, 1996), sorting the data in descending order, according to Saffir-Simpson Scale that establishes the intensity of Tropical Cyclones according to wind intensity. Surge hazard assessment was conducted using the methodology proposed by Salas *et al.*, 1999 and 2006.

To select the best families of curves, it was used the Curve-Expert Computer System (Version 1.3). Best curve fits were obtained through the Weibull model.

### ***Numerical wave modeling***

For wave modeling, it was used the third generation wave model SWAN Cycle 3 Version 40.85 (Simulating Waves Nearshore), Booij *et al.* (2010). The model includes the processes of energy generation and dissipation, wind generation, nonlinear interactions, diffraction, dissipation by white capping and by wave breaking due bottom influence. Propagation processes include refraction due to the spatial variation with the bottom and currents, shoaling because of the variation with the bottom and currents, blocking and opposition by opposing currents and reflection against obstacles in grid points, and propagation through the geometric space.

In SWAN, waves are described with the two-dimensional density action spectrum:

$$N(\sigma, \theta) = \frac{E(\sigma, \theta)}{\sigma}$$

Where

$\sigma$  — is the relative frequency

$\theta$  — is the wave direction

In this case, the spectrum is better represented depending on action density than on the spectral energy density  $E(\sigma, \theta)$  as in the presence of currents, action density is conserved and energy is not. The independent variables are relative frequency and wave direction.

Wave spectrum evolution is described by the action density balance equation that is written in Cartesian coordinates as follows:

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x} C_x N + \frac{\partial}{\partial y} C_y N + \frac{\partial}{\partial \sigma} C_\sigma + \frac{\partial}{\partial \theta} C_\theta N = \frac{S}{\sigma}$$

Where

$-\frac{\partial}{\partial t} N$  — is the reason for local change in action density in time

$-\frac{\partial}{\partial x} C_x N$   $\wedge$   $\frac{\partial}{\partial y} C_y N$  — represent action propagation in geographic space with propagation speed  $C_x$  and  $C_y$  in the space  $X$  and  $Y$  respectively

$-\frac{\partial}{\partial \sigma} C_\sigma N$  — is the relative frequency shift due to variation in depth and current, with propagation speed  $C_\sigma$  in the space  $\sigma$

$-\frac{\partial}{\partial \theta} C_\theta N$  — is the refraction by depth and current with propagation speed  $C_\theta$  in the space  $\theta$

$S = S(\sigma, \theta)$  — are the source terms including generation, dissipation and nonlinear interactions.

The geographic space is discretized with a rectangular grid, with constant resolutions  $\Delta X$  and  $\Delta Y$  in the directions  $X$  and  $Y$ , respectively. Resolutions vary depending on the work area. In the model, the spectrum is discretized with a constant resolution in the directions and a constant resolution of relative frequency  $\Delta\sigma/\sigma$ . For reasons of time, we considered the option of doing the calculation only in those wave components traveling in a predefined direction  $\theta_{min} < \theta < \theta_{max}$ . Discrete frequencies are defined between a fixed cut of low frequencies and another of high frequencies; below the limit of lower frequencies, spectral density is considered 0. In the limit of high frequencies, an  $f^{-m}$  diagnose for spectrum tail is added, in SWAN  $m$  is 4 or 5 depending on the formulation of wind input in the source terms of the balance equation used, in our case  $m = 5$  because we use the formulation by Janssen (1991), as in the model WAM cycle4 (Booij et al. 2004). The reason why a fixed cut frequency is used for high frequencies, rather than a dynamic cut frequency that depends on wind speed or average frequency, as is done in WAM or WAVEWATCH III, is that in coastal water the combined wave may have very different



frequencies. Besides, near the coast a local wind can generate very young waves unrelated to the swell, in such cases the dynamic cut frequency may be low to take into account the characteristics of locally generated wave.

Several software designed for this work are used in MATLAB to speed up the generation of model inputs, supporting it with the use of Geographic Information Systems, wave height on the coast and the period obtained from SWAN model, which can be operated in stationary and non-stationary mode.

The preparation, review, interpolation and processing of bathymetric data is performed using Geographic Information System Mapinfo version 10.5. With the tool Vertical Mapper 3.1.1, bathymetry data are prepared in the form of regular grid, with a spatial resolution defined by the working group depending on the density and quality of data available for the study. It can be designed from 5 meters to kilometers. Bathymetric unstructured grids can also be used from expediting the model processing.

To determine wave height and return period, it is used the methodology applied in Perez *et al.* (1994). These authors developed various curves that calculate for each event return period, wave characteristics in deep water and wind, based on a thorough analysis and statistical processing and existing records, with the support of information from buoys, satellites or records of sensors located on the coast, using them as input to the model, thus analyzing the transformation of wave from deep water until it reaches the coast.

JONSWAP spectrum was used for calculating wave on the boundary, so that the directional spectrum of wind wave at each point is determined by the expression: (Juantorena, 2001; Juantorena *et al.*, 2004).

$$E(f, \theta) = E(f)D(f, \theta)$$

The frequency spectrum is expressed:

$$E(f) = \alpha g^2 (2\pi)^{-4} f^{-5} \exp \left\{ \left[ -\frac{5}{4} \left( \frac{f}{f_m} \right)^{-4} \right] + \ln \gamma \exp \left( -\frac{(f - f_m)^2}{2\sigma^2 f_m^2} \right) \right\}$$

And for angular energy distribution, it is used the expression:

$$D(f, \theta) = \begin{cases} \frac{2}{9} \pi \cos^n(\theta - \phi) & \text{for } |\theta - \phi| \leq \pm \frac{\pi}{2} \\ 0 & \text{for the rest} \end{cases}$$

Where  $\sigma$  — is the peak width and equals  $\sigma = \sigma_a = 0.07$  for  $f \leq f_p$  and  $\sigma = \sigma = 0.07$  for  $f > f_p$ ,  $\gamma$  is the peak widening factor,  $g$  is gravity acceleration,  $\theta$  is wave propagation direction and  $\phi$  is wind direction.



Modeling wave for cold fronts and other events, such as extratropical lows, throughout the territory was done by coastal stretches, unlike for surge that was conducted punctually, due to the existence of several wave courses and the particularities of the coast, mapping only the wave direction that generated greater wave height and setup.

The wave setup associated to extreme meteorological events is a process that occurs by sea level rise due to the transfer of wave momentum to the water column during wave breaking. When waves approach the coast, they carry energy and momentum in the direction of the waves. At the breaker, waves dissipate; however, the momentum never dissipates, but it is transferred to the water column. Thus, a gradient is generated on the water surface that allows for balancing the onshore component of the momentum flow from the breaker zone to the coastline.

## 2.3 VULNERABILITY CALCULATION

### 2.3.1 STRUCTURAL VULNERABILITY

The resistive capacity of housing buildings to the destructive forces of different floods is analyzed. For this, it is taken into account the construction type, technical condition and height of buildings, as well as the soil type depending on the risk scenario.

The classification for Building Typology of the Department of Architecture and Urban Planning is used, which divides buildings according to the construction characteristics of their components (walls, roof, floors, etc.) into five categories (Manual of the Program for Technological Development of Housing, from 1998 to 2000).

Damage to housing, or facilities in general, will depend on the type of hazard. It is expressed by the factor  $D_c$  or coefficient of damage to buildings. This coefficient indicates the degree of damage that buildings may suffer, taking into consideration the quality of housing or buildings in general (type and technical condition) and hazard intensity. It is classified with different gradations: undamaged, with significant damage or serious damages, giving it different weights in the overall equation. The damage factor, increased or not by location elements that also have a weight, will add a total value for structural vulnerability. Administrative, service and industry buildings, warehouses and other targets of accident risks, as well as those playing a major role in meeting the basic needs of the population during disaster response, such as hospitals, clinics, processing plants and other critical facilities are analyzed only taking into account if they exist in the hazard area.

#### ***Structural Vulnerability (Total Weight 20)***

$$V_e = D_c + F_c$$

Where

$V_e$  — structural vulnerability

$F_c$  — location factor pointing out soil impermeability or not due to urbanization, the influence of slope and height where the building is located, housing location with respect to the coast, to consider the effect of waves and the fast flow of water.

Soil permeability is assigned the following weights:

Soil permeability	Weights
Areas covered by permeable lithology	0
Areas half-covered by permeable lithology	0.5
Impermeable areas	1

Slope influence is assigned the following weights:

Slope	Weights
Low (<10 degrees)	1
Medium (10 – 15 degrees)	0.5
High (>15 degrees)	0

Height is analyzed as the coefficient given by the percentage of the flooded area with elevation below the average height of the municipality. The influence of the height of the area where buildings are located is assigned the following weights:

Height of the area	Weights
Above mean height of the municipality	0.0
Half the height of flood area is below the mean height of the municipality	0.5
All the height of the flood area is below the mean height of the municipality	1.0

**Location factors**, is a value expressing the influence of whether the terrain is impermeable or not due to urbanization, the influence of slope and the height of the area where the building is located, this indicator can add a maximum weight of 3.

$Dc_n$  is expressed by the equation:

$$Dc_n = \sum (f_i * p_{ji}) + AET$$

Where

$Dc_n$  — potential damage that the buildings of a particular type may suffer, when facing an event of a given intensity in a People's Council  $n$

$f_i$  — fraction of housings or facilities of  $i$ -th type within a People's Council

$p_{ji}$  — value expressing a weight of potential damage that may suffer a facility of  $i$ -th type, due to the impact of an event of  $j$ -th intensity

**AET** — damage due to the technical condition of the building, considering the predominant technical status in the People's Council.

To assess the damages to which buildings are exposed, an  $f$  factor should be distinguished, expressing the fraction or percent of buildings belonging to a given type, of the total of buildings in the People's Council. For example, if there is a total of 1200 buildings in the Council and 700 of them are of type I, then  $fI$  equals 700 divided by 1200,  $fI=0,58$ . That is to say, 58% of housings in the People's Council are type I.

When evaluating  $P_{ji}$ , three rainfall intensity intervals are considered and weights that should be given are the indicated values, depending on the building type and rainfall. The following table lists the characteristics of building types.

### BUILDING TYPES

Type	Walls	Roof
I	Prefabricated concrete panels, reinforced or not, concrete blocks, clay bricks, masonry.	Reinforced concrete slabs built in situ, prefabricated reinforced concrete slabs, reinforced concrete joists with concrete or clay hollow bricks.
II	Concrete blocks, clay bricks, masonry, pressed blocks or bricks of stabilized floors, mud wall, pebble.	Reinforced concrete joists with flat or arched concrete slabs, or clay roof tiles, stabilized floors, pebble, ferrocement, etc.
III	Concrete blocks, clay bricks, masonry, pressed blocks or bricks of stabilized floors, pebble, mud wall, adobes, hard or fancy wood.	Reinforced concrete, metal or sawn wood joists, covered with clay roof tiles, metal slates, asbestos cement or mortar (tevi).
IV	Pressed blocks or bricks of stabilized floors, rough stone, pebble, mud wall, adobes.	Sawn or sturdy wood joists, covered with corrugated-metal roof tiles or fibrocement panels.
V	Sawn wood or palm board.	Sturdy wood support beams and joists, covered with palm leaves, asphalt cardboard tiles, tar paper.

The location of the houses with respect to the coast will be assigned the following weights:

Location of houses	Type of damage	Weights
On the coastal front	Direct wave impact	2
Houses located in the first block from the coast	Damage caused by the rapid flow of seawater	1
Houses located in the flooding area but farther than the first block	Damage due to the permanence of water on the terrain	0.5
Houses located outside the flooding area	They are not affected by flooding.	0

$D_c$  — factor of damage from coastal flooding

$$D_C = \sum_i^n n_i D_i + ETC$$

Where

$i$  — typology index

$TC$  — total amount of building types within flooded areas, according to the five building types

$n_i$  — factor  $i$ -th of housing types in flooded areas

$D_{ji}$  — weight of the damage that the facility of  $i$ -th type may suffer for the impact of an event with  $j$ -th intensity

$ETC$  — building technical condition

- For building technical condition, the following weights will be considered:

Technical condition	Weights
Poor	5
Average	2.5
Good	0

- For the extent of damages that a facility may withstand, the following weights will be considered:

Damage to the facility	Weights
No damage	0.0
Slight damage	2.5
Moderate damages	5.0
Considerable but repairable damages	7.5
Severe irreparable damages	10.0

### 2.3.2 NONSTRUCTURAL VULNERABILITY

Damages that may suffer the lifelines in the territory are evaluated, such as roads, gasification systems, communication, power generation system, pylons and electricity grids (including the underground grids, in case of flooding), as well as the status of the drainage system and sewerage networks. The structural and nonstructural vulnerabilities express exposure factor, i.e., the degree of exposure of the studied territory to hazard influence is assessed.

#### **Nonstructural vulnerability (Total weight 10)**

The following indicators and weights are taken into account:

- Transport infrastructure: it is assessed the % of roads located in flooded zones that are damaged or blocked.

Damage to roads	Weights
100% affected	3
50% affected	1.5
0% affected	0

- Aqueduct System: it is evaluated what percent of the Aqueduct System in flooded areas has failures in its functioning due to pollution (cisterns).

Damage to aqueduct systems	Weights
100% affected	2
50% affected	1
0% affected	0

- Sewerage system: the disablement of drainage in flooded areas is assessed.

Damage to the sewerage system	Weights
100% affected	3
50% affected	1.5
0% affected	0

- Other damaged lifelines: the underground electricity grids, gas and communication networks are assessed.

Damage to lifelines	Weights
100% affected	2
50% affected	1
0% affected	0

### 2.3.3 FUNCTIONAL VULNERABILITY

In this analysis, the influence of structural and nonstructural vulnerability on the stability or interruption of production and services is studied, for each type of event of a given category. The analysis of this vulnerability allows determining the status of preparedness and response factors, from the availability of emergency power generator sets, preparedness of the health-care system to cope with disaster, shelter capacity for evacuees and certification of facilities, access to remote areas, reserve of basic supplies (water, food, fuel, medicines) and others.

#### **Functional vulnerability (Total weight 20)**

- Availability of emergency power generator sets.

Indicator	Weights
0% availability	4
50% availability	2
100% availability	0

- Preparedness of the health-care system to cope with disasters.

Indicator	Weights
0% prepared	4
50% prepared	2
100% prepared	0

- Shelter capacity for evacuees.

Indicator	Weights
0% sheltered	4
50% sheltered	2
100% sheltered	0

- Access to remote areas.

Indicator	Weights
0% access	4
50% access	2
100% access	0

- Reserves of basic supplies (water, food, fuel).

Indicator	Weights
0% reserve	4
50% reserve	2
100% reserve	0

#### 2.3.4 SOCIAL VULNERABILITY

The extent to which social factors can increase vulnerability will be assessed. It will evaluate the total exposed population, population density or impact on the population (Apob), risk perception and preparedness, presence of solid waste on the streets and preparedness of management bodies.

