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Review
SOME CONSIDERATIONS ON THE BEHAVIOR OF THE AGRICULTURAL DROUGHT IN THE CUBAN AGRICULTURE AND THE USE OF SATELLITE IMAGES IN ITS EVALUATION

Reseña bibliográfica
Algunas consideraciones sobre el comportamiento de la sequía agrícola en la agricultura de Cuba y el uso de imágenes por satélites en su evaluación

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ABSTRACT. The agricultural drought has been classified as a "Silent disaster" that causes considerable impacts in the agricultural systems: in cultivations, grassland, livestock, soils dedicated to the production, etc. But not only in the agriculture, this also caused negative effects in the population, the economy and the environment. Their fundamental causes are given by the shortage of atmospheric humidity, the inadequacy of generating systems of rain or the persistence of a strong subsidence, or, to the combination of some of these factors whose should be studied in the context of the atmosphere general circulation. In Cuba, different events of droughts have taken place during long time that have been affected territories of almost the whole country causing millionaire losses for the impact in the agricultural production and environmental ecosystems, reason for which becomes necessary to know and to study the causes, the behavior and consequences of such phenomena, in order to create policies and confrontation strategies and early warning with a view to reduce and to mitigate their impacts and to guarantee the environmental sostenibility and the alimentary security. Given this background, the present work has the aim to show the state of this topic art through a series of aspects allow to characterize the behavior of this hydrometeorological phenomenon in our country and to international scale, highlighting the use of satellite images in its evaluation which constitutes an effective technological tool for its study and evaluation.

Key words: disasters, effects, agrarian systems, agriculture, natural phenomena

RESUMEN. La sequía agrícola ha sido calificada como un "desastre silencioso" que provoca impactos considerables en los sistemas agrícolas: en cultivos, pastizales, ganadería, suelos destinados a la producción, etc. Pero no solamente en la agricultura, también provoca efectos negativos en la población, la economía y el medioambiente. Sus causas fundamentales están dadas por la escasez de humedad atmosférica, la insuficiencia de sistemas generadores de lluvia o la persistencia de una fuerte subsidencia, o bien, a la combinación de algunos de estos factores, las cuales deben ser estudiadas en el contexto de la circulación general de la atmósfera. En Cuba, se han producido diferentes eventos de sequías a lo largo del tiempo, que han afectado a territorios de casi todo el país provocando pérdidas millonarias por el impacto en la producción agropecuaria y ecosistemas medioambientales, razón por la cual se hace necesario conocer y estudiar las causas, comportamiento y consecuencias de tales fenómenos, con vistas a fundamentar políticas y estrategias de enfrentamiento y aviso temprano dirigidas a reducir y mitigar sus impactos y garantizar la sostenibilidad ambiental y la seguridad alimentaria. Teniendo en cuenta tales antecedentes, el presente trabajo tiene como objetivo mostrar el estado del arte del tema a través de algunos tópicos que permiten caracterizar el comportamiento de dicho fenómeno hidrometeorológico en nuestro país y a escala internacional, destacando el uso de las imágenes por satélites en su evaluación, las cuales constituyen una efectiva herramienta tecnológica para su estudio y evaluación.

Palabras clave: desastres, efectos, sistemas agrarios, agricultura, fenómenos naturales

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INTRODUCTION

As it is well known, the man from his own origin has always had to fight against drought effects, an extreme phenomenon within the natural climatic variability. Frequently, due to its serious damages on the people, economy and environment, together with the limited capacity of people's response to face them adequately, drought reaches the category of disaster, even with dramatic dimensions (1).

In recent decades, its growing influence has been considered among the greatest natural disasters in the world, since it is the most frequent and persistent with higher negative effects on agricultural production and real adverse impacts on the environment[A].

For Cuba, the negative impact of persistent and significant short- and long-term drought events occurring during the last decades, has essentially limited the efforts to ensure people's welfare and a stable economic development, especially in agriculture and livestock (2).

Therefore, according to the author's criteria, the subject discussed in this paper is focused on the most important considerations about the behavior of drought in Cuban agriculture over time and the geo-information technologies that should be used for its evaluation and monitoring.

This kind of bibliographic investigation is important and necessary to socialize these aspects in the academic and scientific community, even though just in July and August 2015 one of the most notable drought events occurred in the country. Thus, the research hypothesis is based on knowing the causes and consequences of drought events in Cuba, in order to design some possible strategies and measures to combat them.

To illustrate how serious this research subject is, it is pointed out that in 30 rainfall stations located along the country, which are involved in this study, both moderate and severe negative effects recorded during annual accumulated rainfalls doubled within the normal period of 1961-1990, compared to the previous thirty years (1931-1960) (2).

Afterwards, quite remarkable effects were registered within the summers of 1993, 1994, 1998 and 2000, despite that during this decade the most notable persistent deficits occurred in the easternmost provinces, which kept on reaching a drought event between 2003 and 2005, which gradually spread throughout the country (1).

The negative impact of drought demanded certain water distribution by several alternative ways to nearly two million people and caused substantial direct as well as indirect losses in various economic sectors, severe environmental damages and countless people's difficulties (2).

Different factors have influenced this situation, such as our population density (102 inhabitants km^2) and the possession of less than 63 % agricultural area throughout the country, with poor soil agro-productive characteristics (3), besides limited water resource availability (4); all of them make up a scene where these events must be carefully addressed. Together with other adverse climatic factors that also influence its frequency, such as extreme rainfalls or strong winds, drought can become an important cause of land degradation that may lead to soil aridity and even desertification if it is not controlled. By comparing the areas known as drylands in Cuba (sub-humid dry and semi-arid) within 1961-1990 and 1971-2000, Cuban researchers could observe an increase of 146 000 ha (5), a fact that confirms the presence and magnitude of these processes.

The clear understanding of drought and its causes, the accurate perception of its danger, the implementation of appropriate measurements of prevention and mitigation of its impacts constitute the basis for the proper management of this phenomenon (1).

The glossary of Agrometeorology terms from the World Meteorological Organization (WMO) (6) states that drought, in its third meaning, is defined as "a sufficiently long abnormal dry period of lack of water causing a serious hydrologic imbalance (crop damage, water shortage, etc.) in affected areas".

It is a slow process of gradual development that is difficult to determine when it begins and ends. Its impact is variable and perceived according to different points of view. Consequently, some authors[B] say that "recommending a single definition based on several existing criteria is a useless task".

[A] OMM. *Función de la Organización Meteorológica Mundial en el Decenio Internacional para la Reducción de los Desastres Naturales*. no. 745, Inst. Organización Meteorológica Mundial (OMM), 1990, Ginebra, Suiza, p. 32.

According to this author[B], there are as many definitions of drought as objectives to define them. However, a common denominator in every definition is the "lack of rainfall" compared to its "normal" behavior. "Normal rainfall" is considered a historical average value obtained from a series of certain length rainfall data.

A widely international accepted definition of drought is contained among the Terms of Reference from the Official Text of the Convention Against Desertification (7), particularly in Africa, where drought means "a phenomenon that naturally occurs when rainfalls have been significantly below the normal levels recorded, causing a serious hydrological imbalance that adversely affects land resource production systems", considering land resources as the whole bioproductive system. Drought should be clearly distinguished as a temporary phenomenon that substantially differs from soil aridity, which is a permanent climatic feature. Moreover, a usual little rainy seasonal period also differs from drought, although both concepts are often confused or used indistinctly. In addition, drought is usually associated to dry regions; however, this phenomenon may take place either in very rainy or little rainy regions of the country and virtually worldwide. A good understanding of these differences is very important for the purpose of a proper management (1).

In general, drought is usually approached from two different points of view: for its *climatic determining factors* (meteorological drought), that is, the character of atmospheric circulation, rainfall, temperature, evaporation, etc. or for *its consequences*, that is, agricultural, hydrological and socio-economic type. Trying to blend with the broad spectrum of approaches, researchers[B] established four main kinds of droughts (8): meteorological, agricultural, hydrological and social or economic type.

