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Water Quality Management in Cienfuegos Bay (Cuba) with Integrative Approaches

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Abstract— *The aim of this paper is to analyze the contributions of some tools developed with integrative approaches for managing water quality, considering the particular case of Cienfuegos Bay, Cuba. One of the contributions was related to the improvement of a hydrologic monitoring program of this bay with the assimilation of Environmental Totality and Integrated Watershed and Coastal Area Management (IWCAM) approaches. The development of an index for assessing water quality (WQI) of estuarine systems associated with a methodology for implementing a conceptual model on the eutrophication management from systemic and causal approaches, were another developed tools. In addition, a strategic program as a guide for the integrated management of this bay was included considering the participatory and systemic approaches. The assimilation of these integrative approaches for developing scientific tools allowed improving the environmental management at a contextual level and could be generalized in similar aquatic systems.*
Keywords— eutrophication, coastal management, integrative approaches, Cienfuegos Bay.

I. INTRODUCTION

At the international level, different scientific tools are used to support coastal environmental management such as environmental monitoring, integrated management programs, indicator systems, among others. Scientific research and environmental monitoring are key components in the decision-making process, as well as for the development and implementation of policies (Vugteveen *et al*., 2014). These contribute to assembling the data and information in useful ways for the managers of the resources.

Watershed and coastal zone to where drain their waters, keep a close relationship. The coastal zone receives direct all processes and phenomena occurring in the basin (González-Díaz, 2015). To contribute to the success of coastal management in an integrated way is a task very important in Cuba. The science using to support this process requires integrative approaches such as Integrated Watershed and Coastal Area Management (IWCAM), systemic, Environmental Totality, causal by means Driver-Pressure-State-Impact-Response (DPSIR) framework, participatory, among others. The integrated management has to be conceived so that national states can develop it voluntarily; adapting it to its ecological characteristics and socio-economic needs and particular cultural contexts (Barragán-Muñoz, 2012).

Cuban scientific institutions related to the environmental management of coastal resources are called to contribute to the strengthening of this process in the provinces, through the development of tools contributing to making decisions based on knowledge. The development of monitoring programs aims to provide an empirical basis for the evaluation of an environmental phenomenon or its trends (Carstensen *et al*., 2011). Consequently, the existence of a program for assessing water quality of the Cienfuegos Bay for more than two decades and projects carried out in the province, all of them related to integrated water and coastal resource management have supported the improvement of this process through the gradual assimilation of integrative approaches in the development of relevant scientific tools. The purpose of this paper is to analyze the contributions of the tools developed with integrative approaches for improving the water quality management in Cienfuegos bay.

II. MATERIALS AND METHODS

2.1. Study area

Cienfuegos bay is situated in the southern central part of Cuba (22°1′ N, 80°20′ W). It is a semi-enclosed bay with an estuarine characteristic. It is connected to the Caribbean Sea

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by a narrow channel 3.6 km long. Its area is 88.46 km^2 and a total volume of 0.84 km^3 with an average depth of 9.5 m (Muñoz *et al.*, 2012).

This bay is divided into two natural lobes. The northern lobe has a more anthropogenic impact: e.g. sewage discharges from the city of 161,432 inhabitants (ONEI, 2012) and the incidence from the industrial area. There is also freshwater input from the Damují and Salado rivers and from other aquatic systems such as Inglés, Calabazas and Manacas creeks (Fig.1). In this region, despite actions by the local government to reduce pollution in the bay, the wastewater treatment is still inadequate. The southern lobe is subjected to a lesser degree of pollution arriving from the Caonao and Arimao rivers.

Fig.1: Localization map of Cienfuegos bay (Cuba) and current sampling stations

2.2. Approaches considered to develop tools

The integrative approaches of Environmental Totality (ET) and IWCAM were articulated, enhancing their multidimensional nature to guide and support the need to improve the Monitoring Program of the Cienfuegos Bay (MPCB) that had been carried out since the 90s, which is considered as the first tool developed.

The theory about the environment as a complex whole is important because considers the reality part where coexist and interact the biotic, no biotic and social elements directed in constant development by the social activity. Thus the integration cannot start from the vision of a mechanical sum of elements; but it must be assumed as an organizational quality that results from the historical character of the society-nature relationship, under an integral relationship (Miranda-Vera, 2000).

On the other hand, the need to integrate spaces for understanding the environment as a whole, in correspondence with the systemic nature of the management, based the assimilation of the IWCAM approach, which articulates the watersheds and the coastal areas (León *et al.*, 2013).