##### **Social Vulnerability (Total weight 20)**

- Impact on the population (*AP*).

$$AP = \frac{DPCP}{DMM}$$

Where *DPCP* — is the population density in flooded areas.

$$DPCP = \frac{\text{Population}}{\text{Area}}$$

*DMM* — is the population average density in the municipality.

Density of the affected population	Weights
< 0.25	0
0.26 – 0.5	2.5
0.51 – 0.75	5.0
0.76 – 1.0	7.5
> 1.0	10.0

- Risk perception by the population.

Indicator	Weights
Low	3.0
Medium	1.5
High	0

- Preparedness of the population.

Indicator	Weights
0% prepared	3
50% prepared	1.5
100% prepared	0

- Presence of slums.

Indicator	Weights
0% presence	0
50% presence	1
100% presence	2

- Presence of solid waste on the streets.

Indicator	Weights
0% presence	2
50% presence	1
100% presence	0

### 2.3.5 ECOLOGICAL VULNERABILITY

Exposure in areas of potential hazard should be considered: Fragile ecosystems or ecologically sensitive areas and protected areas. Ecologically sensitive areas are selected according to the Guide to the preparation of National Biodiversity Studies, adapted to Cuba by Rodriguez and Priego, UNEP, 1998.

#### ***Ecological Vulnerability (Total weight 10)***

- Fragile ecosystems or ecologically sensitive areas.

Indicator	Weights
0% damaged	0
50% damaged	2.5
100% damaged	5

- Protected areas.

Indicator	Weights
0% damaged	0
50% damaged	2.5
100% damaged	5

### 2.3.6 ECONOMIC VULNERABILITY

Economic factors are evaluated taking into account the industrial zones in areas at risk, extent of crop lands and number of animals in areas at risk, implementation level of vulnerability reduction budget, whether the costs of response are accounted for and endorsed with concrete measures in the Disaster Reduction Plan.

Vulnerability is expressed by mathematical functions or matrices. The matrices are developed in Microsoft Excel spreadsheets; there should be a separate sheet for each vulnerability, as part of the Excel workbook that adds the total vulnerability by People's Councils for a given municipality (a mathematical model for vulnerability calculations is included). Vulnerability will only be considered for assets (essential facilities, residential areas, lifelines) or persons exposed in hazard areas.

#### *Economic vulnerability (Total weight 20)*

Indicator	Weights
Implementation level of vulnerability reduction budget	0-4
Industrial zones in areas at risk	0-4
Response costs are accounted for	0-4
Extent of crop lands	0-4
Number of animals in areas at risk	0-4

### 2.3.7 TOTAL VULNERABILITY

Vulnerability mapping is done using a Geographic Information System. The overall vulnerability ( $V_t$ ) of the People's Council, municipality or analyzed area for a particular hazard is the sum of all subtypes of vulnerabilities, calculated independently:

$$V_t = V_e + V_{ne} + V_F + V_s + V_{ec} + V_{ecn}$$

Where

$V_e$  — structural vulnerability

$V_{ne}$  — nonstructural vulnerability

$V_F$  — functional vulnerability



$V_s$  — social vulnerability

$V_{ec}$  — ecological vulnerability

$V_{ecn}$  — economic vulnerability

The cartographic output will be obtained from a GIS, including classification attributes, total number of people exposed, total number of exposed housings, typologies, housing conditions and all information related to each element and indicator analyzed for the different vulnerabilities.

It is classified as high vulnerability (red), medium vulnerability (yellow) and with vulnerability (green). The total vulnerability value is divided by 100 to obtain the following ranges:

- (0 – 33) With Vulnerability**
- (34 – 66) Medium Vulnerability**
- (67 – 100) High Vulnerability**

## 2.4 RISK ESTIMATION

The overall risk is assessed based on the hazard ( $P$ ) value of a potentially harmful event occurring with particular intensity, the total vulnerability ( $Vt$ ) and the cost of exposed assets. In case of unavailability of data on the cost of various exposed assets, the Specific Risk can be calculated by multiplying the above-mentioned hazard by the vulnerability, the latter being implemented throughout the territory.

$$R = C \sum_{i=1}^n V_i * P_i$$

$$R = \sum_{i=1}^n V_i * P_i$$

To compare risks among the People's Councils studied in each municipality or province, it is considered the maximum risk value obtained in all Councils analyzed for the same hazard intensity, the highest value is used to establish the range and break it down into high risk, medium risk and with risk.

Hypothetical example of risk value obtained in the People's Council of a municipality:

CP Los Arabos	0.1741
CP Cañitas	0.0091
CP Cantel	0.1623
CP Cardenas	0.1705
CP Marabu	0.0689
CP Fundicion	0.0895
CP Playa	0.1326
CP Marina	0.0662

The highest risk value (0.1741) of all those obtained is divided by 3 and the result (0.058) allows establishing the interval to classify the risk.

**(0 – 0.058) With Risk**  
**(0.059 – 0.117) Medium Risk**  
**(0.118 – 0.1741) High Risk**

This procedure is performed for each hazard intensity analyzed.

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Strong winds of Hurricane Gustav, 2008

### 3. Methodology for conducting studies on disaster hazard, vulnerability and risks of strong winds

#### INTRODUCTION

The hazard of damage from strong winds has a high incidence in the Caribbean region, with a remarkable effect of extreme hydrometeorological events that cause a great impact on the population, economy, crop areas and ecosystems throughout its extension. Tropical cyclones are the most dangerous hydrometeorological recurring phenomenon in Cuba. Other events generating strong winds that also affect the country are the cold fronts, characteristic of winter or dry period of the year, and severe local storms, which are more frequent between March and September.

#### GENERAL OBJECTIVE:

Establish the methodological guidelines for conducting disaster hazard, vulnerability and risk studies of damages from strong winds.

#### SPECIFIC OBJECTIVES:

1. Establish the basic procedures for collecting and organizing information, and conducting research to ensure a homogeneous level of measurement and analysis in all territories.
2. Calculate the hazard of strong wind impact for different return periods.
3. Identify all elements exposed to strong wind hazard, calculate vulnerability and estimate risk according to indicators defined in this methodology, use of Geographic Information Systems.
4. Perform mapping of vulnerability and risk of strong wind impact.

#### SCOPE:

Studies on disaster hazard, vulnerability and risks of damages from strong winds are conducted by People's Councils, from the existing information and studies. Their results will be delivered at provincial level, with outputs at municipal and People's Council levels. The working scale is 1:25 000 or higher.

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### 3.1 MATERIALS AND METHODS

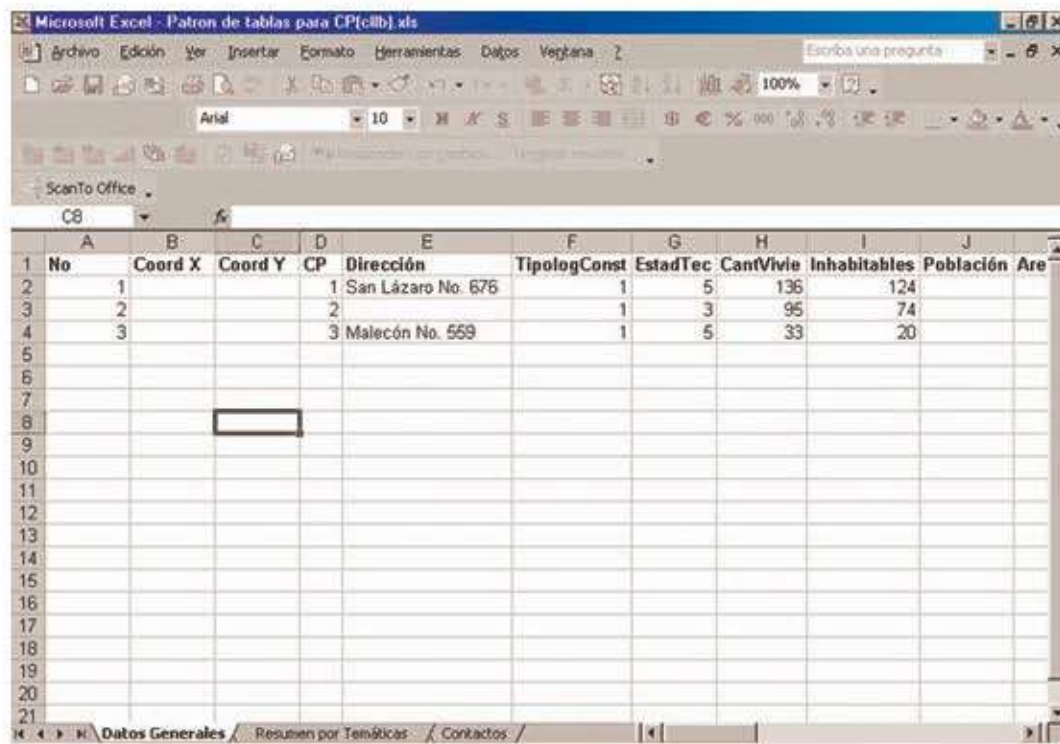
To calculate vulnerability, it is required to compile information on assets and population exposed to strong wind hazard. This information covers the entire People's Council. All information must be georeferenced, for future cartographic expression.

Maps:

- Map showing the limits of municipalities and People's Councils
- Map of roads (major roads or railways)

Information is organized and analyzed at the level of People's Council.

Both vulnerability variables and value judgments are determined in multidisciplinary and multi-sectoral workshops by expert judgment.



No	Coord X	Coord Y	CP	Dirección	TipologConst	EstadTec	CantVivie	Inhabitables	Población	Are
1										
2	1			1 San Lázaro No. 676	1	5	136	124		
3	2			2	1	3	95	74		
4	3			3 Malecón No. 559	1	5	33	20		
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Figure 3.1: Standard charts for gathering information at People's Council level.

### 3.2 HAZARD CALCULATION

To calculate the wind hazard, it is determined the lowest expected value of the possible maximum wind for a predetermined likelihood or return period (according to the likelihood distribution that best fits the observational series considered).

#### ***Climate variable to consider***

For strong winds, it is necessary to use the meteorological variable that best fits this concept, regardless of the meteorological phenomenon or situation that give rise to the wind. Generally, wind gusts that last several seconds are taken into account.

### **Characteristics of observational series**

Observational series of certain length are required to perform calculations, such that they include the highest values of wind generated by the set of synoptic situations and meteorological events (which generate high wind values) affecting the study site. This requires "a priori" knowledge of climate conditions. In addition, the series must be uninterrupted, that is, not having missing data. In the event that the study site has been affected by tropical cyclones and tornadoes of high values in Fujita scale, it is most important that the series also contains the extreme wind values generated by other phenomena or synoptic situations over the years where no tropical cyclones and tornadoes have occurred on that site or zone, since the series should allow calculating expected wind gusts from low (1%) to high (50%) likelihood, as the wind values for high likelihood are necessary in the calculation of vulnerability, mainly of the structural type.

### **Statistical modeling**

By using extreme distribution functions, it is determined which of them is best suited to the observational series, following the classical statistical methodologies. From the selected distribution, minimum wind values of the possible maximum (tail on the right) are obtained for the predetermined likelihood or return periods.

It is important not to confuse the impact likelihood of a tropical cyclone of certain category, e.g. category 1 hurricane on the Saffir-Simpson scale whose maximum winds are within a range, with extreme wind values for a given likelihood, because the first case does not take into account other phenomena or synoptic situations generating strong wind, thus running the risk of underestimating the extreme wind values, which would result in a low hazard assessment.

If there are no series that meet these requirements, it is possible to apply expert judgment.

It is not possible to establish a more detailed methodology, as it varies depending on the specific climate conditions of each site and the requirements of the vulnerability assessment.

TABLE 3.1: CLASSIFICATION OF SCORES ACCORDING TO SOCIAL FACTORS

	Time period in years	Likelihood in %	Expected speeds (km/h)
1	100	1	220
2	50	2	194
3	25	4	169
4	20	5	166
5	10	10	148
6	5	20	130

### 3.3 VULNERABILITY CALCULATION

To facilitate the calculations, vulnerability indicators may be expressed in whole numbers, so that the maximum vulnerability makesto 100, in the worst case, and 0 when there is no vulnerability.

The end result should be divided by 100 to adjust it to the established ranges between 0 and 1.

#### *Vulnerability ranges*

- (0.0 – 0.33) Low Vulnerability**
- (0.34 – 0.67) Medium Vulnerability**
- (0.68 – 1.0) High Vulnerability**

#### 3.3.1 STRUCTURAL VULNERABILITY

The resistive capacity of housing buildings to the destructive forces of strong winds is analyzed, taking into account the type of construction, technical condition and height of buildings, and location parameters, such as density of trees in urban areas.

Damage to housings depends on hazard intensity, which is expressed by the factor *Dc* or coefficient of damage to buildings. This coefficient indicates the degree of damage that may buildings suffer, considering the quality of the housing or building in general (type and technical condition) and the intensity of the hazard.

Structural vulnerability for each People's Council is calculated according to the following formula:

$$V_e = Dc + APOB + CV + ALT + ARB$$

Where

*V<sub>e</sub>* — is the structural vulnerability that adds 30 points.

*Dc* — index of damage to buildings. It is based on building types, their technical condition and the destructive potential of hurricanes. It can be evaluated with different gradations as undamaged, with slight damage, moderate damage, substantial damage or severe damage. Its value varies between 0 and 10.

*APOB* — index of damage to population. It depends on population susceptibility, resulting from the combination of housing susceptibility with population density. It varies between 0 and 7.

*CV* — housing quality index. It is evaluated according to the number of housings with a given susceptibility, i.e. it depends on building types and technical condition. Its value varies between 0 and 7.

*ALT* — height of building index. It is obtained by taking into account the average height of buildings and their average number of floors. It varies between 0 and 3.



Figure 3.2: Collapse caused by Hurricane Sandy's winds.

**ARB** — index of trees that can affect buildings. It depends on the density of trees and their relative location in relation to buildings and lifelines. It varies between 0 and 3.

### 3.3.2 NONSTRUCTURAL VULNERABILITY

It evaluates the damages that lifelines may suffer, in this case the road obstructed by falling trees and power poles and electrical networks, also including the possible impacts on pylons.

The total weight of nonstructural vulnerability is 20 points.

The following indicators and weights are taken into account:

- Blocked Access roads (8 points): assesses the percent of the roads in the People’s Council that may be blocked by fallen trees or power poles.

Indicator	Weights
100% affected	8
50% affected	5
0% affected	0

- Affected overhead power grids and pylons (12 points).

Indicator	Weights
100% affected	12
50% affected	6
0% affected	0

### 3.3.3 FUNCTIONAL VULNERABILITY

The assessment of this vulnerability evaluates response preparedness factors. In this case, the total weight is 10 points and indicators to consider are:

- Availability of emergency power generator sets (2 points).

Indicator	Weights
0% availability	2
50% availability	1
100% availability	0.0

- Preparedness of the health-care system for disaster (4 points).