Meteorological drought occurs when rainfall is much lower than expected over a wide area for a long period; *hydrological drought* occurs when there is a continuous surface runoff deficit that reaches a lower level than normal conditions or when underground water level decreases; *agricultural drought* occurs when the amount of rainfall and its distribution, soil water reserves and evaporation losses are joined to cause significant crop yield and livestock decreases, whereas *socio-economic drought* occurs when water demand exceeds its supply.

It is a combination between rainfall deficit and people or productive activity requirements, water use efficiency and available technology. These four general approaches have been favorably acknowledged by WMO and widely published.

[B] Makarau, A. *Sequía, Variación climática y Desertificación*. Informe a la XI Reunión de la Comisión de Climatologia de la Organización Meteorológica Mundial, Inst. Organización Meteorológica Mundial (OMM), 1993, La Habana, Cuba, p. 55.

Regarding the above classification of other authors (1), Li[C] states that "although the four types of droughts listed are distinguished for their own features of formation, the factors affecting each type are correlated" and he also confirms that "meteorological drought is the most important type, because the others are derived from it and particularly from poor rainfall".

Within agricultural context, drought "does not begin when the rain stops, but when plant roots cannot uptake more soil moisture" and it can be defined on the basis of soil moisture rather than on some indirect interpretation of rainfall records, since productive moisture reserve depends on the soil and the crop (species, variety, developing stage). There is agricultural drought when soil rhizosphere moisture is at such a level that it limits crop growth and production (9).

As a result, agricultural yields decrease, grazing conditions are inadequate, there is low profitability of agricultural works and investments, reduced wood availability for combustion, higher potential risk of fire in plants and desertification as well as occurrence of negative socio-economic impacts related to drought, including insecure food supplies (9).

Not every agricultural drought affects plants in the same way, its effect depends

[C] Li, K. *Drought, desertification and their mitigation technology in the world. Report of the CCL*. Repporteur on Drought and Desertification to the Eleventh session of the Commission of Climatology, Inst. World Meteorological Organization (WMO), 1993, La Habana, Cuba, p. 30.

on the intense plant water stress, the time these conditions have influenced the plants and the affected surface area (9).

With the background information provided in the introduction, the first objective of this study is to highlight the state-of-art of the subject by means of criteria and experiences resulted from processing and analyzing an extensive literature review, besides presenting them in different structures. Having these criteria, knowledge and experiences, a second objective has been stated that consists of characterizing the behavior and evolution of this hydro-meteorological phenomenon mainly in our country. A third objective is to provide criteria and experiences on the use of satellite images for its assessment, monitoring and management, which constitute an effective technological tool for its study and evaluation.

CLIMATIC CHANGE, AGRICULTURE AND DROUGHT

Since the beginning of the 90s, Cuba has paid attention to climatic change subject, as it is involved in its environmental agenda. Investigation results indicate a temperature rise (1,6 to 2,5 °C in 2100); a higher temperature in summer than expected for winter; an uncertain rainfall behavior; greater evaporation due to higher temperature, which will benefit soil aridity and sea level (10).

Climatic change studies made on biodiversity have shown small variations generally observed under future conditions in 39 geographical districts of Cuba; that is, according to projected scenes, our natural ecosystems should not be significantly affected but gradually adapted to the new situation[D].

The most significant variations are described at the eastern districts of the country, particularly on Nipe-Sagua-Baracoa mountainous area, due to the geomorphological and biological complexity of this region, which is the most sensitive to climatic change. The projected situation may indicate some ecosystem variations, especially because of its removal towards higher zones from Maisi-Guantanamo semi-desert coastal strip (11).

Global change will affect not only ecosystems but also its structure, which may be observed by light changes in species composition or greater changes in the type of vegetation covering the land. Current models predict large vegetation changes for most America, in a scene where CO_2 concentration is doubled. Climatic change affects vegetation, which in turn may modify climate. In addition, ultraviolet rays have a negative effect on crop photosynthesis and reduce production[E].

Our climate trend has had a negative impact on agricultural activity and forests. Temperature rise has been accompanied by a reduced annual rainfall of 10 to 20 % that have also declined during the rainy season of the year (May-October) and increased within the poor rainy season (12).

Climate projections and its effect on agriculture have been studied by some researchers[F], who consider that climatic conditions will lead to a higher potential evapotranspiration and unfavorable hydrological cycle trends, with lower soil moisture values and greater degree of soil aridity, reaching its maximum values at the eastern region of the country; besides, a higher drought frequency, duration and severity is expected.

Regarding agricultural yields, several authors have pointed out that as a trend, climatic change will negatively affect many crops by causing progressive decreases along the XXI century (13). This reduction will reach values from 10 to 25 % in most crops during 2100 compared to current yields. They will particularly be from 5 to 10 % in sugarcane whereas from 45 to 50 % in potato. Crop evapotranspiration will generally decrease and dryland crop yields will reduce from 15 to 30 %.

So far as pests and diseases are concerned, projected climatic conditions will consequently modify crop behavior substantially.

[D] UNEP. *Biodiversidad*. UNEP: Impacto del cambio climático y medidas de adaptación en Cuba, no. FP/cp/2200-97-12, 1999, La Habana, Cuba, p. 32.

[E] IPF. *Los Cambios Globales*. Los asentamientos humanos, el uso de la tierra y los Cambios globales en Cuba, Proyecto 01304089, Inst. Instituto de Planificación Física (IPF), 2001, La Habana, Cuba, p. 35.

[F] INSMET. *Agricultura y Silvicultura*. Impacto del cambio climático y medidas de adaptación en Cuba, Proyecto FP/cp/2200-97-12, Inst. UNEP/INSMET, 1999, La Habana, Cuba, p. 47.

Diseases such as late blight of potato and blue mold of tobacco, which have been very harmful in the western region of the country, will lose importance, but they could be replaced by other better adapted diseases under the expected conditions. *Thrips tabacci* could grow in garlic crop and the same may happen with corn moth, which is uncontrollable during the dry season (13).

DROUGHT AS A YDROMETEOROLOGICAL EVENT

Like other atmospheric phenomena, drought should be studied in the climatic signal overlapping context of different frequencies, magnitudes and origins (intra-seasonal, seasonal, hyper-annual, decades, etc.). Referring to such process complexity, which firstly causes drought, scientists have pointed out quite rightly that it can be linked to "the lack of atmospheric humidity, insufficient rain-generating systems or persistence of a strong subsidence, or may be due to the combination of some of these factors, whose causes must be studied in the general atmospheric circulation context (14)."

On the other hand, Cuban scientists[G] have stated that in recent decades, our climate has undergone notable irregularities as a result of "a high level response of regional atmospheric circulation to the main climatic system changes occurred at a global scale." The principal changes have been detected since late 70s, together with significant global modifications recorded in the air and sea surface temperatures.

Correspondingly, important anticyclonic regime variations have been tested[H, I, J] on the region, as a result of the gradual intensification of Atlantic anticyclonic ridge. This process does not fit rain-generating mechanisms basically during the rainy seasonal period.

Therefore, the study of atmospheric circulation characteristics in Cuba under extreme dry conditions from the 70s up to nowadays makes evident the prominent role of variations in position, morphology and intensity of the oceanic anticyclone within the lower and middle troposphere and Mexican summer anticyclone within the middle and upper troposphere under these circumstances.

In fact, abnormalities observed at speed and pressure surface heights as well as air mass vertical movement direction, within different tropospheric levels of this geographic region, associated with such variations, among other parameters, explain the latest and persistent drought processes that mainly occurred in the eastern part of Cuba[K, L, M] (2, 11, 15).

In close relationship with all these aspects, the Intergovernmental Panel on Climatic Change, in its fourth report (16) entitled RT.6.2 "*Observations on Climatic Changes*," considers as a solid finding the fact that "droughts are very common since the 70s, especially in the tropics and subtropics". Moreover, the section entitled RT.6.4.3 "*World Projections*" also considers as a strong finding the fact that "rainfall changes show solid large-scale patterns: rainfall generally increases within maximum tropical rainfalls, decreases in subtropics and increases in high latitudes, due to a general hydrological cycle intensification."

This report also estimates that due to a notable temperature rise, soil aridity and drought processes could be intensified and expanded, even in cases where rainfall increases as a result of high evaporation rates.

[G] Centella, A. A.; Naranjo, D. L. R. y Paz, C. L. R. *Variaciones y cambios del clima en Cuba*. Inst. Centro Nacional del Clima, Instituto de Meteorología (INSMET), Ministerio de Ciencia, Tecnología y Medioambiente (CITMA), 1997, La Habana, Cuba, p. 59.

[H] Brenes, M. A. y Jiménez, R. M. V. *Cambios en la circulación general y su influencia en la tendencia de la precipitación en América Latina*. Inst. Departamento de Información, Instituto Meteorológico Nacional, 1993, Costa Rica, p. 62.

[I] Naranjo, D. L. R. y Centella, A. A. *Mecanismos de Circulación de la Atmósfera en la América Tropical*. Inst. Centro del Clima, Instituto de Meteorología (INSMET), Ministerio de Ciencia, Tecnología y Medioambiente (CITMA), 1999, La Habana, Cuba, p. 48.

[J] Fonseca, R. C. F. *Cambios en la posición e intensidad del Anticiclón del Atlántico y modificación del régimen de las lluvias en la región del Caribe*. [Tesis de Maestría], Instituto Superior de Ciencia y Tecnología de Avanzada (InsTec), 2001, La Habana, Cuba, 48 p.

[K] Lapinel, P. B. P.; Centella, A. A.; Fonseca, R. C. y Cutié, C. V. *La Sequía en Cuba. Componente Meteorológico*. Análisis y pronóstico del tiempo y el clima terrestre y espacial, Proyecto 4072, Inst. Instituto de Meteorología, Ministerio de Ciencia, Tecnología y Medioambiente (CITMA), 2007, La Habana, Cuba, p. 317.

[L] Lapinel, P. B. P.; Fonseca, R. C.; Cutié, C. V. y Rouco, D. B. *Movimientos troposféricos verticales sobre Cuba y sus características en condiciones de lluvias medias y extremas durante el período estacional lluvioso*. Inst. Centro del Clima, Instituto de Meteorología del Ministerio de Ciencia, Tecnología y Medio Ambiente, 2007, Ciudad de La Habana, Cuba, p. 16.

[M] Rodríguez, C. M.; Pérez, A. L.; Boquet, A.; Favier, L.; Lapinel, B.; Centella, A.; Fonseca, C. y Cutié, V. *Impacto, vulnerabilidad y adaptación a las condiciones de sequía en el norte de la provincia de Las Tunas* [en línea]. Observatorio Geografico de America Latina, 2006, [Consultado: 28 de abril de 2016], Disponible en: <http://observatoriogeograficoamericalatina.org.mx/egal11/Procesosambientales/Proteccioncivil/08.pdf>.

All these essential elements related to climatic change can be also seen as part of the current problem and the great challenge we will have to face in the future (16).

The imperceptible manner that drought shows and the fact that a same event impacts differently on various social, economic or environmental sectors, logically induce the simultaneous generation of multiple perceptions of this phenomenum. Consequently, it is hardly surprising that international literature is plenty of indexes to calculate meteorological, agricultural, hydrological, edaphic, ecological and socio-economic drought, which are usually well-argued and of great theoretic-practical value (2).

On the contrary, such index profusion, undoubtedly considered subject strength, rather than favoring, has negatively and sensibly influenced the available balanced interpretation and an integrated approach of the risk that this harmful phenomenon potentially represents and thus to establish an accurate and timely assessment of "Drought Risk" (16). In many countries, these drought characteristics have prevented and hindered the implementation of timely and accurate estimates of its degree of hazard, hampering the development of confrontation plans, compared to other harmful phenomena. In Cuba, the most recent drought episodes have highlighted the need to strengthen the efforts to make integrated methodologies that help optimize the perception of "Drought Danger" and thus the risk-reducing plans (16).

The country has increasingly favorable conditions to organize a good strategy and an effective plan against drought. The state and government political will is implemented through plans for reducing disasters guided by Board no.1 from the Chairman of the National Defense Council (17), that precisely points out the progressive adoption of a set of measures focused on arranging and integrally ensuring the activities related to drought confrontation, thereby reducing as much as possible the risk to these undesirable events.

There is a National Environmental and Development Program in the Republic of Cuba (PNMAD) (18), which was developed due to country needs and in response to what was discussed in the United Nations Convention to Combat Desertification in seriously drought-affected countries or those experiencing desertification (CCD) (7), a United Nations' paper confirmed in 1996. This plan has outlined strategies so as to identify, coordinate and implement actions from national to local levels for fully addressing these phenomena. Efforts have also been directed to develop synergies along with other environmental conventions and meet compliance with international commitments related to this convention.

Among many preventive actions to face drought contained in the National Program of Action[N], there are: the adoption of appropriate farming practices for soil protection; the introduction of more water stress resistant crop varieties, which may significantly reduce its effects by retaining water from the soil and restricting transpiration; improving protective and profitable measurements of water resources, as well as spreading accurate and timely information of available early warning systems to key sectors.

The Institutes of Meteorology (INSMET) and Hydraulic Resources (INRH) have Early Warning Systems for Drought, which were designed by means of advanced computational techniques and international standards required for these purposes. Its basic functions are to identify and provide early warning at the start of any drought event, keep track of its development, evaluate its characteristics, estimate its possible evolution and determine its goal. Such systems are being constantly improved and have the basic technological means to regularly ensure its operational functioning. The progressive strengthening of available abilities to make rainfall seasonal predictions at present, based on the diagnosis of factors regulating climatic variability in the region and the national forecasting models, allows better estimates related to drought process evolution and meets various hydrological and agricultural interests, among others[O].

Despite these advances, current requirements demand that drought subject should be approached with a wide focus, properly structured for risk management.

[N] Urquiza, R. N.; Peña, V. F.; Herrero, E. G. y Febles, G. *Comité de Revisión sobre la Implementación de la Convención (CRIC) de las Naciones Unidas de Lucha contra la Desertificación y la Sequía*. III Informe Nacional de la República de Cuba, Inst. Agencia de Medioambiente (AMA), Ministerio de Ciencia Tecnología y Medioambiente (CITMA), 2006, La Habana, Cuba, p. 49.

[O] INSMET. *La Sequía. Causas, Percepción y Enfrentamiento*. Inédito, 2010, 10 p.

Therefore, other parameters of ecological, edaphic and socio-economic profiles must be gradually considered, besides some climatic and water aspects, in order to identify in advance more prone and vulnerable areas.

Studies on drought hazard, vulnerability and risk with this new approach are underway and will provide a relevant tool to planners and decision makers. Within the climatic change context, those actions aimed at reducing drought effects must be simultaneously coordinated with the implementation of strategies and adaptive measures carried out by this other concept and adjusted to their actual physical, environmental, economic and social dimensions[O].

MORE STRIKING DROUGHT PROCESSES IN CUBA FROM 1960 TO 2005 AND ITS CAUSES

To understand the origin of drought processes in Cuba, it must start by the fact that climate in recent decades has undergone notable modifications, as a result of a high level response from regional atmospheric circulation to the main climatic system changes occurred at a global scale[G], which substantially provoke adverse impacts on economic, social and environmental fields[G, H].

In particular, several authors have pointed out the anticyclonic influence on the region caused by Atlantic anticyclone ridge intensification, a process that consists of a gradual increase in the East zonal current intensity, affecting rainfall-producing mechanisms, mainly during the rainy seasonal period, due to increasing low atmospheric currents and decreasing high atmospheric currents, which is closely linked to climatic variability[G, H, I, J].

The most notable changes in the anticyclonic influence characteristics of the area have been detected since the middle of the 70s, together with the presence of significant and sustained positive anomalies in the air surface temperatures at a global level and sea temperature in the tropical region. In this sense, INSMET[I] highlighted the progressive and marked penetration of the ocean anticyclonic wedge into Cuban archipelago at low and mid tropospheric levels, as well as a greater influence of Mexican summer anticyclone on the troposphere; these aspects require further attention, so as to determine the main causative agents of severe drought processes that occurred in Cuba and particularly in the eastern region of the country within recent years.