Indicator	Weights
0% prepared	2
50% prepared	1
100% prepared	0.0

- Shelter capacity for evacuees (2 points).

Indicator	Weights
0% sheltered	2
50% sheltered	1
100% sheltered	0.0

- Reserve of basic supplies (water, food, fuel) 2 points.

Indicator	Weights
0% reserve	2
50% reserve	1
100% reserve	0.0

### 3.3.4 SOCIAL VULNERABILITY

This study is carried out considering the following indicators and weights, with a total weight of 10 points. Its aim is to assess the degree to which social factors can increase vulnerability.

- Impact on the population (AP) (5 points).

Density of affected population	Weights
0.1 – 0.25	1
0.26 – 0.5	2
0.51 – 0.75	3
0.76 – 1.0	4
> 1.0	5

- Risk perception of the population (2 points).

Indicator	Weights
0% prepared	2
50% prepared	1
100% prepared	0.0

- Preparedness of the population (2 points).

Indicator	Weights
0% prepared	2
50% prepared	1
100% prepared	0.0

- Existence of unhealthy neighborhoods or slums (2 points).

Indicator	Weights
0% existence of slums	0.0
50%	0.5
100%	1

### 3.3.5 ECONOMIC VULNERABILITY

Economic vulnerability is calculated considering the indicators that can somehow affect the economy of the province and the country in case of wind impact, that is, it depends on what the most important elements of the economy are in each province, and its total weight is 20 points.

Indicator	Weights
Implementation level of vulnerability reduction budget	2
Industrial zones in areas at risk	2
Response costs accounted for	2
Extent of crop lands in areas at risk:	10
-Sugar cane	3
-Tobacco	4
-Other crops	3
Number of animales in areas at risk	4

### 3.3.6 CALCULATION OF ECOLOGICAL VULNERABILITY

The total weight is 10 points.

For the calculation of the ecological vulnerability, the indicators to consider are:

Indicator	Weights
Ecologically sensitive areas	5
Protected Areas	5

The overall vulnerability of the People's Council to the strong wind hazard is expressed by the following formula:

$$V_t = V_e + V_{ne} + V_F + V_s + V_{ec} + V_{ecn}$$

Where  $V_e$  — structural vulnerability

$V_{ne}$  — nonstructural vulnerability

$V_F$  — functional vulnerability

$V_s$  — social vulnerability

$V_{ec}$  — ecological vulnerability

$V_{ecn}$  — economic vulnerability

The cartographic output will result from a GIS project, with classification attributes, all exposed persons, total of housings exposed, building types, housing conditions and all information related to each indicator considered for the different vulnerabilities.

It is classified using colors as high in red, medium in yellow and low in green.

This classification is based on the following ranges:

- (0 – 0.3) Low Vulnerability**
- (0.4 – 0.6) Medium Vulnerability**
- (0.7 – 1) High Vulnerability**

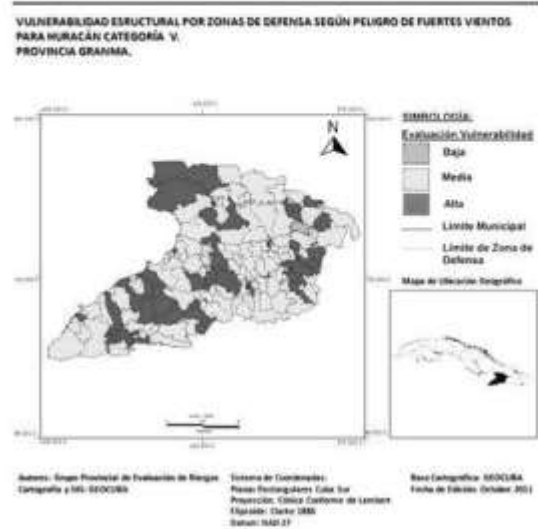


Figure 3.3: Example of a map of vulnerability to strong winds for a province.

### 3.4 RISK ESTIMATION

The specific risk is assessed from the convolution of the hazard ( $P$ ) that a potentially damaging event occurs, multiplied by vulnerability ( $V$ ) of exposed assets, for different intensities  $i$  of that hazard.

$$R = \sum_{i=1}^n V_i * P_i$$

The risk will be classified according to the following ranges:

- (0.0 – 0.11) Low Risk**
- (0.12 – 0.43) Medium Risk**
- (0.44 – 1.0) High Risk**

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## 4. Methodology for conducting studies on disaster hazard, vulnerability and risks of severe drought

### INTRODUCTION

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In recent decades, the increasing influence of drought has brought about that it is considered as “one of the greatest disasters in the world, the most frequent and persistent, with higher negative effects on agricultural production, as well as real adverse impacts on the environment”(WMO, 1990).

Drought affects many more people than any other natural hazard and gives rise to a high economic, social and environmental cost. Efforts are being devoted to develop more effective and preventive preparedness plans to cope with drought, and to take management actions based on risk estimation and reduction (WMO, 2006).

In Cuba, during the last decades, significant stress has been generated on surface and groundwater resources, as well as their reserves and management and exploitation characteristics, due to the strong impact of persistent and significant drought events of short and long periods, causing harmful effects on agricultural production and soil conservation, constituting an obstacle to the efforts to ensure welfare, health and stable development of the economy.

Drought is usually approached from two different points of view: by its climate determinants (meteorological drought), i.e. the character of atmospheric circulation, rainfall, temperature, evaporation, among others; or by its consequences, whether agricultural, hydrological or socio-economic (**Figure 4.1**).

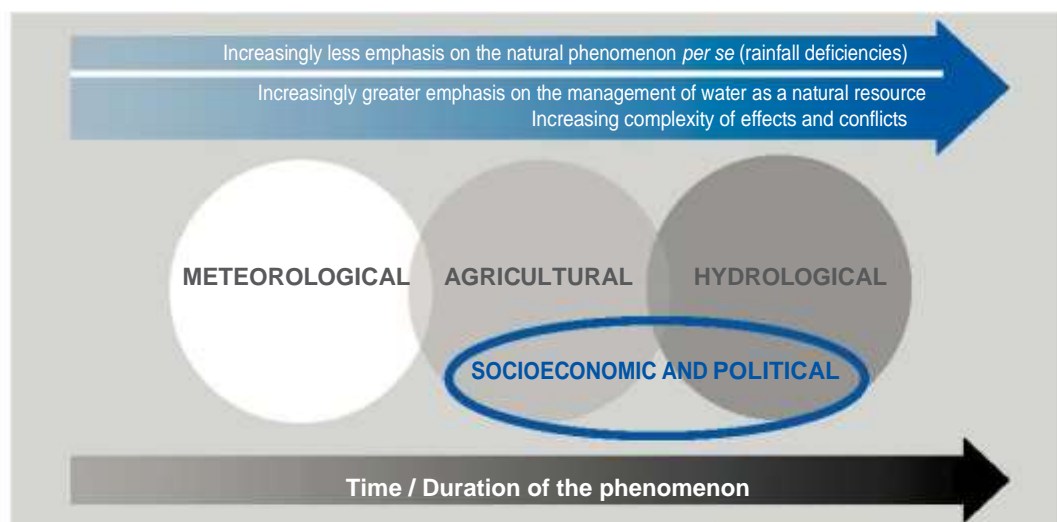


Figure 4.1: Interactions among meteorological, agricultural, hydrological and socio-economic drought. (From: WMO, 2006)

Drought has three distinctive features: **intensity**, **duration**, and **magnitude**. **Intensity** reflects the precipitation deficit and severity of effects associated to the deficit (Figure 4.3); **duration** because once drought has begun, it can last for months or years, and

**magnitude** is closely related to the time when rainfall shortage begins and the **intensity** and **duration** of the phenomenon.

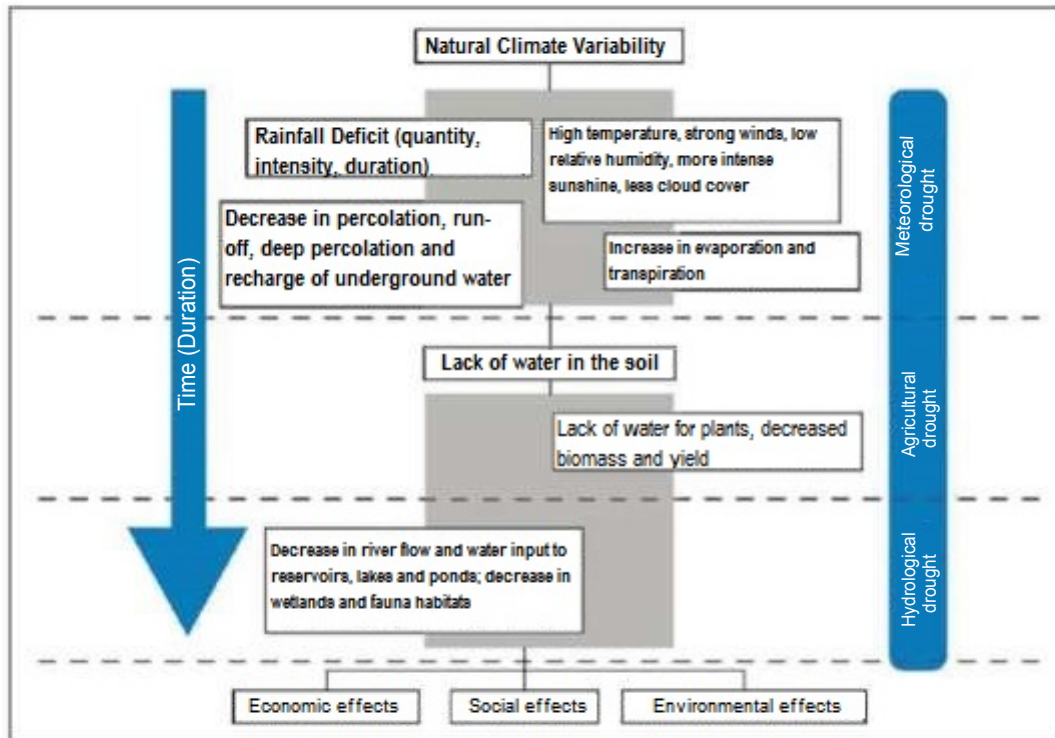


Figure 4.2: Sequence of drought events and their effects for commonly accepted types of droughts. (From: WMO, 2006).

Drought effects are not structural and cover more extensive geographic areas than those affected by other hazards, which added to the imperceptible way it manifests, makes it particularly difficult to quantify its effects and even more to assist in case of disaster; therefore, it is not easy to know when a drought event begins and ends, or the criteria to decide it.

#### GENERAL OBJECTIVE:

Establish the methodological guidelines for conducting disaster hazard, vulnerability and risk studies of severe drought throughout the country.

#### SPECIFIC OBJECTIVES:

- Calculate the hazard of meteorological, agricultural and hydrological drought from representative indices of the “hazard” as a potential expression of the phenomenon.
- Conduct hazard mapping using GIS and create maps of relative frequency corresponding to different hazard levels (1, 2, 3), from the point of view of meteorological and agricultural drought.



Figure 4.3: Cuba is experiencing a drought event that showed its first few signs between 2002 and 2003 in the eastern region and has gradually reached the rest of the country.

- Calculation and mapping of the Integrated Hazard of agricultural and meteorological droughts to achieve a comprehensive assessment of these events.
- Calculation and mapping of hydrological drought hazard from calculating the hazard index at municipal level, as a tool for decision-makers, taking into account not only the status of supply sources, but also demand behavior.
- Identify all exposed elements and determine vulnerabilities according to the indicators defined in this guideline, using GIS and field data.
- Develop the risk assessment for two seasonal periods (rainy and dry seasons) at municipal level, for analysis and comparison with other municipalities within the country, and its cartographic representation using GIS.
- Technical report with the results and cartographic output for each unit of analysis.

#### **SCOPE:**

Hazard, vulnerability and risk studies on severe drought are performed to determine the meteorological, agricultural and hydraulic hazard, vulnerabilities and risks of the elements exposed to hazard impact. The results will be delivered at provincial level, with output at the municipal level according to the characteristics of the phenomenon from the spatial and temporal point of view. The resulting information will be processed and analyzed for the dry (December-April) and rainy (May-November) seasonal periods.

The study results are represented in spatial scales: town, municipality, province and nation. Although in the national grid, each grid point represents 4 km<sup>2</sup> of spatial resolution; if necessary, the methods used allow obtaining information from grids up to 1 km<sup>2</sup> by interpolation.

Time scales cover decades and months (ten-day and one-month periods), for rainy and dry seasons.

#### **4.1 MATERIALS AND METHODS**

For hazard studies of severe drought, it is taken into account:

1. Data and products from the Surveillance and Early Warning System (EWS) for Meteorological Drought operated by the Climate Center, specifically data on rainfall cumulative values and drought indicators (rainfall cumulative values expressed by deciles technique, standardized precipitation index or SPI, etc.), for different time periods.
2. Components and products from the Surveillance and Early Warning System (EWS) for Agricultural Drought, executed by the Center for Agricultural Meteorology of the National Institute of Meteorology, based on obtaining land indices of agricultural interest from decadal observation of meteorological parameters and soil at any station in the network. Rainfall data are referred to the same database used for meteorological drought and selected hazard categories are similar.



3. Application of interpolation algorithms to rain data sets from rain gauges to obtain the grid that facilitates the analysis of the characteristics of cumulative rain and drought values.
4. Historical information available, both spatial and temporal, on the status of supply sources, on the behavior of characteristic and critical water levels, and historical exploitation of groundwater or surface supply sources, based on the behavior of climate factors, and also the behavior of water demand.
5. Survey and analysis of information in the territory on indicators of vulnerability across involved sectors, like agriculture, water, industry, population, governments and others.
6. Quantification of vulnerability is given by a weighting scheme linked to a numerical scale that indicates the relative importance of different elements within the hierarchical structure. To calculate the weights, an evaluation method is used applying best suited procedure for each hierarchical level according to their characteristics. Used methods include binary comparison of the analytical hierarchical method by T.L. Saaty and the expected value method, among others (ITC, 2007).
7. Geographic Information Systems to take all available information into digital format, with a geospatial database assigned to each treated thematic layer, thus ensuring greater cartographic precision when performing the analysis.

## 4.2 HAZARD CALCULATION

### 4.2.1 INTEGRATED HAZARD OF AGRICULTURAL AND METEOROLOGICAL DROUGHT

In recent years some countries have made great efforts to address simultaneously the main components and factors that are involved, in one way or another, in drought risk reduction.

From these experiences and also those developed in Cuba, for the purposes of Risk Reduction Plans, it is established that for determining the “Drought Risk” it is necessary to have representative indices of drought “Hazard” (meteorological, agricultural and hydrological components, etc.) to be integrated and evaluated in the equation that represents this risk, in its open interpretation (Centella, 2007). These indices show the results, for a given time and place, of a complex combination of attributes relating to rain behavior.