In Cuba, moderate and severe drought events doubled during the normal period of 1961-1990, compared to the previous period of 1931-1960 and within the 90s with notable losses (1). Meanwhile, between 2001 and 2005, there was a significant rainfall deficit in the eastern region of the country, following 1997-1998 hydrological deficits; however, such deficit started at the beginning of the 90s during the rainy seasonal period and Las Tunas was the most affected province.

In this region, the increasing degree of soil aridity within recent years together with the behavior of projections as a result from applying climatic change models to Cuba explain the cause of serious and persistent drought events during 2003-2005 period, classified as the most intense over the last 100 years in the country, with dramatic impacts on agricultural activities, fishery, environment and people living in the territories, who essentially lost available drinking water; thus, their reaction was immediate with quick, temporary and definitive responses to reduce the situation created in those damaged territories[M].

Through the research project from United Nations Development Program (UNDP) entitled "*Capacity Building for Stage II of Climatic Change Adaptation in Central America, Mexico and Cuba*", a scientific study was developed on drought phenomenon in Las Tunas province, located in the eastern part of the country that was the territorial case of study. During this research development, some analytical methodologies were enhanced in order to specify, through a broad participatory process, the level of impact and vulnerability in rural and population sectors and determine the response capacity existing in each analyzed sector and the territory as a whole.

In this province, the deficit rate recorded within hydrological years from 1991 to 2005 accumulated 1300 mm; then, there was an annual rainfall regime of 1038 mm which constituted an absolute record.

The drought event that started in May 2003, which affected most of the country until May 2005 (four consecutive seasonal periods), recorded the lowest rainfall values over the latest 100 years in Cuba, mainly in the eastern region. Such event affected significant areas of the eastern provinces within 2005 rainy seasonal period; meanwhile there were plentiful rainfalls for most of the country, resulting from the direct influence of the tropical storm *Arlen* in June and hurricane *Dennis* in July, as well as the close influence of hurricanes *Katrina* in August, *Rita* in September and *Wilma* in October, over the most active cyclone season of the Atlantic and Caribbean history[M] (2).

Along with the recurring occurrence of drought events on the eastern region of the country, there was a slight expansion of dry lands (semiarid and dry sub-humid) when comparing the annual performance of soil aridity index (P/E0) in Cuba, during the normal periods of 1961-1990 and 1971-2000. This expansion reached 1464 km^2 (146,400 ha) and additional calculations show that 52 % increase occurred in Las Tunas and Holguin provinces (2, 9).

Meanwhile, the central and western regions of Cuba could recover from its water deficit completely since 2003, even though 2005-2006 dry seasonal period (November-April) behaved extremely dry throughout the whole country, restarting the temporarily interrupted drought process in western areas and extending it temporarily in others (2, 19).

In short, the increased climatic variability observed in Cuba since the middle of 1970s, consistent with larger scale changes, is shown by significant alterations in the typical synoptic patterns influencing the region, among other processes.

It was proved that markedly anticyclonic conditions overlapped in the troposphere (oceanic anticyclone at low and middle levels, as well as Mexican summer anticyclone at high levels) with higher interaction on the eastern region of Cuba, makes strong subsidence that inhibits convective processes and consequently drought establishment. The natural environmental impact of drought is highlighted along with the gradual expansion of drylands in the region (2).

Therefore, several authors (9, 20) present some of the most important drought periods that have affected Cuba: 1870-1871, 1875-1876, 1879-1880, 1897-1898, 1906-1907, 1922-1923, 1944-1945, 1955-1956 and 1961-1962. Others, while studying 1961-1990 period, report an intensified "*East*" wind component and a significant increase of drought number or severity, which recorded a considerable growing amount of extreme cases[H, P] (1).

To illustrate how serious this problem is, it can be noted that moderate and severe drought events in Cuba doubled in the normal period of 1961-1990, compared to the previous one of 1931-1960 (1).

Within the 90s, 1993, 1994, 1998 and 2000 summer damages were quite remarkable, 1998 being the most intense event for April-May-June period, according to available Climate Center statistics since 1941[Q].

The short-term drought event from April to July, 1998, was sensibly observed across the country and in some eastern municipalities (frequently affected by drought); its harmful impact reached the category of disaster, causing extensive damage and discomfort to the local population, who even temporarily migrated. Official figures of economic losses just in these areas raised nearly four hundred million US dollars and several million Cuban pesos (1).

Table I lists some agricultural drought indicators (5), which can be compared with different episodes identified in distinct regions of the country (9).

As for the significant 1961-1990 triennial droughts in Cuba, it should be noted that moderate and severe deficits recorded within annual accumulated rainfalls doubled in relation to the previous triennium (1), at the same time that persistent drought events affected eastern provinces since the early 90s, which became significant from 1996 up to nowadays.

[P] Centella, A. A.; Llanes, R. J. F.; Paz, C. L. R.; López, C. C. y Limia, M. M. E. *Primera Comunicación Nacional de Cuba a la Convención Marco de Las Naciones Unidas sobre Cambio Climático*. Inst. Instituto de Meteorología (INSMET), Agencia de Medio Ambiente (AMA), Ministerio de Ciencia, Tecnología y Medioambiente (CITMA), 2001, La Habana, Cuba, p. 166.

[Q] Lapinel, P. B. P.; Fonseca, R. C.; Cutié, C. V.; Pérez, B. D. y Rivero, L. I. *La Sequía en Cuba*. Análisis y Pronóstico del Tiempo y el Clima y sus implicaciones socioeconómicas, Proyecto 0451, Inst. Instituto de Meteorología, Ministerio de Ciencia, Tecnología y Medioambiente (CITMA), 2003, La Habana, Cuba, p. 243.

Table I. Indicators corresponding to national agricultural drought episodes diagnosed during 1951-2005 period

Drought period	Classification	The highest affected year	Affected area in the country (%)	With "severe" and "very severe" intensities	More affected regions
1951-1952	Long period	1951	66	92	Central and Eastern
1955-1956	Long period	1956	68	88	Central and Western
1961-1963	Hyper-annual	1961	68	91	Central and Eastern
1965	Short seasonal period	1965	64	89	Eastern and Central
1967	Long period	1967	63	86	Eastern and Central
1970-1971	Long period	1971	63	87	Central and Eastern
1974-1976	Hyper-annual	1975	82	84	Central and Eastern
1981	Long period	1981	63	87	Central and Eastern
1984-1987	Hyper-annual	1986	70	90	Eastern and Central
1989-1990	Hyper-annual	1989	68	76	Eastern and Central
1993-1994	Short seasonal period	1994	42	86	Western
1998	Short period	1998	53	87	Eastern
2000-2001	Long period	2000	41	93	Eastern and Central
2003-2005	Hyper-annual	2004	66	67	Eastern and Central

In this regard, the behavior of cumulative rainfall anomalies was observed within the hydrological years of 1991-1992 and 2004-2005 at the western and central regions of Cuba, with significant deficits over the latest two years.

However, in the eastern region of the country, annual cumulatives showed continued deficits since 1996 and particularly those for the seasonal rainy period started from the very beginning of the 90s. Among eastern provinces, Las Tunas has been one of the most heavily impacted. Hydrological years of insufficient cumulatives began almost simultaneously with deficits recorded during the 90s rainy periods (2).

Deficits from 1991 to 2005 hydrological years accumulated 1300 mm, while during the rainy seasonal period, they reached almost 1200 mm.

Considering the limited rainfall quantities in Las Tunas, such deficits were not only highly significant, but also absolute values in its available real records since 1961 (2, 9).

The drought event from May, 2003 to April, 2005 (24 consecutive months) is one of the most intense ever known, since there are reliable rainfall records in the country, which had a very serious impact on broad sectors of society, economy and environment. Official statistics claim that direct damages to economy caused by this event exceeded 1,4 billion US dollars. The most significant deficit since 1962 for Cuba was considered during the hydrological year of May, 2004-April, 2005, especially for its central and eastern regions, whereas the accumulated deficit within the latest two years was the most significant for the eastern region, including Las Tunas province (1, 9, 21).