Then, the calculation of an “Integrated Drought Hazard Index” is done, incorporating in this version the meteorological and agricultural drought types. The results or outputs of each of these components, similarly expressed in terms of “Hazard Category”, allow articulating and weighing the categories found for each locality, thus achieving a balanced perception of this phenomenon.

## HAZARD OF METEOROLOGICAL DROUGHT

### *Conceptual analysis of Meteorological Drought Hazard*

The definition of Meteorological Drought (WMO, 1990) states that this phenomenon takes place when “a period of abnormally dry weather long enough to cause a serious hydrological imbalance” occurs. In this case, the “long enough” expression is key in the process of approximation to a “Hazard” perception that reflects the damaging potential of the phenomenon, beyond the value that a particular drought index (meteorological) may represent, evaluated for a determined time period (month, quarter, etc.).

In examining the rainfall behavior over a selected (n months) period of time (t), “long enough” to capture the harmful potential or “Hazard” of a drought event, it is considered that this is a function of factors such as rainfall anomalies in certain time periods contained in a reference time period. The position of each of these periods in that time horizon and their relative weight in the annual cumulative rainfall, according to its normal values, finally expresses the result in “Hazard degrees or categories” (1, 2 or 3).

The Meteorological Drought Hazard Index (B12) specifically evaluates to what extent the deficit in cumulative rainfall in any quarter (minimum time unit to begin considering drought) is influenced by the behavior of rains in previous quarterly periods, until a predetermined time period capable of accurately expressing the degree of dominant hazard in that quarter (the cut criteria used in the present version always includes the previous 12 months, represented by the last four calendar quarters, from the month in which the assessment is made).

This idea focuses on the developed “Hazard Index” a “State of Prevalence”, which possesses a high added value, since it quantitatively integrates a “Hazard” perception, so far obtained only through a qualitative assessment of rain behavior in specific time periods (1,3,6, ..., n previous months).

The use of internationally recognized basic indices, like the Standardized Precipitation index (SPI) or the Deciles, as well as the application of the most recommended thresholds for characterizing deficit, facilitates developing this new index. Besides, approaching a task of this type would not be viable without the availability of operational calculation systems, implicit in the National Drought Surveillance and Early Warning System (Lapinel *et al.*,2007), able to successfully resolve all necessary requirements.

### *Calculation of Meteorological Drought Hazard*

Any historical series of monthly cumulative rainfall, representative of a given locality, grid point or grouping, expressed by the standardized precipitation index (SPI) or deciles technique, is transformed according to the procedures formulated in the previous section, into a new series consisting of scores expressing in each month the “degree of hazardousness” prevailing by its end.

Knowing all scores (positive and negative) by months, in the course of all the analyzed years (historical series), it is possible to calculate the selected percentiles (deciles, quintiles, quartiles, or tertiles) for an agreed "Standard", which can be used to set the thresholds of recommended hazard gradations, and transform these scores into "Hazard Categories".

**a) Identifiers for the detailed calculation of this index are described below:**

First Quarter ( $T_1$ ) corresponding to the closure of any month in question (for example: in January 1962,  $T_1$  corresponds to November 61- January 62). A quarter is always the minimum time unit required to refer to meteorological drought.

The immediately preceding quarter to  $T_i$  is identified as  $T_{(i-1)}$  from  $i=\overline{1,3}$ .

Positive or negative anomaly ( $A$ ), classified as  $A_1$  (Weak),  $A_2$  (Moderate),  $A_3$  (Severe) and  $A_4$  (Extreme) at any of the drought indices used (Deciles, SPI or others). The anomaly may reach values between +4 and -4 (see **Table 4.1**).

$K_1$  — coefficient that involves pondering position or proximity of each quarter analyzed in the time horizon from and relative to the first ( $T_1$ ). Then  $K_1 = 5-i$  for  $T_i$  from  $i=\overline{1,4}$ .

$K_2$  — coefficient  $K_2 = (p_t / p_a)$ , which considers the weight of cumulative rains in the quarter under review, compared to the annual total (according to standard). It is considered  $p_t$  = quarter cumulative average or standard ( $T_i$ ) with  $i=\overline{1,4}$  and  $p_a$  = cumulative average or standard. Este coeficiente usually varies between 1 and 4.

$\Sigma$  — algebraic addition of scores reached by all contributing quarters:

$$PP = \sum [AT_1 K_1 K_2 + AT_2 K_2 K_1 + AT_3 K_3 K_2 + AT_4 K_4 K_2] = \sum_{(i=1)}^4 AT_i K_i K_{2i}$$

Where

$PP$  — hazard score

$A$  — anomalies

In summary:

- Anomalies ( $A$ ) vary between 1 and 4 points (positive or negative) (see **Table 4.1**)
- Proximity coefficient or deficit position ( $K_1$ ) varies between 1 and 4 points: for  $T_i=5-i$  from  $i=\overline{1,4}$
- The ratio between the cumulative rainfall in any quarterly period and the annual cumulative rainfall ( $K_2$ ) is usually between 0.1 and 0.4. The obtained value is multiplied by 10 to balance the pondering scale.

**TABLE 4.1: ANOMALIES OF CUMULATIVE RAINFALL EXPRESSED ACCORDING TO SPI AND DECILES. HAZARD SCORES AND RELATED CATEGORIES**

SPI Scale	Deciles Scale	Hazard scores	Category
$\geq 2$		10	4 Extreme
$\geq 1.5 < 2$		9	3 Severe
$\geq 1 < 1.5$		8	2 Moderate
$\geq 0.5 < 1$		7	1 Weak
$> -0.5 < 0.5$	5 and 6		0 Normal
$\leq -0.5 > -1$		4	-1 Weak
$\leq -1 > -1.5$		3	-2 Moderate
$\leq -1.5 > -2$		2	-3 Severe
$> -2$		1	-4 Extreme

**b) Detailed procedure for obtaining scores:**

- **Step 1.** The first month in the series to start transforming is selected (e.g., January 1962). Here the sum begins, corresponding to January 1962 and according to the cut criteria used in this version, it values up to 4 quarters back  $T_i$  from  $i=1,4$ , which comprise the previous 12 months (February 1961 to January 1962).

January 1962 points, in fact, at  $T_1$ , i.e. the first quarter that ends with this month (November-December 1961 - January 1962).

- **Step 2.** Anomaly ( $A$ ) of this quarter ( $T_1$ ) is classified on the scale of selected scores and multiplied by the coefficients  $K_1$  and  $K_2$  as specified (Weightings and Table 1 on scales of drought indices). The first score is thus obtained.
- **Step 3.** Then, the quarter August - October 1961 ( $T_2$ ) is analyzed similarly and its score is added algebraically to that obtained previously.

The anomalies of the previous three calendar months, from May to July ( $T_3$ ) and from February to April ( $T_4$ ) 1961, will continue and finalize the contribution to the sum already started in ( $T_1$ ), according to punctuations that determine the value scale of the indices and the  $K$  coefficients that correspond to them.

- **Step 4.** Once the score of the first month (January 1962) is obtained, the next (February 1962) is analyzed, proceeding similarly, and doing so until all the months and years of the series have been evaluated.

**c) About the selection of Hazard categories.**

Once transformed the reference series (grid point, rainfall gauge or grouping on a given location: municipality, province, region) in a new series of "hazard scores", it proceeds to calculate for each month percentiles requiring thresholds or values below and above chosen hazard gradations.



The Meteorological Drought Hazard Categories will be, for the purposes of this methodology, still under calibration using the following percentils:

**Hazard Category 1**      from 21 to 30 percentil    Weak (W)

**Hazard Category 2**      from 11 to 20 percentil    Moderate (M)

**Hazard Category 3**      from 1 to 10 percentil    Severe or Extreme (S)

The calculation of the thresholds (30, 20 and 10 percentile), required to perform the categorization of scores, will be obtained through the percentile distribution of the own scores of each month in question, according to the selected standard (e.g., 1971-2000).

The hazard category obtained each month for any location or grid point allows coupling with the corresponding category of agricultural drought and obtaining the “Integrated Hazard”.

## AGRICULTURAL DROUGHT HAZARD

### *Conceptual Analysis of Agricultural Drought Hazard*

In the context of agriculture, drought “does not begin when the rain stops, but when the roots of plants cannot get any soil moisture” and it can be defined on the basis of soil moisture, rather than on some indirect interpretation of rainfall records.

Since the productive soil moisture reserve depends on soil and crop (species, variety, stage of development), agricultural drought exists when soil moisture in the rhizosphere is at a level that limits crop growth and production.

The **Combined Agricultural Drought Index** (CADI) has been developed from the diagnosis of the status of agricultural drought (start and permanence), its duration and intensity.

On the basis of monitoring dry weather periods assessed by the modified wetness index Solano *et al.*, (2003b), and the scale proposed by Solano *et al.* (2000a) that evaluates the start, end and duration of agricultural drought, depending on water stress conditions affecting the dominant vegetation in the studied area, the status of agricultural drought (SAD) has been conceptualized by Solano *et al.*, (2005) in six categories:

- **Short dry period (SDP) [1]:** that period in which the agro-meteorological conditions were very dry ( $Pr < ET/2$  and  $0.00 \leq W/Wx < 0.40$ ), causing moderate water stress on crops; or severely dry ( $Pr = 0$  and  $W/Wx = 0$ ), causing severe water stress on crops for two consecutive decades.

$Pr$  is the rain,  $ET$  or reference evapotranspiration,  $W$  is the current soil water reserves and  $Wx$ , the maximum soil moisture reserves.

- **Moderate dry period (MDP) [2]:** that period in which agrometeorological conditions caused moderate or severe water stress on crops for three decades.

- **Starting agricultural drought (SAD) [3]:** that period in which agrometeorological conditions caused moderate to severe water stress on crops for five or more decades.
- **Permanence of agricultural drought (PAD) [4]:** that period in which agrometeorological conditions caused moderate to severe water stress on crops for five or more decades.
- **End of agricultural drought (EAD) [5]:** the second decade where wet conditions occur after a dry period, though there may be a slightly dry period between them.  $Pr < ET_0$  and  $0.40 \leq W/W_x < 0.80$
- **Absence of agricultural drought (AD) [6]:** that period in which the agrometeorological conditions do not cause dry periods or droughts.

Once determined the beginning and end of agricultural drought, it is possible to determine the duration and intensity. According to their intensity (defined as levels of severity by the presence of water stress in a determined previous time period (up to 12 decades), the Agricultural Drought was conceptualized by Solano *et al*, (2003c) as follows:

- **Very light (1):** This corresponds to a period of dry weather in, which the sum of very dry or severely dry decades that compose it does not reach 20% of the total length of a dry period at least 12 decades long. Short periods of dry and moderate weather are also included.
- **Light (2):** It occurs when a dry period, the sum of very dry or severely dry decades equals or exceeds 20%, but does not reach 40% of the length of a dry period at least 12 decades long. Periods of dry weather with 4 or 5 decades evaluated as very dry or severely dry are also included.
- **Moderate (3):** This corresponds to a period of dry weather in which the sum of the very dry or severely dry decades equals or exceeds 40%, but does not reach 60% of the length of a dry period at least 12 decades long. Periods of dry weather with 6, 7 and 8 decades classified as very dry or severely dry are also included.
- **Severe (4):** It occurs when a period of dry weather, the sum of very dry or severely dry decades equals or exceeds 60%, but does not reach 80% of the length of a dry period at least 12 decades long. Periods of dry weather with 9, 10 and 11 decades evaluated as very dry or severely dry are also included.
- **Very severe (5):** This corresponds to a period of dry weather in which the sum of dry or severely dry decades equals or exceeds 80% of the length of a dry period at least 12 decades long.

### **Calculating the risk of agricultural drought**

For calculating Agricultural Drought Hazard, it is taken into account components and products from the Agricultural Drought Surveillance and Early Warning System, executed by the Center for Agricultural Meteorology at INSMET, based on obtaining land indices of agricultural interest from decadal observation of meteorological and soil parameters at any station in the network. Rainfall data are referred to the same database used for meteorological drought and selected hazard categories are similar.

Agricultural drought is calculated by a model (Solano, 2005a), based on the diagnosis of this adverse climate event from water stress in vegetation caused by soil moisture deficit. To calculate this term, it is required to determine water demand and supply for each component of soil-plant-atmosphere complex in past, present and future conditions.

For this calculation, the following input variables are used:

- **of soil**, texture, volume fraction of available water, field capacity and slope inclination of the terrain;
- **of vegetation**, the crop coefficient, which in turn depends on the type of crop and its development stage and depth of absorbing roots;
- **of the atmosphere** (meteorological), height of rainfall layer, maximum and minimum air temperature, air humidity, saturation deficit, solar radiation and wind speed.

The method of soil water balance in the rhizosphere, used for determining the se-agricultural drought, has been traditionally used by FAO and was simplified by Solano *et al.* (2003a) for pedoclimate conditions of the country.

**Figure 4.4** summarizes the process followed, grid to grid, to assess agricultural drought by combining Geographic Information Systems (GIS) and the calculation algorithms.

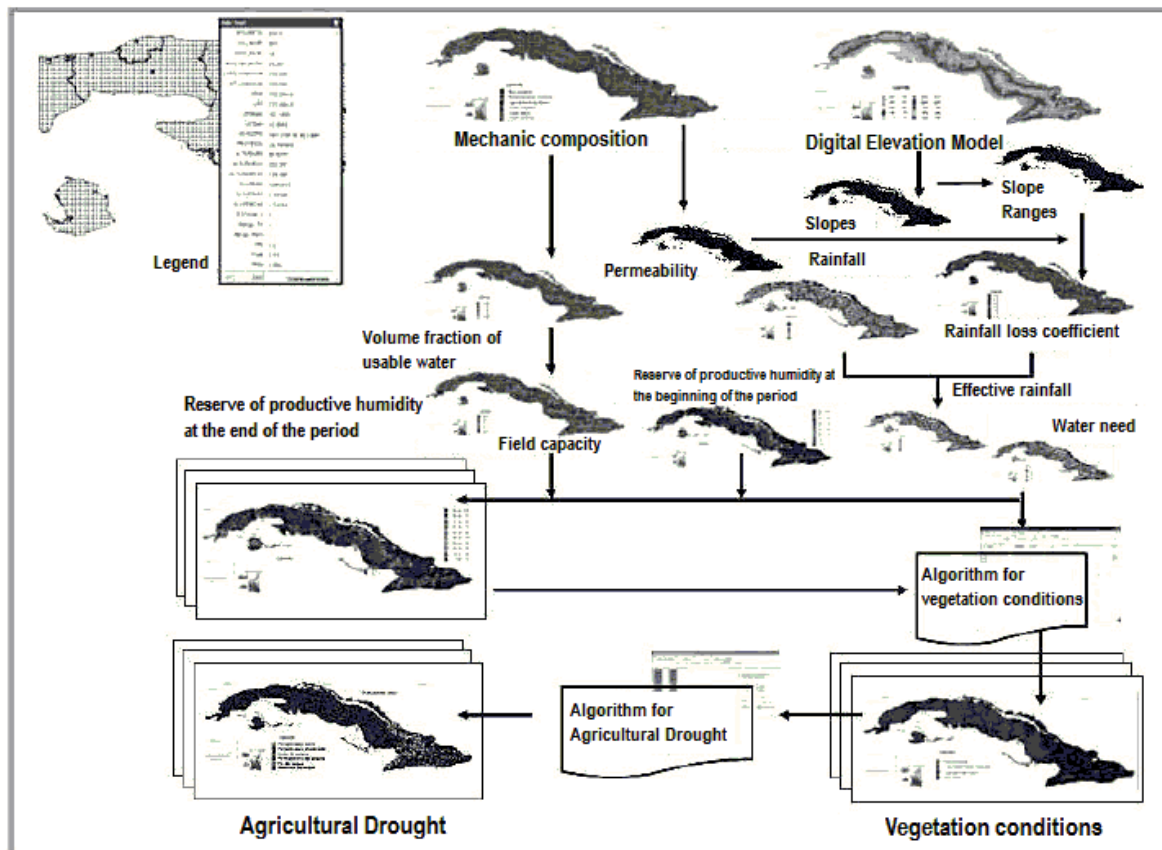


Figure 4.4: Arrangement of operations performed to assess agricultural drought using GIS. (Source: Cuban Center for Agricultural Meteorology, INSMET).