MORE STRIKING DROUGHT PROCESSES IN CUBA FROM 2005 TO 2014 AND ITS CAUSES

Among the most outstanding aspects related to drought causes in Cuba, some authors[R] generally indicate the following points (22):

♦ Significant increases in mid annual geopotential heights of the main pressure surfaces, observed from mid-70s in the central region of Atlantic anticyclone and Cuba. This has to do with changes in the global air and sea surface temperature from the tropical region, which constitutes a coherent process with rainfall inhibition and, consequently, the establishment of persistent drought processes affecting this region.

[R] INSMET. *Causas de la sequía en Cuba y su pronóstico*. Informe de Resultado científico-técnico, 2000, La Habana, Cuba, p. 112.

♦ Existence of a strong relationship between the marked polarity on the frequency of occurrence of warm and cold phases of ENSO events (*El Niño*-Southern Oscillation) before and after the 70s, as well as important changes in the atmospheric circulation over the area, which favor the development of drought processes.

♦ Significant change of typical characteristics of anticyclonic influence over Cuba under dry extreme conditions during the first phase of the rainy period (May-June); it is possible to notice that the watercourse of average levels, which is typically set in the Central region of Mexican Gulf for this period, may move westward or not under such conditions, predominating an anticyclonic center over Cuba.

♦ The vertical structural characteristics of wind zonal and meridional components during the first phase of the rainy season over Cuba, which indicate a greater presence of Eastern and Northern components under dry conditions in the upper troposphere, respectively, favoring drought processes.

♦ The existence of a statistically significant relationship between rainfalls and an integrated water vapor content in the atmosphere over Cuba, both for the first phase of the rainy season as for the remaining months of the whole year. Its variation from one month to another is associated with the degree of rainfall process efficiency, probably linked to the variable intensity of anticyclonic influence and rainfall-generating systems in the area.

♦ The great variability in rainfall frequency, route and characteristics of different cyclonic systems affecting Cuban archipelago, which makes the task of linking them to drought phenomenon extremely complex. However, there is no doubt about the role that cyclonic processes play in contributing to the annual accumulated rainfall, whether it is not present, they generate a considerable deficit that may help the development of drought phenomenon within its different spatial-temporary scales.

Specifically during 2009-2014 period, according to a study made by specialists from the Agricultural Meteorology Center of the Institute of Meteorology (INSMET)[R], it should be noted which was the hyper-annual trend of the area covered with agricultural drought in the country. The author highlighted that, despite at the end of 2013 the country had 67 % area affected by agricultural drought, since 2009 the trend is to decline; the same happens during the rainy season (PII), whose tendency is to decrease too; however, within the dry season (PpII) it has a contrary behavior, closing in 2014 with 81 % affected area, accounting for 9 % of the worst affected country compared to 2009-2010 drought (Figure 1)[S].

In some studies made[R] (22), it was found that during the analyzed period, values remained above historical averages of the area affected by agricultural drought, except within 2011 and 2012 rainy seasons, whose behavior was below historical averages. A similar behavior was observed in the Western and Central regions whereas in the Eastern region the annual trend was to rise per period (Figure 2)[S].

These same authors point out[R] (22) that during 2009-2010 period, drought hit the country every year, impacting rigorously on Pinar del Rio, Mayabeque, Artemisa, Havana, Cienfuegos, Sancti Spíritus and Santiago de Cuba provinces, meanwhile recently, in 2013, the most affected territories were Pinar del Rio, Havana, Las Tunas, Santiago de Cuba and Guantanamo.

[S] Vázquez, M. R. *Sequía agrícola. Comportamiento durante el 2009 al 2014. Comparación com el promedio histórico*. Informe científico-técnico, Inst. Centro de Meteorología Agrícola, Instituto de Meteorología, 2014, La Habana, Cuba, p. 25.

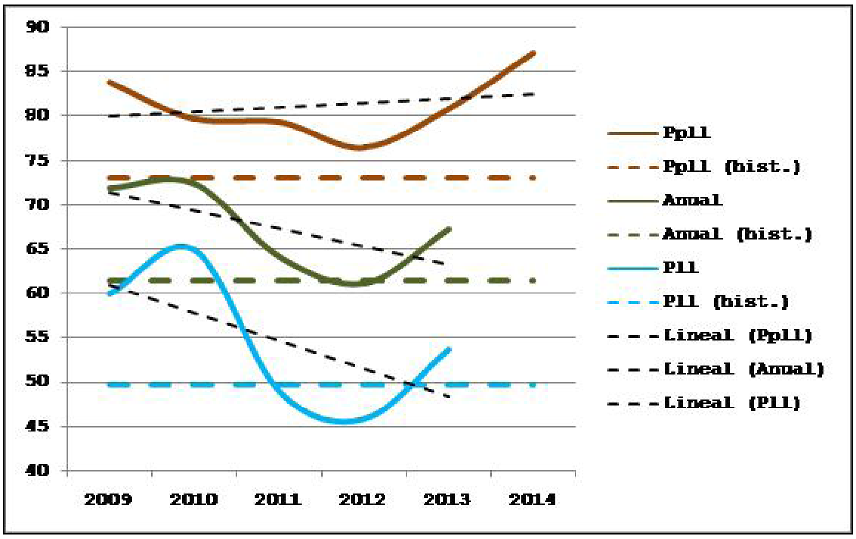

Figure 1. National hyper-annual trend of the area covered by agricultural drought during 2009-2014 period

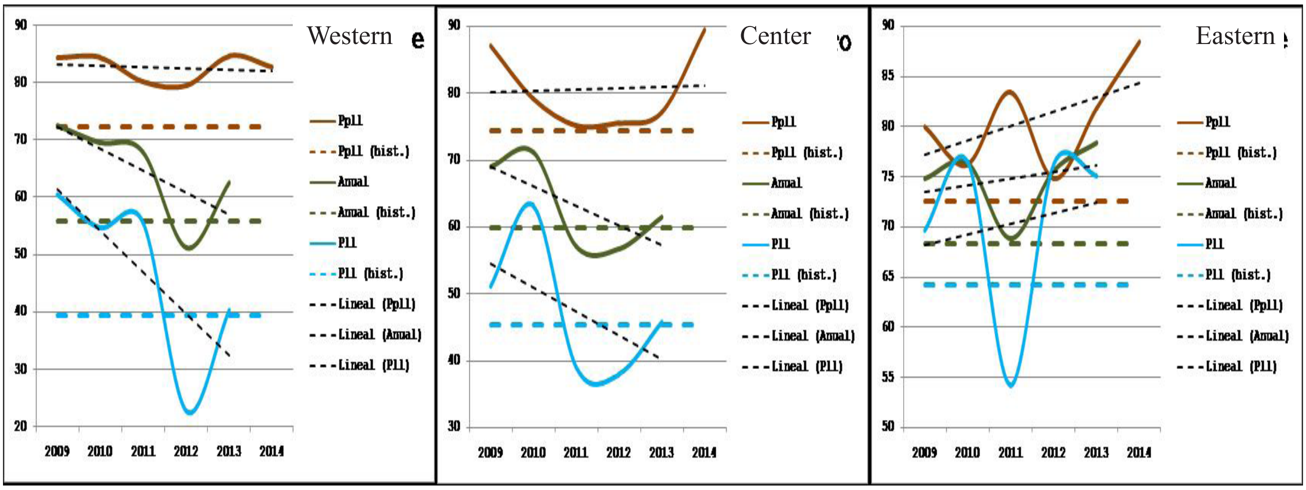

Figure 2. Hyper-annual trend of the area covered by agricultural drought during 2009-2014 period per region

On the other hand, it was noted that the dry period usually behaved drier than normally, particularly in 2014, when the most affected areas were in the territories of Matanzas, Cienfuegos, Ciego de Avila, Camaguey, Las Tunas, Santiago de Cuba, Guantanamo and the Isle of Youth. However, 2011 and 2012 were wetter years than normally.

In the rainy season of 2013, Santiago de Cuba and Guantanamo were more affected than normally by up to 30 %. Regarding the behavior of temporary agricultural drought in the country, the study allowed to verify that annual lengthening of historical average agricultural drought was about 57 % of 36 decades; nevertheless, for the dry and rainy periods, the historical average agricultural drought lasted about 73 and 47 % respectively of 18 decades comprising the temporary period. For 2009, 2010 and 2011, it lasted 67, 69 and 61 % respectively, meanwhile in 2013 it was of 58 %, very close to the standard and 64 % in 2013[R] (22).