The Combined Agricultural Drought Index (CADI) is the multiplication of scores given by classifying the status of agricultural drought (SAD) and its intensity. SAD is reclassified into four levels in order to compose the CADI, as follows:

- **Absence of agricultural drought (0):** groups categories 5 and 6.
- **Low agricultural drought (1):** groups categories 1 and 2.
- **Moderate agricultural drought (2):** Category 3 or beginning of the agricultural drought is taken into account, comprising the dry period that has kept vegetation subjected to moderate or severe water stress for a period of up to five decades after the start of ground water depletion.
- **High agricultural drought (3):** it is assumed that category 4 is the most important, because it indicates the establishment of agricultural drought, i.e. vegetation has remained subject to moderate or severe water stress, for a period greater than or equal to six decades after the start of soil water depletion.

**Table 4.2** shows the score matrix for the proposed analysis in the case of agricultural drought. The evaluation is done by multiplying the values that determine the quality of both status and intensity of agricultural drought.

**TABLE 4.2: SCORE MATRIX FOR THE PROPOSED COMPILING OF CADI ACCORDING TO THE ANALYSIS OF AGRICULTURAL DROUGHT (AD) STATUS AND INTENSITY**

		Absence / End of AD	SDP / MDP	SAD	PAD
		Absence (0)	Low AD (1)	Moderate AD (2)	High AD (3)
			1	2	3
Very light (1)	1			2	3
Light (2)	2			4	6
Moderate (3)	3			6	9
Severe (4)	4			8	12
Very severe (5)	5			10	15

This gives us a matrix of results with a route from 2 to 15. The absence category is not analyzed; it is assumed that there is no presence of water stress. Nor are taken into account the periods classified as low agricultural drought. This is due to the fact that in a preceding period of up to 12 decades, water stress repetitions that may arise would never be consecutively enough to begin a process of agricultural drought. Within 12 previous decades, water stress may arise in up to 9 decades, but if they have alternate wet periods, that would facilitate the recovery of vegetation and drought would not start.

In a diagonal analysis of the proposed table, it becomes evident the increasing severity and hazard of the studied phenomenon. The hazard posed by the presence of agricultural drought is expressed by the calculation of tertiles, to divide the route of scores into three groups (**Table 4.3**).

Categories ICSA	Nomenclature
	Absence (0)
CADI = 2, 3 or 4	Low Hazard of Agricultural Drought (1)
CADI = 6, 8 or 9	Moderate Hazard of Agricultural Drought (2)
CADI = 12, 10 or 15	High Hazard of Agricultural Drought (3)

The representation based on categories is done, first, to provide greater overview of the hazard that the phenomenon represents naturally, and secondly to facilitate linking integrated hazard analysis with meteorological drought.

**4.2.2 PROCESS OF COMBINING THE CATEGORIES OF BOTH HAZARDS**

Regarding the components of meteorological and agricultural drought, the experience and the equations of fluid balance showed that in the dry season there is agricultural drought, even if there is no meteorological drought, and in the rainy season there may be meteorological drought without agricultural drought, being stronger the relation between the two types when the meteorological drought is severe and prolonged (Rivero *et al.*, (1999)). This contributes to justify integrated assessment of both types.

After conducting the standard runs of meteorological and agricultural drought historical indices in the corresponding Early Warning Systems and including them in the database, the integrated index is obtained by procedures stored within this database, programmed in SQL Server, as regulated.

As described above, to obtain the “Integrated Hazard” the scores of each drought hazard (meteorological and agricultural) were previously categorized, in each month of the common time period analyzed and using the same standard reference, corresponding to the following rating:

- |                                |   |
|--------------------------------|---|
| <b>AS [without hazard (0)]</b> | <b>W [weak hazard (1)]</b>              |
| <b>M [moderate hazard (2)]</b> | <b>S [severe or extreme hazard (3)]</b> |

Once opened the possibility of advancing the process of integrating both hazards, then it follows to recategorize each month, on the basis of combining the categories obtained using the 16 possible combinations that can be made (Table 4.4).

In each combination, the categories of both hazards are added, and it turned out that for all possibilities, the magnitudes of the sum were between 0 and 6, which allows advancing to the new scale of “Integrated Category” that is expressed as follows:

- |                          |                       |             |
|--------------------------|-----------------------|-------------|
| <b>Absence of Hazard</b> | $\sum$ <b>0</b>       | <b>...0</b> |
| <b>Weak Hazard</b>       | $\sum$ <b>1 and 2</b> | <b>...1</b> |
| <b>Moderate Hazard</b>   | $\sum$ <b>3 and 4</b> | <b>...2</b> |
| <b>Severe Hazard</b>     | $\sum$ <b>5 and 6</b> | <b>...3</b> |

**TABLE 4.4: PROCEDURE FOR THE CATEGORIZATION OF “INTEGRATED DROUGHT HAZARD”**

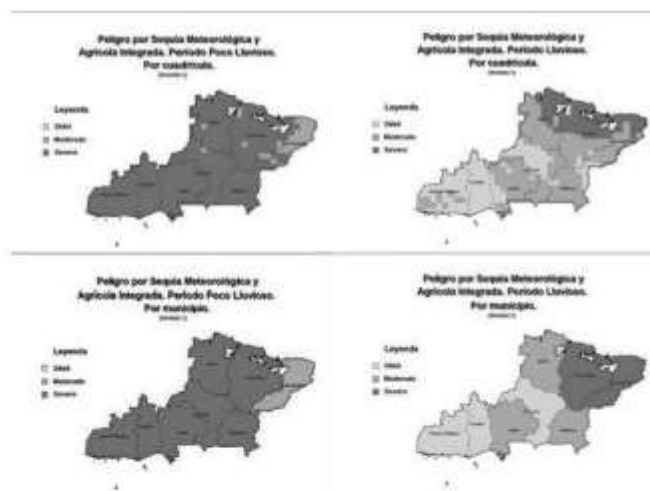
MDH	ADH	$\Sigma$ Category	Integrated Category	Integrated Category	New Integrated Category
A (0)	A (0)	0	0	Absence	
A (0)	W (1)	1	1	Weak	0 Absence
A (0)	M (2)	2	2	Weak	1 Weak
A (0)	S (3)	3	3	Moderate	2 Moderate
W (1)	A (0)	1	4	Moderate	3 Severe
W (1)	W (1)	2	5	Severe	
W (1)	M (2)	3	6	Severe	
W (1)	S (3)	4			
M (2)	A (0)	2			
M (2)	W (1)	3			
M (2)	M (2)	4			
M (2)	S (3)	5			
S (3)	A (0)	3			
S (3)	W (1)	4			
S (3)	M (2)	5			
S (3)	S (3)	6			

MDH - Meteorological Drought Hazard / ADH - Agricultural Drought Hazard / A - Absence of Drought  
 Weak drought - (W - 1 point) / Moderate - (M - 2 points) / Severa - (S - 3 points)

$\Sigma$  both categories (reaching from 1 to 6 points) / New integrated category: 1 to 6 points

Integrated Category: Absence (0 points), Weak (1 and 2 points), Moderate (3 and 4 points) and Severe (5 and 6 points).

If there is an extensive historical series of Integrated Hazard monthly values from a rainfall gauge or grouping that represents certain area, it is possible to assess the seasonal behavior of the series. Similarly, if there is a network of gauges with the necessary spatial density and temporal extent, or a properly prepared rainfall grid and with these same attributes, maps for any time period and desired work surface can be prepared (country, region, municipality, town).



Examples of integrated hazard maps for meteorological and agricultural drought for rainy and dry seasons for Las Tunas province are shown on the left.

**Calculation of the hydrological drought hazard**

Hydrological drought occurs when the availability of stored water does not guarantee the annual pace of deliveries to surface and underground sources of a hydrological territory and / or hydraulic system.

**Figure 4.5:** Maps of integrated drought for rainy and dry season: a) by grid, b) by municipality in Las Tunas province, Cuba. (Source: Cuban Center for Agricultural Meteorology, INSMET)

\* The value scale indicates the severity of the drought.

As key indicators for hydrological drought hazard assessment are considered the characteristic and critical levels of both surface sources (reservoirs) and groundwater, as well as the historical exploitation of these sources. The analysis of the period under review is also very important.

Whereas the assessment, from the statistical point of view of information on the status of supply sources, both spatial and temporal, depends not only on the behavior of climate factors, but also the behavior of water demand, three key elements is considered for each analyzed municipality for the quantitative assessment of hydrological drought hazard: the amount of supply sources associated with the territory; volume of water provided by each source and number of times each source did not satisfy demand (failure) in the period of analysis, which is identified as volumes or levels below the respective threshold values.

According to available information, a computerized database will be created using spreadsheets and database management system, containing time series at provincial level with the following data: surface and groundwater sources, volume percentage, failure rate, number of sources per municipality for the province.

In order to reconcile the quantities of each of these elements, it was used as an index of volume ( $V_o$ ) the percentage of the total volume representing the volume provided by each source; and as failure rate ( $Fa$ ), the percentage of the total number of observations, that represents the number of failures from each source.

Determining the Hazard Index ( $I_p$ ) of hydrological drought is based on the multiplication of the weighted failure ( $Fap$ ) by the source index ( $Fu$ ).

$$I_p = Fap * Fu$$

Given that for each country there is the possibility of having more than one source, a single failure index ( $Fap$ ) was defined for the territory, from the weighting of failure percentage, based on the percentage of volume.

$$Fap = \frac{\sum_{i=1}^{i=n} V o_i \times F a_i}{\sum_{i=1}^{i=n} V o_i}$$

Where:

$n$  — is the number of sources associated with the municipality

The source index ( $Fu$ ) is defined in terms of the amount of associated sources.

Amount of sources	Source index
1	1.0
2	0.8
3-4	0.6
More than 4	0.4



Finally, the obtained hazard index values are classified as follows:

Hazard index ( $I_p$ )	Classification
0.0	Without hazard
0.1 – 10.0	Low
10.1 – 50.0	Medium
50.1 – 100.0	High

Likewise, the weighted hazard index of municipalities is calculated; these may be weighted based on the area for obtaining a hazard index for the zones (HIZ) ( $I_{pz}$ ).

$$I_{pz} = \frac{\sum_{i=1}^{i=n} Fap_i \times A_i}{\sum_{i=1}^{i=n} A_i}$$

For hazard mapping, the geodatabase is exported to GIS. For the preparation of maps of hydrological drought hazard, a qualitative background thematic map is generated to differentiate 3 hazard categories: green for low, yellow for medium and red for high (Figure 4.6 b).



Figure 4.6: Hazard map; a) Hydraulic Drought, b) Management of hydrological drought hazard, for Las Tunas province.

### 4.3 VULNERABILITY CALCULATION

Once the estimation of meteorological, agricultural and hydraulic hazards is done, vulnerability will be assessed, taking into account the exposed elements in drought hazard zones.

Total vulnerability assessment is based on various exposure factors and the relative importance of each type of vulnerability, and it is calculated by the following expression:

$$Vul_{total} = p1 * Vul_{soc} + p2 * Vul_{noestr} + p3 * Vul_{func} + p4 * Vul_{econ} + p5 * Vul_{ecol}$$



Where

$Vul_{total}$  — total vulnerability

$Vul_{soc}$  — social vulnerability

$Vul_{noestr}$  — nonstructural vulnerability

$Vul_{func}$  — functional vulnerability

$Vul_{econ}$  — economic vulnerability

$Vul_{ecol}$  — ecological vulnerability

$p1... p5$  — are the weights corresponding to each vulnerability

**Table 4.5** lists each of the criteria or dimensions of vulnerability (level 2). At levels 3 and 4, sub-criteria that enable the achievement of each dimension are identified; and finally, at level 5, more disaggregated categories or indicators are determined for measuring vulnerability. Thus, it was identified a hierarchical evaluation system starting from the evaluation of these indicators and successive combinations to assess the overall vulnerability to drought in each territory. Besides identifying the elements for each stratum, the instruction also quantifies each criterion, variables, indicators and attributes at each level of the hierarchical structure.

Weights are organized so that their sum is 1 within the same level and the same group of indicators.

The hierarchy of vulnerability indicators, its standardization and assigning weights allows a more coherent analysis of these indicators and makes it possible to recognize the causes of vulnerability for a given territory.

Vulnerability information for each of the five dimensions will be provided at municipal level, as territorial unit for the output of the studies.

In general, the baseline information required for the vulnerability calculation depends on the cooperation and involvement of institutions and sectors accountable for each (Housing, Health Care, Education, Physical Planning, Civil Defense, Water Resources, Agriculture), and in particularly municipal and local governments, who bring their own integrated approach and have experiences on coping with drought events.

To perform vulnerability calculations it is recommended to collect the information using charts in Excel format, designed as a template to allow calculating all vulnerability indicators at all levels, including total vulnerability.

Each vulnerability indicator is defined below and it is explained how to calculate it. Vulnerability causes and situation in the territory are known from the analysis of each indicator.