DROUGHT IMPACT IN AGRICULTURE

Drought effects can be observed in the short and long term, affecting not only productive activities in the field, such as agriculture and livestock, but also basic industrial activities and well-being and health of inhabitants from rural and urban communities.

Such drought effects are mainly related to water shortage and worsened by other factors associated with the lack of moisture, which makes the situation more critical. Among others are the following factors: high or low temperatures, hurricane winds, occurrence of certain pathogens, heavy rains after dry periods, vegetation cover degradation, neglec ted and damaged natural water channels[R] (5, 19, 23-25).

The man through some of his practices makes drought impacts more acute, as for instance those that reduce moisture retention capacity or favor erosion, such as organic matter destroyed by burning stubble, overuse of chemical fertilizers, monoculture, uncontrolled grassland burning, fallow periods during low rainfall seasons, stones taken up on slopes, inappropriate land agriculture and excessive use of water (5, 21, 24).

Drought impacts in different ways, which can be direct and indirect, single or cumulative, immediate or delayed; some affect large areas permanently while others semi-permanently or isolated. The main impacts that occur as a consequence of drought are of three types: economic, social and environmental. This paper essentially refers to the impacts on agriculture through its economic and environmental dimensions (5, 19, 24).

Agricultural impacts with economic repercussion have been studied and documented in nearly all countries affected by this phenomenon, due to growing losses are priorities of governments and agencies to assess its amount, so as to establish insurance strategies to mitigate and reduce risks.

Obviously, studies have been conducted to evaluate and prove drought damages on agricultural production, either in field crops, fruits and vegetables, or forests and livestock[R] (5, 19, 23-25).

Available background data on drought susceptibility in a given area and drought sensitivity of different crops in the region should be tested and evaluated by using all research resources of the region available on this subject (5, 24, 26).

Various technological tools, such as scenario modeling, crop damage curves and infrastructure of affected agricultural entities, obtained through mathematical and probabilistic analysis, spatial analysis of the phenomenon range by using GIS, spatial-temporary and spectral analysis through satellite images should be considered by researchers carrying out projects on this subject (27, 28).

Such technological tools can be used in comparative analysis of harvests, together with climatic and hydrological conditions, in order to give better responses on drought intensity within the periods studied as well as on the concrete damages and economic losses in agricultural production. This integrated analysis may help discover differences between species and varieties of cultivated plants, their tolerant capacity to water deficit and lengthening of their vegetative periods, as they are important characteristics to reduce injuries.

It is also necessary to study the preceding crop effect on rotation and determine the best plants and rotations in the region studied, so that drought damages can be sensibly reduced (5, 24, 25).

Another important aspect is the effect of sowing or planting density; if it is too high, drought effects will be even higher. The other agricultural practices should be also evaluated, such as tillage and soil care, its preservation, nutrient supply procedure, defense against weeds and plant diseases, etc. (5, 24, 25).

In short, drought effects on agricultural production, livestock, forestry and fishery with economic impact, is highlighted in the following indicators (24).

Agricultural losses: annual and perennial crop losses, crop quality damages, farmers' income losses due to harvest reduction, limited farmland productivity (wind erosion, organic matter losses, etc.), insect pests, plant diseases, wildlife damage to harvests, increased costs of irrigation and new or additional water resource development.

Livestock losses: decreased milk production, reduced livestock, limited or closed public grazing lands, unavailability or high costs of water for livestock, new or additional water resource development costs, unavailability or high costs of food for livestock, increased costs of food transport, high rates of cattle mortality, disruption of reproductive cycles and decreased cattle weight.

Timber production losses: forest fires, tree diseases, insect pests, reduced forest productivity and direct loss especially of young trees.

Fish production losses: fish habitat damages, losses of fish and other aquatic organisms due to reduced water flows.

General economic effects: losses in industries directly related to agricultural production and enterprise income, reduced economic development and rural population.

Energy-related effects: reduced energy supply due to restrictions caused by drought and increased costs due to expensive fuel replacement.

Impacts related to water supply: costs of water transport and of new or additional water resource development.

With regard to reduced food production: the following impacts include: increased food prices and higher food importation costs.

Tourism effects: significant damages due to negative drought impacts may cause a rapid decline of the national and international tourism as well as large losses in those countries where this sector is very important.

Trade effects: reduced production of basic raw materials and product storage losses caused by negative drought effects on trade, particularly in export and import relationships. The country whose economy is affected by drought needs to compensate its losses by increasing mainly food and feed imports, which represents an extraordinary expense.

Financial effects: the financial world generally responds with a rise in prices to agricultural production losses, food processes, commodity exchange and energy consumption, quickening inflation and promoting inconvenient processes and trends in the financial world: farmers and producers go bankrupt, investments are removed and improved production conditions are suspended, etc.

Every year, drought risk has represented the largest percentage of total risk compensation covered by the insurance branch of agricultural goods in Cuba (9). These figures only apply to compensation caused by drought damage to insured farmers nationwide, not to the total losses for this concept in the country.

The data presented in Table II show a substantial difference among insurance expenses of agricultural goods from the National State Insurance Company for drought risk (5, 8). Eight years prior to 1998 (1990-1997), even considering late 1997, when there was an intense agricultural drought that caused great damages in Cuba, averaged annual expenses of about 6 563 million pesos in compensation for drought risk to insured farmers.

The next eight years (1998-2005) averaged annual expenses of 44 238 million pesos for the same concept, that is, the average value of damages caused by drought risk during the latest eight years exceeded almost seven times the average value of drought expenses during the previous eight years (9).

A summary of drought impact on 1998[T] is presented to show the extent of its effects on Cuban agriculture (23, 25), which caused heavy losses to this sector and severe hardships or pressures throughout the country, mainly in its eastern region that can be summarized as follows (23, 25):

Table II. Nationwide compensations for drought risk covered by the insurance branch of agricultural goods from the National State Insurance Company in Cuba

Year	Drought compensation (thousands Cuban pesos)	Total risk percentage (%)
1990	3 610,80	22,5
1991	7 754,00	45,6
1992	4 962,30	43,9
1993	6 229,50	39,4
1994	8 115,30	43,3
1995	5 906,50	27,0
1996	3 722,70	9,9
1997	12 203,90	25,4
1998	24 402,80	29,1
1999	40 854,00	37,9
2000	56 154,60	50,3
2001	60 667,00	38,1
2002	30 425,00	25,4
2003	30 408,70	32,3
2004	42 602,10	34,3
2005	68 391,60	40,9

♦ The agricultural sector of various crops estimated losses of 166 000 t of food in five eastern provinces.

♦ Among the most affected crops from May to June, 1998, are food grains (rice and corn mainly) in Las Tunas, Holguin, Santiago de Cuba and Granma provinces; various crops as bananas, beans and vegetables such as garlic, onion and other species. According to a study performed by the World Food Program (WFP), 205 548,7 ha were lost just in potato, banana, tomato, cabbage, cucumber, mango, avocado, strawberry and bean crops, which are equivalent to 59,6 million pesos, as for example, cabbage production lost 6 954,0 t at the cost of 0,5 million pesos, whereas cucumber production lost 942,0 t at the cost of 0,1 million pesos and bean production lost 4 369,8 t at the cost of 5,3 million pesos.

♦ Sugarcane agricultural sector lost about 8 000 ha of spring cane in the five eastern provinces and only in Granma, Las Tunas and Guantanamo, sugarcane losses exceeded 700 000 t.

♦ Livestock sector evacuated 25 000 animals and water was supplied by tank vehicles to more than 225 000 cattle. The five eastern provinces reported losses of 5 million liters of milk, many

[T] CYTED-INSMET. *La Sequía Agrícola. Estado del Arte*. edit. Red UTEEDA del Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo (CYTED), 2006, La Habana, Cuba, 101 p.

burned grasslands and about 13 000 dead animals by malnutrition in the state sector from January to April.