TABLE 4.5: VULNERABILITY HIERARCHY AND INDICATORS WITH WEIGHTS PER LEVEL

Level 1	Level 2	Weights	Level 3	Weights	Level 4	Weights		
TOTAL VULNERABILITY	Social	0.435	Population	0.731	Exposed population	0.500		
			Stress (additional pressures)	0.188	Demand	0.300		
					Dependency	0.200		
	Non-structural	0.259	Drought perception	0.081	Social disadvantage	0.560		
					Sanitation	0.440		
			Hydraulic facilities	0.507	Surface	0.550		
					Underground	0.450		
			Quality in aquifers	0.303				
			Real water supply	0.148				
			Hydroelectric systems	0.042				
			Water reservoirs	0.414				
			Functional	0,165	Physical access	0.360		
							Plan of disaster reduction measures	0.120
	Health-care system	0.106						
	Economic	0.106	Sensitivity	0.637	Preparedness			
					Agriculture	0.530		
					Industry	0.258		
					Livestock farming	0.146		
					Other activities	0.066		
	Ecological	0.035	Compatible land use	0.258				
Disaster reduction budget					0.105			
Sensitivity to fires			0.500					
				Protected Areas	0.300			
Sensitive zones			0.200					

#### 4.3.1 SOCIAL VULNERABILITY

This dimension or criterion assesses the extent to which social factors can increase vulnerability, considering the exposed population, the additional stresses to which the population can be subjected, and population’s perception of drought. The three variables identified for assessing this dimension are **Population**, **Stress** and drought **Perception**. The formula for this calculation is shown below.

$$Vul_{soc} = 0,731 * Vul_{pobl} + 0,188 * Vul_{estrés} + 0,081 * Vul_{perc}$$

## POPULATION

Population was considered the most important variable to measure vulnerability in case of prolonged exposure to drought variable. In this variable, three indicators were identified, **Demand for potable water**, **Food dependency** and **Exposed population** and it is calculated:

$$Vul_{pobl} = 0,300 * Vul_{dem} + 0,200 * Vul_{dep} + 0,500 * Vul_{pobexp}$$

Where

$Vul_{pobl}$  — is the total vulnerability of the population

$Vul_{dem}$  — is the vulnerability of unmet demand for potable water

$Vul_{dep}$  — is the vulnerability of local food dependency

$Vul_{pobexp}$  — is the vulnerability of exposed population, according to size of municipality

The **demand for potable water** reflects the estimated percent of the population that does not receive potable water regularly from aquifers or reservoirs, and it is calculated according to the following formula:

$$Vul_{dem} = 1 - \frac{\%demandacub}{100}$$

Where

$Vul_{dem}$  — is the vulnerability by unmet demand for potable water

$\%demandacub$  — percent of potable water demand served or covered

**Food dependency** refers to the amount of population depending on local food production or food self-sufficiency, with respect to total population of the municipality, and it is evaluated according to the classification in **Table 4.6** and related formula. These productions may be severely limited in the event of a prolonged drought event affecting living conditions and will require some kind of response.

Population with	$P_i$ Weight
Self-sufficiency / Local supply	1.00
External supply	0.50

$$Vul_{dep} = \frac{\sum_{i=1}^n P_i * Pobl_{abast_i}}{Pobl_{abast}}$$



Figure 4.7: Water tanks and potable water supplied by tanker trucks in cities to placate drought. Source: IPS Cuba

Where

$P_i$  — weight depending on the type of supply

$Pobl_{abast}_i$  — amount of population for which  $i$  type of supply predominates

$Pobl_{abast}$  — resulting total population in the municipality

The exposed population is measured by the population size of the municipality being analyzed. **Table 4.7** shows the classification of the population corresponding to municipality size and the weight it is assigned.

Municipality size	Population Range	$P_i$ Weight
Very large	$\geq 100,000$ inhabitants	1.000
Large	$\geq 60,000$ and $< 100,000$	0.500
Medium	$\geq 30,000$ and $< 60,000$	0.333
Small	$< 30,000$ inhabitants	0.250

To calculate vulnerability, it is carried out the pondering of the size with the weight corresponding to the range according to the following formula:

$$Vul_{pobexp} = \sum_{i=1}^n P_i * T_{mun}$$

Where

$P_i$  — weights depending on the size of the municipality  $i$

$T_{mun}$  — size of municipality  $i$

### STRESS (ADDITIONAL PRESSURES)

In various municipalities there are groups of people who are affected by some social disadvantage, and if the country suffers a severe drought event, these groups will be subject to a reinforcement of that tension. Two indicators were identified and the evaluation of this variable is done with the following function:

$$Vul_{estrés} = 0,560 * Vul_{desv} + 0,440 * Vul_{saneam}$$

Where

$Vul_{estrés}$  — Vulnerability due to additional stressful situations

$Vul_{desv}$  — Vulnerability by presence of social disadvantage

$Vul_{saneam}$  — Vulnerability by sanitation status

**Social disadvantage** refers to situations that affect the adaptation capacity of households (Table 4.8), such as families composed of elderly people living alone, a situation that tends to worsen with the demographic perspective worldwide; women heads of single-parent households; also families that have disabled members with varying severity, and cases where there is a combination of at least two of these disadvantages.

Types of disadvantages	$P_i$ Weight
Women heads of single-parent households	0.350
Elderly people living alone	0.500
Disabled people	0.250
Combination of disadvantages	1.000

The vulnerability by social disadvantage is calculated according to the following formula:

$$Vul_{desv} = \frac{\sum_{i=1}^n P_i * CantNucl_i}{CantNucl}$$

Where

$Vul_{desv}$  — vulnerability due to social disadvantage

$P_i$  — weighting for the situation of disadvantage  $i$  according to type of household

$CantNucl_i$  — number of households with disadvantaged situation  $i$

$CantNucl$  — number of households in the municipality

The **sanitation** variable refers to concentrated settlements (urban and rural) without stable solutions for solid and liquid waste, excluding areas or territories with dispersed population. The actual existence of recycling systems together with the presence of the official activity of collecting garbage, including its transfer and final disposal in landfills, are recognized as “stable solutions” in the case of solid waste; and for liquid waste: the existence of sewage, septic tanks, latrines and collectors.

A settlement with a different solution to those described, or not having any, qualifies as “without stable solution”, according to Table 4.9, and the following equation is used:

$$Vul_{saneam} = \sum_{i=1}^n \frac{CantAsenti}{CantAsent} * P_i$$

Where

$Vul_{saneam}$  — vulnerability due to lack of stable sanitation solutions

$CantAsenti_i$  — number of settlements without stable sanitation solution of type  $i$

$CantAsent$  — amount of settlements concentrated in the municipality

$P_i$  — is the weighting for the lack of stable sanitation solution  $i$

TABLE 4.9: CLASSIFICATION OF SANITATION	
Settlements without stable solution for	$P_i$ Weight
Solid waste	0.450
Liquid waste	0.550

### DROUGHT PERCEPTION

Studies on hazard perception provide, from a quantitative perspective, the general idea of the population about the hazard, through their judgments and assessments in recognizing the hazard, knowledge of the factors involved, evolution, preparedness, critical capacity on the performance of people before, during and after the event, on hazard impacts, levels of confidence on the institutions and organizations responsible for coping with hazard impacts, proactive capacity to prevent and minimize the negative effects of this hazard.

The characterization of these perceptions and the determination of groups by perception levels: appropriate, insufficient and erroneous or null, makes possible their inclusion in the component of social vulnerability at municipal scale, as shown in **Table 4.10** using the following equation:

$$Vul_{perc} = \frac{\sum_{i=1}^n P_i * CantGrupo_i}{Tmuestra}$$

Where

$Vul_{perc}$  — Vulnerability due to degree of drought perception

$P_i$  — weighting for the degree  $i$  of perception

$CantGrupo_i$  — number of interviewed people who classified in the type  $i$  of perception and that should be added in  $Tsample$

$Tsample$  — Total number of persons interviewed in the municipality (sample size)

TABLE 4.10: CLASSIFICATION OF PERCEPTION	
Perception	$P_i$ Weight
Adequate (group A)	0.333
Insufficient (group B)	0.500
Erroneous or null (group C)	1.000

### 4.3.2 NONSTRUCTURAL VULNERABILITY

Nonstructural vulnerability is linked to those facilities that provide service to the territory, which may lose functionality due to a prolonged drought event. As such were identified exploitable surface and underground water resources, the quality of water in aquifers, potable water delivery systems and hydroelectric systems through the following formula:

$$Vul_{noestr} = 0,148 * Vul_{abasto} + 0,507 * Vul_{instal} + 0,042 * Vul_{sisth} + 0,303 * Vul_{calid}$$

### REAL WATER SUPPLY

The classification in **Table 4.11** is used to evaluate the ease of access to the actual potable water supply. Household connection includes both intra-household and extra-household types, which are characteristic of urban areas; easy access means that the transfer is done by carrying water up to distances of 300 meters from the housing, both in urban and rural areas; while public service refers to the delivery of water through vehicles, such as tanker trucks.

TABLE 4.11: CLASSIFICATION OF THE FORMS OF SUPPLY	
Housings with supply by	$P_i$ Weight
Household connection	0.250
Easy access	0.500
Public service	0.500
Inadequate or unknown forms	1.000

In the rest of the houses that do not have these services, their dwellers do not have appropriate access to the resource. Actually existing water supply is evaluated with the following formula:

$$Vul_{abasto} = \frac{\sum_{i=1}^n P_i * NroViv_i}{VivTot}$$

Where

$Vul_{abasto}$  — Vulnerability due to access to potable water supply

$P_i$  — weighting for the type  $i$  of access to potable water supply

$NroViv_i$  — number of housings with type  $i$  of access to potable water supply

$VivTot$  — Total number of housings in the municipality

### WATER SUPPLY FACILITIES

This vulnerability refers to facilities related to surface and groundwater supply sources, for each of which an indicator is created. The facilities that are taken into account are those for which drought may affect in the reduction and / or cessation of water extraction. Evaluated facilities are those that provide service to the municipality; calculations are made according to the following equation:

$$Vul_{instal} = 0,550 * Vul_{sup} + 0,450 * Vul_{sub}$$

For **surface sources** are considered those shown in **Table 4.12**, accompanied by their respective weights; this indicator is calculated using the following formula:

$$Vul_{sup} = \frac{\sum_{i=1}^n P_i * Tipofuente_i}{Tipofuente}$$

Where

$Vul_{sup}$  — vulnerability of surface supply sources

$P_i$  — weighting for the type  $i$  of surface source

$Tipofuente_i$  — amount of surface source of type  $i$

$Tipofuente$  — amount of surface sources in the municipality

Type of supply sources	$P_i$ Weight
Available dams	0.250
Available micro-dams	0.500
Rivers with historical delivery	1.000
Canals	0.330

For **groundwater sources** are considered those shown in **Table 4.13**, accompanied by their respective weights. For the assessment of vulnerability by groundwater sources, an equation similar to that of surface sources is used.

$$Vul_{sub} = \frac{\sum_{i=1}^n P_i * Tipofuente_i}{Tipofuente}$$

Where

$Vul_{sub}$  — Vulnerability of groundwater supply sources

$P_i$  — weighting for the type  $i$  of groundwater sources

$Tipofuente_i$  — amount of groundwater source of type  $i$

$i Tipofuente$  — amount of groundwater sources in the municipality

Type of supply sources	$P_i$ Weight
Exploitable aquifers	0.500
Individual wells	1.000



## HYDROELECTRICITY SYSTEMS

With this variable, it is estimated the number of homes that rely on mini-hydroelectric plants to generate electricity and are independent of the National Electric Grid (NEG), which are considered more vulnerable, because they can be without electricity service in case of a severe drought.

Vulnerability in this area is evaluated by estimating proportion of households depending on mini-hydroelectric systems in the municipality.

The estimated percent of non-dependent housings is determined and the inverse proportion is calculated. The value corresponding to the proportion of number of dependent housings is calculated with the following formula:

$$Vul_{depend} = 1 - \frac{\%nodedependientes}{100}$$

Where

$Vul_{depend}$  — vulnerability due to the number of homes depending on mini-hydroelectric plants for power generation

$\%nodedependientes$  — estimated percent of housings not depending on mini-hydroelectric plants for power generation.

## WATER QUALITY IN AQUIFERS

The quality of water in aquifers is recorded from records kept by institutions that manage water resources, through a network of observation points in the territories, to assess the status of basins and restrict extraction if necessary. The different situations of interest are shown in **Table 4.14** with their corresponding weights; the category “No criterion” refers to the absence of criteria for assessing the possible effects on the quality and value with the following equation:

$$Vul_{calid} = \frac{\sum_{i=1}^n P_i * Nropuntos_i}{PuntosTot}$$

Where

$Vul_{calid}$  — vulnerability due to pollution at sources

$P_i$  — weighting for the type  $i$  of pollution

$Nropuntos_i$  — number of observation points reporting type  $i$  of pollution

$PuntosTot$  — number of observation points in the municipality

Causes of pollution	$P_i$ Weight
Overexploitation	1.000
Natural saltwater intrusion	0.500
Proximity to polluting sources	0.333
No criterion	0.250

### 4.3.3 FUNCTIONAL VULNERABILITY

This type of vulnerability refers to the municipality's response capacity to face a drought event. For this, it is considered the type of water reservoirs, physical access to settlements, measures in the disaster reduction plan to cope with drought, and preparedness of the health-care system existing in the municipality. This vulnerability is evaluated with the following equation:

$$Vul_{func} = 0,120 * Vul_{plan} + 0,414 * Vul_{almac} + 0,106 * Vul_{salud} + 0,360 * Vul_{accf}$$

### COPING WITH DROUGHT

Coping with drought is measured from the existence of preventive measures within the disaster reduction plan of the territory. To calculate this vulnerability, the corresponding category is classified as expressed in **Table 4.15**. A weight is assigned according to the option that best characterizes the situation in the municipality. It is evaluated through following equation:

$$Vul_{plan} = \sum_{i=1}^n P_i * Cplan_i$$

Where

$P_i$  — is the weight for the  $i$  type of the specified category in disaster reduction

$Cplan_i$  — is the situation  $i$  in the disaster reduction plan

Disaster reduction	$P_i$ Weight
Plan without measures	0.500
Plan with measures	0.330
Without reduction plan	1.000

### WATER STORAGE

In a situation of discontinuous water distribution, the population needs to have the possibility of accumulating it to satisfy their needs. According to **Table 4.16**, three alternatives are evaluated for settlements (urban, rural and dispersed) that can be affected in the municipality: collective or individual solutions by tanks or cisterns and nonexistence of solution.

Storage	$P_i$ Weight
Collective	0.500
Individuals	0.333
No solution	1.000

As regards **collective** forms of storage, it should be considered the number of settlements where this way to ensure water supply predominates, regardless of the means (tanks, cisterns, etc.); as for the **individual** form, it should be taken into account the number of settlements where a solution of a particular type predominates. When the settlement (concentrated or dispersed) has no way to guarantee water storage, it is considered **unsolvable**, for example, in extreme situations when temporarily water is served by tanker trucks, and the population of the settlement does not have any means of storage, a situation that results in neither having a safe water source for the population, nor having solved the problem with the shape of distribution adopted.

It is calculated according to the formula:

$$Vul_{almac} = \frac{\sum_{i=1}^n P_i * NroAsenti}{AsenTot}$$

Where

$Vul_{almac}$  — vulnerability due to the predominant form of storage

$P_i$  — weighting for the  $i$  form according to the specified category

$NroAsenti_i$  — is the number of settlements where the  $i$  form of storage predominates

$AsenTot$  — total of concentrated and dispersed settlements in the municipality

### HEALTH-CARE SYSTEM

Vulnerability in this area is assessed by estimating the proportion of preparedness to reach in the municipality to face drought events. Criteria from other sectors in the municipality should be managed, and not only municipal health-care structures, so that it is possible assess whether or not the welfare service is guaranteed, despite drought; this enables a more complete view of the problem.

From the estimated percent of preparedness guaranteed by the health-care system to face a drought event, the inverse proportion is calculated. The value corresponding to the proportion of non preparedness is calculated with the following formula:

$$Vul_{prep} = 1 - \frac{\%preparedness}{100}$$

Where

$Vul_{prep}$  — vulnerability due to lack of preparedness in the health-care system to respond to a drought event

$\%preparedness$  — percent of preparedness of the health-care system to respond to a drought event

#### PHYSICAL ACCESS

Having easy access to settlements is very convenient for the dynamics of everyday life, and to ensure that water will be carried by vehicles, when necessary; it also facilitates other tasks, like possible evacuations and transfer of patients to health-care centers. The starting point is the connection provided by the network of highways, roads, dirt roads and others existing in the territories. On the other hand, given the concentration of population in urban and rural settlements, it becomes more viable to provide response in extreme drought conditions. For the classification, the number of areas with significant presence of dispersed population in the municipality is counted as shown in **Table 4.17** and using the following equation.

$$Vul_{acef} = \frac{\sum_{i=1}^n P_i * NroAsent_i}{AsentTot}$$

Where

$Vul_{acef}$  — vulnerability according to physical access to settlements

$P_i$  — weighting for the  $i$  type of physical access

$NroAsent_i$  — number of settlements of  $i$  type, or areas of scattered settlement

$AsentTot$  — total amount of settlements and sparsely populated areas

Acceso físico	$P_i$ Weight
Urban settlements	0.333
Rurales settelements	0.500
Zones with dispersed population	1.000

#### 4.3.4 ECONOMIC VULNERABILITY

Economic vulnerability identifies, evaluates and differentiates the effect of drought in the productive activities developed in the territory, which are affected or interrupted in various ways when facing severe events, thus impacting on the economic life and consumption of the territory's inhabitants.

This vulnerability has been identified by the variables **Sensitivity to drought**, **Compatible land use** and **Disaster reduction budget**, and it is calculated as follows:

$$Vul_{econ} = 0,637 * Vul_{sensib} + 0,105 * Vul_{presup} + 0,258 * Vul_{usoc}$$

## SENSITIVITY TO DROUGHT

The sensitivity to drought includes the generic term **activities** to delimit the sphere of productive activity related to industry, agriculture, livestock farming, and others, such as aquaculture and apiculture, all them sensitive to a severe drought. The vulnerability by sensitivity to drought in the municipality is measured by the following equation:

$$Vul_{sensib} = 0,258 * Vul + 0,530 * Vul + 0,146 * Vul + 0,066 * Vul$$

As for vulnerability by **Industry**, the classification given in **Table 4.18** should be taken into account, according to the level of water consumption in their respective productions. Not being possible to obtain accurate information, it is proposed as a reference the following: **High consumers**: sugar mills, slaughterhouses, activities related to dairy industry, processing of food and meat products, textile and paper production, leather processing, processing of citrus fruits, yeast plants, production of bagasse boards, oil refineries and its derivatives, thermoelectric plants. **Medium consumers**: Cannery, factory of refractory materials, bottle factory, plaster plants, marble production. **Low consumers**: Towel factory, ice cream factory, packaging plants, sack-producing plants, sawmills; factories of asbestos cement, ceramics and clay pipes.

This list of industries is not exhaustive and there could be other facilities not mentioned, so it is recommended to investigate the territory to gain in precision.

Industrial activities	$P_i$ Weight
High water consumers	1.000
Medium water consumers	0.500
Low water consumers	0.333

$$Vul_{ActI} = \frac{\sum_{i=1}^n P_i * CantActI_i}{TotalAct}$$

Where

$Vul_{ActI}$  — vulnerability due to industrial activities

$P_i$  — weighting for each level of water consumption in industrial activities

$CantActI_i$  — number of industries with  $i$  level of water consumption

$TotalAct$  — total number of industries in the municipality

Vulnerability in **agricultural activities** is given by the surface in km<sup>2</sup> in each category in **Table 4.19** and is measured by the following equation:

$$Vul_{ActA} = \frac{\sum_{i=1}^n P_i * CantActA_i}{TotalAct}$$

Where

$Vul_{ActA}$  — vulnerability due to agricultural activities

$P_i$  — weighting for each  $i$  type of surface in agricultural activities

$CantActA_i$  — crop area in each category

$TotalAct$  — total crop area of the municipality

Agricultural activities	$P_i$ Weight
Surface of unirrigated crops	1.000
Continuous irrigated surfaces	0.500
Non-continuous surface with irrigation	0.333

To determine vulnerability by **livestock farming activities**, the number of cattle heads is taken into account according to **Table 4.20** and by the following equation.

$$Vul_{ActG} = \frac{\sum_{i=1}^n P_i * CantActG_i}{TotalAct}$$

Where

$Vul_{ActG}$  — vulnerability due to livestock farming activities

$P_i$  — weighting for each  $i$  type of livestock

$CantActG_i$  — number of cattle heads in each category

$TotalAct$  — total number of cattle heads per type of livestock in the municipality

Livestock farming activities	$P_i$ Weight
Bovine cattle, horses and mules	1.000
Sheep, goats and pigs	0.500

In **other productive activities**, vulnerability is given by the volume of production according to the classification in **Table 4.21** and by the following equation.

$$Vul_{ActO} = \frac{\sum_{i=1}^n P_i * CantActO_i}{TotalAct}$$

Where

$Vul_{ActO}$  — vulnerability due to other productive activities

$P_i$  — weighting for each  $i$  type of activity

$CantActO_i$  — amount of tons produced in each category

$TotalAct$  — total amount of other productive activities in the municipality

Other activities	$P_i$ Weight
Aquaculture	0.600
Apiculture	1.000

### DISASTER REDUCTION BUDGET

The budget for disaster reduction should be considered in certain sectors of the economy, such as local structures for agriculture, water management and governments.

Vulnerability by non-execution is calculated from budget implementation percent according to the following expression:

$$Vul_{ejecuc} = 1 - \frac{\%ejecución}{100}$$

Where

$Vul_{ejecuc}$  — vulnerability due to non-implementation of the disaster reduction budget

$\%ejecución$  — estimated proportion of implementation of disaster reduction budget

### COMPATIBLE LAND USE IN FOOD CROPS

This variable measures the compatibility between land use and potential of cultivated soil only for the following food crops: rice, various crops, banana, citrus and other fruits. The greater the incompatibility, the lower yields are, and drought tends to worsen this situation. Data and / or maps of agricultural productivity by crop should be consulted to find the relationship between soil suitability and land use.

From the estimated percent of the total area of compatible food crops in the municipality, the value of the non-compatible proportion is calculated as follows:

$$Vul_{usoc} = 1 - \frac{\%usosueloc}{100}$$

Where

$Vul_{usoc}$  — vulnerability due to non-compatibility between land use and cultivated soil potential

$\%usosueloc$  — estimated proportion of compatibility between land use and cultivated soil potential

#### 4.3.5 ECOLOGICAL VULNERABILITY

This type of vulnerability evaluates the expected impact that results from a severe drought in certain fragile ecosystems, where it can have a unique behavior, according to adaptive capacities.

Three variables are identified: Sensitive wetland zones, Categorized protected areas and Sensitivity to natural and human-induced fires; the first two may or may not be present in the municipality and the third can be declared binding.

In those municipalities where the wetland surface is also a categorized protected area, they should be reported only as the latter to avoid data duplication. This vulnerability is calculated with the following expression:

$$Vul_{ecol} = 0,200 * Vul_{zsensib} + 0,300 * Vul_{areap} + 0,500 * Vul_{incend}$$

#### SENSITIVE WETLAND AREAS

Only the effects on fragile ecosystems of wetland type are considered; this category includes: swamps, temporarily flooded zones within the municipality (lagoons in karst Dolinas) and temporary waterlogging crops (rice). This vulnerability is evaluated as:

$$Vul_{zsensib} = \frac{Areahum}{Areamun}$$

Where

$Vul_{zsensib}$  — vulnerability due to potential impact on wetlands in the municipality

$Areahum$  — wetland area

$Areamun$  — area of the municipality

#### CATEGORIZED PROTECTED AREAS

Only categorized protected areas are considered, since they mean certain use restriction and a higher rating of ecosystems present in these areas. For this, you should take into account the classification of National Protected Area System, and other international categories, such as Biosphere Reserve and RAMSAR sites.

$$Vul_{areap} = \frac{Areaproteg}{Areamun}$$



Where

$Vul_{areap}$  — potential vulnerability due to the impact on protected areas in the municipality

$Areaproteg$  — area of the protected area

$Areamun$  — area of the municipality

#### **SENSITIVITY TO FIRE OF NATURAL AND HUMAN-INDUCED ORIGIN**

Besides forest fires (historically shown), this variable also includes those that occur in sugarcane crops and pastures, associated with worsening conditions of humidity in extreme drought. As it is very difficult to establish the cause of fire, and drought is only conducive to more favorable conditions to unleashing fires, experts must assess historical fire reports to know which are linked to extreme and enabling conditions for their occurrence. It is calculated using the formula:

$$Vul_{incend} = \frac{Areasensible}{Areamun}$$

Where

$Vul_{incend}$  — vulnerability due to fires of natural and human-induced origin

$Areasensible$  — area of forest, pasture and sugarcane crops sensitive to fire

$Areamun$  — area of the municipality

#### **4.3.6 TOTAL VULNERABILITY**

The overall vulnerability for each municipality is the result of contributions from partial vulnerabilities, evaluated and pondered by their weight as shown below:

$$Vul_{total} = 0,435 * Vul_{soc} + 0,259 * Vul_{noestr} + 0,165 * Vul_{func} + 0,106 * Vul_{econ} + ,035 * Vul_{ecol}$$

This is the integrated vulnerability calculated for a municipality from the sum of the different types of vulnerabilities, weighted by the varying degrees of importance within each dimension. The resulting value is bounded on a continuous scale between 0 and 1.

Appropriate ranges should be established to qualify vulnerability, for this it is recommended to apply a method of bivariate classification, based on the values of quartiles, which divides the list of vulnerability values of municipalities into four groups (beginning and ending with the minimum and maximum values, respectively); thus the lower quartile accumulates 25% of the distribution and corresponds to the low vulnerability, while the upper one accumulates 75% and correspond to the most critical.

Once these values are calculated, it should be identified each vulnerability value in each municipality within each range, as follows:

The open square bracket to the left of each range means that the greater than or equal value ( $\geq$ ) is taken and the closing parenthesis to the right means that the less than ( $<$ ) value is taken.

**TABLE 4.22: CLASSIFICATION OF VULNERABILITY**

Vulnerability	Classification	Ranges 10
Very high	4	[Third quartile –maximum value)
High	3	[Second quartile – Third quartile)
Medium	2	[First quartile – Second quartile)
Low	1	[Minimum value – First quartile)

It is proposed to adjust in only one the two higher intervals (which constitute the most severe vulnerability situation), always specifying within the higher range that there are some municipalities with more critical values; this should be reflected in the report and in the corresponding map (**Table 4.23**).

According to the proposed re-classification, the ranges would be:

**TABLE 4.23: RE-CLASSIFICATION OF VULNERABILITY**

Vulnerability	Re-classification	Ranges
Very high and High	3	[Second quartile–maximum value)
Medium	2	[First quartile – Second quartile)
Low	1	[minimum value– First quartile)

The information available and processed through Excel template should be used to make thematic maps of vulnerability at municipal level (Figure 4.8); as well as of some particular vulnerability, or of some of its most significant indicators, to complement the results achieved and provide the authorities with an additional tool to aid in decision-making. This allows making viable the proposals of policies based on adaptation measures that can be taken at local level to reduce the effects of vulnerability to drought.



**Figure 4.8:** Total Vulnerability Map of Las Tunas Province.

In those municipalities that present significant values in partial vulnerabilities, it is recommended a more detailed analysis from the behavior of the indicators that most contributed to each of these vulnerabilities.

Similarly, in the case of municipalities that classify higher in the ranking of total vulnerability, a detailed analysis of partial vulnerabilities that most affected that outcome is recommended.

#### 4.4 RISK CALCULATION

Once you have determined the hazard and vulnerability in a territory, risk is estimated as the essential element for determining recommendations for disaster prevention, in addition to preparedness and coping.

For the purposes of this methodology and as there are no conditions to estimate the cost of the elements at risk, the specific risk formula is used:

$$\text{Risk} = (\text{Integrated hazard} \times \text{Total vulnerability})$$

Where risk components are given by assessments of the integrated drought hazard and total vulnerability, respectively, at municipal level.

The integrated drought hazard is formed by the combination of the meteorological and agrometeorological hazards as results formulated for two periods: rainy and dry seasons.

Total vulnerability is the result of contributions from the five partial vulnerabilities obtained through the template in Excel, evaluated and weighted according to the different degrees of importance and finally re-classified into three categories (see **Section 2**), without making any distinction between the two periods, as in the case of hazard.

So that each municipality should have a drought hazard category for the rainy season and another for the dry one, and therefore two risk assessments, one for each period, as shown in the following equations; while vulnerability does not have this feature.

The formulas for the assessment of the two types of risk are:

$$\text{Rainy period risk} = \text{Rainy period hazard} \times \text{Vulnerability}$$

$$\text{Dry period risk} = \text{Dry period hazard} \times \text{Vulnerability}$$

The starting point was to level the results of both components in an ordinal qualitative scale, as expressed in **Table 4.24**.

**TABLE 4.24: CATEGORIES OF HAZARD, VULNERABILITY AND RISK**

Ordinal value	Risk categories	Drought hazard	Vulnerability to drought
3	High	Severe	Very high
2	Medium	Moderate	Medium
1	Low	Low	Low

Regardless of the greater or lesser level of complexity of the procedures used in each component, once the results were re-classified in order to obtain three categories, the process was simplified. The simplest method, among several possible, is selected to quantify risk regardless of any weighting, and assuming that both hazard and vulnerability are equally important and equally contributing to the risk of drought.

The product of both components qualifies as shown in table 4.25:

**TABLE 4.25: RISK ASSESSMENT**

Hazard x Vulnerability	Risk
	9 High
	6 High
	4 Medium
	3 Medium
	2 Low
	1 Low

As hazard and vulnerability will never be greater than 3, risk does not take values higher than 9, and obviously, values 5, 7 and 8 are also excluded from the assessment.

In those municipalities with significant risk levels, we recommend a more detailed qualitative analysis, to know which of the two components (hazard or vulnerability) most affects the territory. This way it is more feasible to identify adaptation measures (if the most critical is vulnerability) or, if possible, identify mitigation measures (if the most critical is hazard), although it is known that reducing vulnerability is the most feasible option.