♦ In the insurance branch of agricultural goods, the concept of drought was the risk of greater expenses for compensation by the National State Insurance Company in 1998 to its insured farmers, with more than 24 400 million pesos.

♦ Food production losses in the eastern provinces within April-May-June period were of US 270 million dollars.

At present, it is known that from the second half of the XX century, agricultural drought has increased surface extension, intensity and duration. The drought knowledge learned in Cuba can explain its surface extension has increased, with an average annual growth of about 8,000 ha in previously unaffected areas, characterized by a higher surface extension within the rainy season and the decline of these indexes during the dry season (26).

As for environmental impacts of drought, it is known that the area affected by forest fires in Cuba, since 1980, has increased with an average annual growth of about 400 ha in previously unaffected areas, whereas dryland (arid and dry sub-humid) has increased during the last decades (9, 24, 25).

Environmental losses are the result of damages to plant and animal species, wildlife habitat, air and water quality, fires, landscape quality degradation, loss of biodiversity and soil erosion. Some of them are short-term effects, others take longer and some become permanent. An extensive drought can lead to short-term desertification, forest fires and the general degradation of soil quality.

Sometimes the effects are short, so that normal conditions are quickly reestablished when drought ends. Wildlife habitat may be degraded by the loss of wetlands, lakes and vegetation. However, many species eventually recover from this temporary aberration. Landscape quality degradation, including growing soil erosion, may lead to more permanent loss of biological productivity (9, 24, 25).

In general, the most harmful and dangerous effects of drought are observed in the environment, natural resources, species habitat and ecosystems. Such problems require great attention, because society can do little to recover from damages caused to ecosystems that have been affected or even dead. Therefore, the only effective measure for these cases is the adequate protection of natural resources, especially in sensitive areas, from the environmental point of view (9, 24, 25).

Among the strategies to be followed by agencies of the State Administration responsible for drawing up plans and programs of action against drought, such as the Ministry of Science, Technology and Environment (CITMA), the National Institute of Hydraulic Resources (INRH) and the Ministry of Agriculture (MINAG), is to carefully evaluate all those drought impacts affecting the main environmental elements, such as impact quality and quantity on water, soil, air and living organisms (flora and fauna)[U] (20, 21).

An aspect of priority that should be considered is the evaluation of protected natural areas and natural parks, where it is necessary to foresee specific actions to protect species, habitat and fragile ecosystems, paying particular attention to combined environmental effects, such as increased pollution and volume of various types of environmental wastes and, particularly, toxic materials and wastes. These effects, combined and complex, may become worsen during drought periods, especially due to less dilution and purification capacity of their receptors (9, 24, 25).

The environmental impacts caused by drought events (24) are the following ones:

Damage to animal species: reduction and degradation of wildlife and fish habitat, lack of food and drinking water, higher animal mortality rate, diseases, wildlife migration and concentration as well as biodiversity loss.

[U] Grupo Nacional de Lucha Contra la Desertificación y la Sequía. *Programa de Lucha contra la Desertificación y la Sequía en la República de Cuba*. Inst. Centro de Información, Gestión y Educación Ambiental (CIGEA), Secretaría de la Convención de las Naciones Unidas de Lucha contra la Desertificación y la Sequía (CCD), Organización para la Agricultura y la Alimentación (FAO), Fondo Internacional de Desarrollo Agrícola (FIDA), 2003, La Habana, Cuba, p. 154.

Hydrological effects: low water levels in reservoirs, lakes and ponds, reduced spring flows and streams, loss of wetlands, impact on estuaries (changes in salinity levels), decreased groundwater and effect on water quality.

Damage to plant communities: loss of biodiversity and trees in urban and rural areas.

CRITERIA ON THE USE OF SATELLITE IMAGES FOR SPATIAL-TEMPORARY STUDIES IN ARID AND DRY AREAS (ESPECIALLY IN DROUGHT EVENTS)

Satellite images are nowadays technological tools to address a large part of environmental phenomena, generating maps and indicators that allow managers, technicians and specialists from agricultural and environmental sectors to establish risk mitigation strategies of disasters and strengthening policies for environmental sustainability.

Agricultural drought phenomenon together with the evaluation of arid and dry areas at the environmental sphere and specifically in land management is where the use of satellite images has an increasing application (29).

Drought monitoring exists in most countries using terrestrial information with parameters related to rainfall, climate, harvest condition and water availability. These parameters are composed of data obtained from terrestrial observation from satellites, which enable to monitor them more effectively (21).

The reasons that make possible the use of a technological tool of space-remote sensing are its ability to discriminate large areas with different characteristics in their physic-chemical composition of soil surface (as is often the case of areas affected by salinization processes, moisture, arid and dry areas), due to its property to reflect the electromagnetic energy coming from the sun in different magnitude and also because of the response capacity of satellite sensors of natural resources to detect different levels of reflectance[V].

One of the great advantages of satellite images is that satellites that capture them go through the same place periodically, ensuring multi-temporality studies. Another advantage is that depending on its spatial characteristics, they can be used to generate subject mapping at variable scales, from some level of details as is the case of NOAA-AVHRR (used to study scale of 1: 1 000 000) up to scales of high level of details (1: 20,000), as is the case of IKONOS, Spot, etc., going through those of an intermediate level of details (scales between 1: 250 000 to 1: 50 000), as is the case derived from Landsat TM or ETM, SPOT, MODIS, etc. Others have the advantage of being a relevant document to update topographic mapping, as is the case of Google Earth images, provided they are of recent times[U, V, W].

Considering this background information, the satellites used to support drought management are (33):

For prediction: stationary meteorological satellites are used (GOES-US; METEOSAT-ESA; GMS-Japan, INSAT-India; Fen Yun–China; SSMI (Special Sensor Microwave Imager) from DMSP (Defense Meteorological Satellite Program) and AMI (Active Microwave Instrument) on ERS-2.

For monitoring and early warning: AVHRR (Advanced Very High Resolution Radiometer; TOVS (TIROS Operational Vertical Sounder) from NOAA series; IRS/WIFS (India); Spot-4/Vegetation (CNES); MMRS, HRTC/SAC-C. But also for monitoring, although an evaluation is necessary, (TRMM (Tropical Rainfall Measuring Mission)-NASA and NASDA; MODIS/Terra and MERIS/Envisat can be used.

For drought system based on GIS: high spatial resolution satellites Landsat (USA), IRS (India) and Spot (CNES).

In the case of Cuba, there is an available full coverage of satellite images of different spatial, spectral and temporary resolution, which is an important element when selecting geospatial data from past and present times to implement studies on this phenomenon.

The different types of images from available sensors of Earth observation in our

[V] *Ventajas y desventajas de las imágenes de satélites en la evaluación, monitoreo y manejo de los recursos naturales*. Inst. UNAH, 2015, Mayabeque, Cuba, p. 10.

[W] Pérez, G. E. *Cobertura*. Inédito, 2015, Comunicación personal.

country covering absolutely the whole territory[W] are:

- ♦ Landsat Thematic Mapper (TM) Enhanced Thematic Mapper (ETM): both current and old images can be downloaded for free from dissimilar portals.
- ♦ Spot-HVR: current satellite images are not free, as the previous case; it is necessary to buy them from dealers; however, a large part of the national territory is covered with distinct patches from different organisms and research centers, where they can be requested to perform these studies.
- ♦ NOAA/AVHRR: these satellite images are available for free throughout the entire country and can be purchased by requesting various institutions, such as the Institute of Meteorology that daily captures and downloads for operational work of monitoring and weather forecasting.
- ♦ GOOGLE EARTH: there is complete coverage of many regions in Cuba with this type of images that are downloaded for free via Google Earth Pro software, existing organizations as GEOCUBA, which has an available bank of them.
- ♦ There is also another group of images from IKONOS and MODIS sensors that have been bought by several business and scientific institutions of the country or received from collaborative projects with international scientific and academic institutions, which can also be requested by fulfilling a specific protocol.

As it was stated in preceding paragraphs, droughts in Cuba constitute one of the major events that have affected some regions interruptedly or extremely severe and, in other cases, it has damaged almost all the national territory.

Nevertheless, the little use of these valuable geospatial data on important studies carried out in the country constitutes a limitation of our system of science and technological innovation as well as environmental strategies, like the cases of drought event in Las Tunas from 2003 to 2005[M], the city of Camagüey in 2004 (25), Sancti Spiritus in 2004-2005 (23) and Guantánamo[X].

These studies have essentially employed GIS tools and mapping, but not spatial remote sensing tools. Hence, experiences on this subject are scarce and emerging in the country, so that a deep analysis is needed by authorities and specialists of different national environmental agencies, water resources and scientific or academic centers that have to do with drought phenomenon in Cuba, which must evaluate the research projects that will be undertaken in the future, in order to promote the use of these tools for a more objective assessment of drought phenomena by using satellite images.

This is not considered the international case, where studies have been conducted in countries like Argentina, to identify and assess drought severity by using satellite images combined with rainfall data derived from surface meteorological stations.

In this particular, satellite images have been used to assess drought on a global scale (25, 29) and it was studied in Pampas region, so as to see its influence on wheat yields (30-33). Drought was identified and evaluated in several locations of Cordoba and Buenos Aires using information from weather stations and satellite images (29).

The potential contribution of the existing satellites today is far from being fully exploited; thus, it is necessary to use more effectively the synergy provided by the combination of data from internationally distributed satellite sensors (31, 33).

Drought monitoring mechanism in many countries is based on obtaining terrestrial information about the phenomenon, by linking parameters such as rain, weather, crop conditions and water availability, etc. In this regard, Earth observations from satellites are used as additional data collected by "*in situ*" systems as mentioned above. However, satellites are often necessary, since they provide summary information, covering large areas and frequent data required for spatial monitoring of drought conditions.

Hence, nowadays, the status of satellite data for monitoring drought and early

[X] Cruz, D. R. O. *Experiencias en la rehabilitación de áreas del Valle de Guantánamo afectados por la desertificación y la sequía*. Informe Científico, Inst. Agencia de Medio Ambiente (AMA), Ministerio de Ciencia, Tecnología y Medioambiente (CITMA), 2004, La Habana, Cuba, p. 32.

warning is based on rainfall data, surface moisture, temperature and vegetation tracking (33).

At present, there are data sources of multi-spectral and multi-sensor geostationary platforms, such as GOES, METEOSAT, INSAT and GMS, and polar orbit satellites as NOAA (National Oceanic Atmospheric and Administration), EOS-Terra, DMSP (Defense Meteorological Satellite Program) and IRS (Indian Remote Sensing Satellite), which have been used or planned to evaluate meteorological parameters, data interpretation, validation and integration. They are employed to estimate rainfall intensity, amount and coverage as well as to determine the effects of surface moisture on the soil and for studies on drought events (32-35).

At the international level, a group of recommendations have been given to establish a system of indicators based on satellite images aimed at forecasting, monitoring and managing drought, some of which are outlined below. In Spain, some authors have referred to the need and significance of establishing a system of indicators based on the use of satellite images that allows tracking drought indicators (36).

The main objective of these indexes is to provide general principles as a basis for developing others, taking into account some clear notions about the own concept of drought and others close to it as well as those with which it is often confused.

These authors have developed important studies for the rapid detection and spatial-temporary characterization of drought by means of using certain indexes drawn from MODIS satellite images, so enabling to generate strategies for impact mitigation. An approach to the problem of early warning against drought has been made at the regional level in southeast basins of Spain, considering indicators based on satellite images and meteorological data.

Among the indicators based on remote sensing are those obtained through interpreting the space described by land surface temperature (LST) representation and Normalized Difference Vegetation Index (NDVI). The study enabled to determine that the relationship between surface temperature and moisture regime in the soil detected the onset of drought conditions before strongly adverse impacts appeared on vegetation and crops.

Regarding these results, it was concluded that probabilistic indexes only based on rainfall do not show the same spatial-temporary behavior observed from satellite images (35, 37).

At present, in Spain, a Normalized Superficial Drought Index (NSDI) was validated and adapted from the model developed by the University of Nebraska with MODIS images (Normalized Difference Drought Index, NDDI) index. Such index is obtained from MERIS images by combining a water content index at the terrestrial surface (NDWI, Normalized Difference Water Index) with a vegetation index (NDVI) (37).

Meanwhile, in Argentina, grasslands productivity was analyzed, which is the main extensive sheep food of Santa Cruz province, and its variation per year, so determining it is closely linked to annual rainfall, its quantity and distribution in that period (37).

These authors showed a quick form to perform inexpensive studies by using remote sensors to monitor large areas, analyzing vegetation through spectral indexes.

In this case, a multi-temporary analysis of the province was conducted by using MODIS images from Terra/Aqua satellites, which have large sweeping coverage (about 2 300 km), high temporary (going through the same site every 16 days), spatial (pixel of 250 m) and spectral resolution. The growing season (September, 2007- April, 2008) was also analyzed with respect to historical values, obtaining the variation of vegetation indexes per each month, enabling to have an idea of drought severity. During 2007 and 2008, indexes decreased, compared to historical average, which implies a smaller quantity of green biomass that can be explained, among other factors, by a less rainfall amount.

The analysis was performed with two vegetation indexes: NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index). The authors employed algorithms implemented in NASA to generate different types of products from MODIS images. One of them is MOD13Q that has 12 bands. Bands 1 and 2 correspond to NDVI and EVI vegetation indexes, respectively. Such indexes are very useful for multi-temporary analysis whereas synthetic images of 16 days supply maximum pixel values during the period, thus reducing cloud and snow effects.

This team obtained a drought characterization in the pampas grasslands by using drought indexes and satellite information (37). They also tested an early warning system to evaluate drought occurrence in the national territory through terrestrial and satellite weather information, which is subjected to a developing and validating status. Droughts are characterized by its intensity, frequency and geographical spread throughout the country. Although a priority area is considered the one destined for summer and winter annual crops, the system will be used in other marginal cattle and agricultural regions too.

In order to complement the analysis carried out by Water Planning Offices using Hydrological Drought Indexes, a new methodology was developed with weekly MERIS satellite images, so as to calculate a Normalized Surface Drought Index (NSDI) adapted from the model of the University of Nebraska (37, 38). This is obtained by combining a water content index on the terrestrial surface (NDWI) and the normalized differential vegetation index (NDVI).

NSDI index is not based on hydrological variables, but it reflects what is happening on the terrestrial surface related to water content and plant housing cover vigor. Therefore, NSDI does not replace the existing hydrological indicators, but it can be a very useful complementary tool to manage resources in river basin districts.

Drought was identified and evaluated in several locations of Cordoba and Buenos Aires during 1982-1983 and 1988-1989, by applying Palmer Drought Index (PDI) and vegetation index. This work allowed comparing and validating the results of drought analysis through traditional methods using data from terrestrial stations, with the information obtained from satellite images (37, 38).

CONCLUSIONS

- ♦ There is an international consensus on four basic types of droughts: meteorological, agricultural, hydrological and social or economic. The factors affecting each type are correlated and meteorological drought is the most important; therefore, the others are derived from it and particularly from the lack of rainfall.
- ♦ Research studies performed in Cuba advice that the increased degree of soil aridity in recent years along with the behavior of climatic change model projections for the country have provoked drought events occurred within 2003-2005 period, classified as the most intense in the latest 100 years along the national territory.
- ♦ This research allowed to appreciate that there are three main types of impacts resulting from drought occurrence: economic, social and environmental. The economic impact of drought within 1990-1997 period caused agricultural losses in Cuba for an annual average cost of 6 563 million pesos, in compensation to insured farmers for drought risk, whereas during 1998-2005 period, annual average expenses of insurance agencies was of 44 328 million Cuban pesos for the same concept.
- ♦ Specialists and technicians can assess drought by using their own technological tools, such as: scene modeling, direct economic damage curves for crops and affected agricultural entity infrastructure, spatial analysis of the phenomenon extent by using GIS, spatial-temporary and spectral analysis using satellite images, among others.
- ♦ The situation of our country advices that there is still much to search for, since it is necessary to promote their use; although there are some international experiences susceptible to be applied and adapted to our conditions, they are not practically applied to various projects due to different objective and subjective reasons.

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