In addition, it is necessary to emphasize actions on the transformation of risk scenarios, focusing on reducing vulnerability, with socially acceptable and economically viable solutions to contribute to sustainable development.

Mapping of vulnerability and risk is similar: using a qualitative thematic background map, the different categories must be differentiated (**Figure 4.9 a and b**).

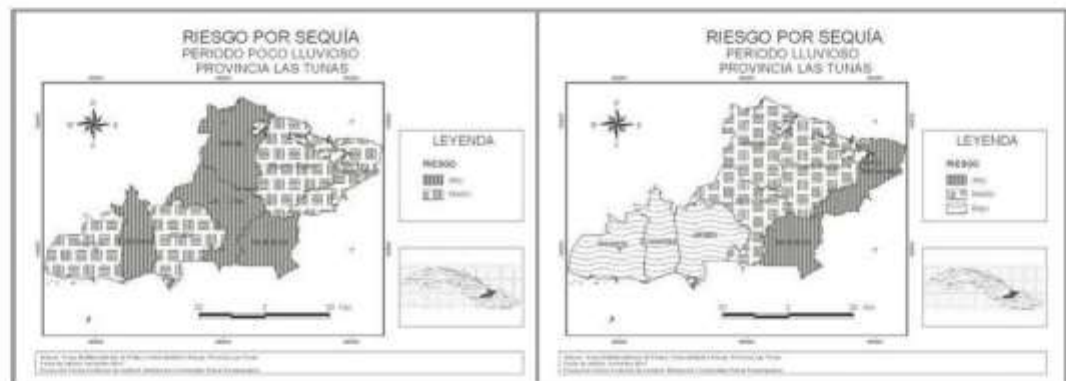


Figure 4.9: Risk Map: a) Drought for the rainy season, b) Drought for the dry season, in Las Tunas Province, Cuba.

There are two variants:

A color code is used: green for low category, yellow for medium and red for high. In the case of vulnerability, red is also used for Very high category, specifying in the report which municipalities are the truly critical within that range. In the event that there is no possibility of color printing, three categories can be distinguished with striped or dotted symbols, always displaying the three situations of vulnerability or risk, so that identification is not misleading.

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Flooding in Havana's Malecon (seafont)

## Main terms

**Agricultural drought:** when the amount of precipitation and its distribution, soil water reserves and losses due to evaporation combine to cause considerable decreases in the yield of crops and livestock (WMO, 1990).

**Astronomical tide:** periodic movement of seawater ascent and descent on the coast under the influence of the combined attractions of the sun and moon.

**Basin:** area of the Earth's surface where the rain that falls onto it (if it were impermeable) tends to be drained by the system of flows to the same outlet point.

**Bathymetry:** study of water depth or the shape of the bottom surface of a water body.

**Climate variability:** corresponds to variations in the average status and other climate statistics in temporal and spatial scales. Variability is broader than individual climate events and may be the result of a natural internal process in the climate system, or variations depending on external natural or human-induced forces.

**Coastal flood by sea encroachment:** an overflow of a water expanse that submerges land; its origin is linked to meteorological events, such as tropical cyclones and extratropical lows that produce strong wave, sea level rise and the consequent impact to facilities and homes on the coast.

**Coastal settlement:** it is every human settlement spatially located in direct link to the waterfront, where the direct impact of sea flooding occurs by way of the accompanying phenomena of severe meteorological events, such as the storm surge of tropical cyclones and hurricanes, or waves generated by the wind. The first 1000 m from the coastline and with a height above mean sea level lower or equal 1 m is recognized as an area of greater impact. For the purposes of this research, are considered coastal human settlements even those that, in spite of being farther than 1000 m, may be affected by sea encroachment with a lower likelihood of occurrence, with values greater than 1.0 m to less than 7.0 m and depth greater than 1000 m and less than 10,000 m.

**Coastline:** it is the line on the surface of the earth that defines the boundary between sea and land.

**Cold front:** surface discontinuity that separates the masses of cold dry air of high latitudes, from the masses of warm humid air originating from lower latitudes.

**Decyl:** they are each of the nine values that divide a data set into ten groups equally effective (Gibbs, 1987).

**Deep water wave:** wave whose length is less than twice the depth of the water.

**Deep waters:** zone where the depth is greater than half the surface wavelength.

**Desertification:** a process of degradation and declining productive capacity of arid, semi-arid, sub-humid lands, or those having a dry season, mainly caused by overexploitation or inappropriate land use interacting with climate variability.

**Diffraction:** this phenomenon commonly occurs when the wave finds a barrier in its path. This blockage causes the energy to be transferred along the crest and the progressive reduction of diffraction - wave height, when a wave propagates in the shadow zone behind a barrier after the wave has passed over.

**Digital elevation model:** numerical data structure that represents the spatial distribution of the quantitative and continuous height value on the terrain with respect to a specific reference, by applying an interpolation method.

**Disaster:** name usually given to an event or series of events of great magnitude, which seriously affect the basic structures and normal functioning of a society, community or territory, causing casualties and damage or loss of material goods, infrastructure, essential services or livelihoods at a scale or dimension beyond the normal capacity of affected communities or institutions to address them without help.

**Dolina:** valley or depression in karstic relief.

**Drought Impact Assessment:** process of observing the magnitude and distribution of drought.

**Drought:** a period of abnormally dry weather long enough to cause a serious hydrological imbalance, (WMO, No.82, 1990).

**Duration of the wave generation region (fetch duration):** amount of time that a wave generation region, where the wind blows at a speed and in a specific direction, remains about the same area of ocean surface.

**Event:** description of a phenomenon in terms of its characteristics, its size and geographical location; temporary record of a phenomenon that poses a threat.

**Extreme event:** event with a very low annual likelihood of exceedance. It sometimes defined as an event above the extrapolation level and therefore dependent on record length and quality of data available.

**Fast or dynamic flooding:** it usually occurs in mountain streams or rivers whose catchment areas have steep slopes, due to heavy rains. The floods are sudden and of short duration. These are the floodings that tend to cause the greatest havoc on the population, especially because there is virtually no reaction time.

**Fetch:** length of ocean surface on which the wind blows at a speed and in a specific direction.

**Flood area:** territory that is affected as a result of heavy and/or prolonged rains causing overflow in rivers, streams, dams and flooding in low-lying areas with little runoff. Floods can also occur as a result of ruptures in dam walls.

**Floodplains or planes:** these are surface areas adjacent to rivers and streams, subject to recurrent flooding.

**Functional vulnerability:** it is related to the elements that allow normal operation of facilities: networks for water supply, power, telephone, sewerage, access roads and the existing organization system of people who use and/or manage the facilities, especially in disaster situations.

**Heavy sea:** height of storm tide above the foreseen tide that can reach around 0.5 meters in an annual return period, and can potentially reach a higher limit.

**Height:** a value representing the characteristic or interest points on the terrain surface, with a height value determined through precise methods and expressed in meters.

**Hydrological drought:** prolonged absence or marked deficiency of precipitation. It originates when the availability of stored water does not allow guaranteeing the annual rate of supply required from surface and groundwater sources around a hydrological territory and/or system.

**Level curves:** isolines linking points of equal height.

**Lifelines:** basic network infrastructure, piping or connected elements that allow mobilization or transportation of electricity, water, fuel, information, persons and goods, essential to develop society activities with quality and efficiency.

**Maximum total sea height:** maximum height of the sea in a place where two or more groups of waves or wave occur at the same time.

**Mean sea level:** sea level estimated as the mean value of the average annual values for a period of no less than 19 years and ideally more than 50 years.

**Meteorological drought:** a period of abnormally dry meteorological conditions long enough to cause a serious hydrological imbalance due to lack of precipitations, (WMO, 1990).

**Mitigation:** actions, programs or policies implemented in the short and long term with prior to the occurrence of a hazard, or in the early stages, in order to reduce the degree of risk to people, property and the productive capacity.

**Nonstructural vulnerability:** it is related to the level of damage that non-structural elements (partition walls, woodwork, objects, equipment) may experience.

**People's Council:** governance structure introduced in Cuba at the level of neighborhoods and small towns, which responds to a community organization and is an intermediate level of government between the municipal and the district.

**Plunging breaker:** violently breaking wave in shallow water.

**Preparedness:** the set of actions taken prior to the impact of a hazard, designed to increase the alert level or improve operational capabilities to respond to the event. The preparedness is a mitigation action.

**Quadrature tide:** tide that occurs when the moon is waning or growing.

**Response:** actions undertaken immediately before, during or just after the occurrence of a hazard event to reduce impacts and improve recovery.

**Risk perception:** study of beliefs, attitudes, judgments and feelings, as well as social and cultural values and provisions that people take against hazard sources.

**Risk:** potentially adverse effects of a hazard as a result of both the frequency and intensity of the hazard and its related vulnerability.

**River flooding:** caused by overflowing rivers and streams, it is attributed to the sharp increase in water volume beyond what a bed or channel is capable of carrying without overflow during the flood.

**Riverbed:** course of riverbeds and streams where the rain waters flow.

**Runoff:** the water from rainfall flowing above or below the Earth's surface and reaching a current to finally be drained to the outlet of the basin.

**Sea level analysis:** basic research process by which various mathematical procedures are applied to know how sea level varies and its various components, as well as the causes of these variations.

**Sea level hourly heights:** sea level height in cm, referred to the benchmark, measured at hourly intervals.

**Sea encroachment:** coastal flood by the accumulation of seawater on a land that does not normally suffer the effects of the tide, usually in low coastal areas.

**Shallow water wave:** wave whose length is greater than 20 times the water depth.

**Shallow water:** water of a depth that surface waves are markedly affected by the bottom topography. It is customary to consider water depths less than one-twentieth of the surface wavelength as shallow water depths.

**Shoaling:** changes in wave characteristics that occur as they move from deep to shallow waters. As the wave approaches shallow water, its height increases and its wavelength and speed are reduced, because the wave retains its period in shallow water.

**Significant wave period (Ps):** average wave period used to calculate significant wave height.

**Slow or static flooding:** occurs when persistent and widespread rains produce a gradual increase in river flow to exceed its maximum transport capacity. Then, the river overflows out of its banks, inundating nearby flat areas.

**Social vulnerability:** the degree of exposure of a family, town, region or country due to the likelihood of occurrence of a potentially damaging or hazardous event, and inadequate capability to protect themselves, or those social, physical, material and organizational aspects related to attitudes or motivation that are strengths or not in providing response or coping with the potential impacts of disasters.

**Southern winds (Sures):** they affect Cuba's southern coast and the western provinces of the country with greater force during the cold front season. They have S to SSW directions and speeds that can reach 18 m/s.

**Spatial resolution:** the pixel dimensions of the image expressed in topography units. Frequently, the GSD (ground sample distance) abbreviation is used for reference. The spatial resolution is a parameter that is set according to the technical application that will use the data.

**Spectral wave model:** model using a frequency spectrum through time and space to measure a finite sum of wave components of different lengths and widths.

**Spilling breaker:** wave that gradually breaks in shallow water over a substantial distance, gradually pouring water over the crest as the wave approaches the coast.

**Standardized precipitation index (SPI):** designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of different sources of water resources. Ground moisture conditions respond to precipitation anomalies for a relatively short time scale, 1, 3, 6 months; while surface water, groundwater, streams and reservoirs reflect rain anomalies of longer periods: time scales of 12, 24 and 48 months (McKee, 1993).

**Structural vulnerability:** vulnerability referred to the physical characteristics of the exposed element (buildings) that make it susceptible to damage.

**Surge:** abnormal and temporary elevation of mean sea level, on the astronomical tide, caused by stress from strong winds, and to a lesser extent by the drop in air pressure due to the passage of a cyclone, either tropical or extratropical.



**Surging breaker:** breaking wave that peaks and rises on the beach without the wave crest reaching break.

**Swell:** waves that have left the wave generation region that produced them.

**Tide:** the rhythmic alternating rise and decline in ocean surface (or water level) of water bodies connected to the ocean, such as estuaries, bays, gulfs and channels, which occurs twice a day on most of the land and results from the gravitational pull of the moon and, to a lesser degree, of the sun, acting unequally on different parts of the rotating Earth.

**Tropical cyclone:** a generic term for a frontal system that forms over tropical or subtropical waters and has an organized convection. The tropical cyclone has an extensive area of influence that can reach a diameter of 800-1000 km. Tropical cyclones have three dangerous elements to consider: strong winds, heavy rains, storm tide or surge. The stages of tropical depression, tropical storm and hurricane are included within the term 'tropical cyclone'. Depending on the speed of the winds, it is classified as tropical depression when its maximum sustained winds reach 62 km/h; tropical storm when its maximum sustained winds are between 63 and 118 km/h, and hurricane when its maximum sustained winds exceed 118 km/h.

**Uvalas:** those irregular depressions, generally elongated, frequently caused by the union of individual dolinas.

**Water deficit:** human-induced temporary imbalance of water resources. Water deficit in a supply system involves use restrictions regarding demand, which can occur due to drought or other human-induced causes.

**Water shortage:** indicates a permanent condition of imbalance between water resources and water demands in a region (or in a water supply system) characterized by an arid climate, or a rapid increase in water demand associated with population growth, expansion of agriculture under irrigation, or other causes.

**Wave amplitude:** the maximum magnitude of mean sea level displacement.

**Wave angular or lateral dispersion:** sideways dispersion of wave energy as they move away from the area generation.

**Wave crest:** the highest part of a wave or the part above sea level.

**Wave direction:** direction of the wavefronts.

**Wave dispersion:** a phenomenon that describes the separation of the components of a wave group according to their wavelength and period. Periods and waves with wavelengths longer move faster and away from the waves with shorter periods and wavelengths in the same group.

**Wave dissipation:** transformation in wave period and height that occurs while the wave moves away from the wave generating zone.

**Wave frequency:** the number of successive crests passing a fixed point in a second.

**Wave generation region (fetch region):** wind zone that constitutes a wave generation region. Wave generation regions have length and width.

**Wave growth:** is related to the speed, scope and duration of the wind.

**Wave height:** is the elevation difference between the surface of the wave crest and the preceding wave valley.

**Wave period:** the time interval of two successive waves passing through a fixed point.

**Wave reflection:** a phenomenon that occurs when the waves crash against an obstacle and return in the opposite direction to where they come from.

**Wave refraction:** a phenomenon that occurs when the waves start to interact with the bottom. As waves enter and transitional waters and do not travel perpendicular to the isobaths, then the waves that travel through deeper waters move at a faster speed than those on shallow waters.

**Wave spectrum:** distribution of different wave periods in a wave group.

**Wave valley:** lower part of a waveform between successive peaks; also, the part of a wave below sea level.

**Wave:** oceanic disturbance that occurs in the sea surface and is animated by wave motion, apparent translation and true rotation.

**Wavelength:** horizontal distance between two successive peaks.

**Wind rise:** sea level elevation in a water body caused by water accumulation on the coast because of the wind.

**Wind waves:** surface wave generated by wind action on the ocean surface.



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