The MPCB has been implemented to assess its water quality and its design was based on geomorphologic features, as well as on the identification of activities with the highest incidence and distribution of pollutants. However, various socio-economic changes and the training of personnel in new integrative approaches motivated their improvement according to the context demands. This task required the analysis of the polluting sources (direct and indirect), the uses of this bay, as well as the basic elements of the monitoring program design (sampling points, frequency, physical-chemical parameters and depth levels considered, etc.) considering the data obtained during ten years.

The evaluation of the MPCB was based on the analysis of its effectiveness to identify the incidence of new socio-economic activities (the activity change of the Fertilizer Factory, the increase of tourist activity in the northern sector of the bay, etc.) using a methodology with four stages (Seisdedo *et al*., 2004). Some of these stages included cluster analysis to identify spatial and month associations by the Euclidean distances and the proposal of the modified MPCB with its argumentation (Seisdedo and Muñoz, 2005). In addition, a flowchart of the information from the MPCB was proposed for its consideration in an appropriate way on integrated management of this bay (Seisdedo *et al*., 2005).

Subsequently, it was necessary to have a contextualized tool to assess the water quality that would eliminate the difficulties related to the large number of parameters and data, and the inadequacies in the technical regulations (NC 22, 1999; NC 25, 1999) on the criteria for systems with estuarine characteristics such as the Cienfuegos bay. In addition, this would be useful for the presentation of results to decision makers and the general public. Therefore, an adaptation was made to the proposal of the Canadian Council of the Ministries of the Environment (CCME, 2001) to developing a Water Quality Index (WQI) for this estuarine system, which is based on the consideration of the quality criteria established in Cuban technical regulations, as well as of the results obtained in the two levels of depth and also, the change from a temporal to spatial focus of the frequency factor, in order to provide a spatial assessment of water quality corresponding to a single campaign instead of a temporal evaluation in a single station. The selection of the parameters to be included in the WQI was based on the evaluation of the correspondence between the anthropogenic incidence and the results of this index considering all the parameters regulated or only some proposed for estuarine systems of South Africa (SOE, 2000), which cover three categories: trophic status (N-nitrate and orthophosphates), convenience for aquatic biota (dissolved oxygen, Biochemical Oxygen Demand and ammonia), for human contact (fecal coliforms) and two others (N-nitrites and chlorophyll *a*), with importance for the assessment of trophic status according to some results reported (Seisdedo *et al*., 2011).

To this was added, the assimilation of integrative approaches such as the systemic and causal (DPSIR) to design and implement the environmental management of this bay with a preventive point of view based on the analysis of eutrophication risk. This was necessary considering the appearance of several events of algal blooms in some areas of this bay since 2005 (Moreira *et al*., 2009). Therefore, an analysis of current trends and the context was carried out for designing the conceptual model considering some aspects (principles, main characteristics and indicator categories) and selecting the indicators. Besides, expert criteria and statistical analyzes (Kendall coefficient, test Wilcoxon and coefficient Rho of Spearman) were used to validate the conceptual model of eutrophication management, its methodology and associated tools (Seisdedo *et al*., 2016).

Also, it was necessary to have an Integrated Management Program of the Cienfuegos bay, to contribute to the implementation of IWCAM approach as a participative and inclusive social process oriented towards the sustainable development of the Cienfuegos province. In its elaboration, relevant information provided by various institutions was considered and this program was conceived from a strategic point of view. It has been pointed out that the formal approach to integrated management should be oriented towards strategic management budgets: flexible, adaptive, broad perspective, participatory, designed for the long term, which assumes adverse scenarios and takes into account both the process and the results (Barragán-Muñoz, 2012).

III. RESULTS AND DISCUSSION

The approach of ET allowed us to assume a philosophical understanding of the environmental, and therefore expand the view, which must be taken into account for any environmental analysis. The comprehension of its existence as an integrated whole leads us to consider the methodological assumptions that on the totality are enunciated from the dialectical - materialist vision. In fact, three basic methodological assumptions served as a basis to consider the entire bay and its social environment as ET (Miranda-Vera, 2003), which are:

1. The necessary articulation and interconnection of the essential parts of the whole. This allowed us recognizing which are the essential parts of the area to be studied as ET, which in this case were: Cienfuegos city and its bay, so that the systemic nature of this relationship is visualized.
2. The internal contradictions of the whole, which define its dynamics of change and development. This allowed us recognizing the environmental problems of the study area considered as ET and

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that must be transformed in all manifestations of the material level: biotic, no biotic and social.

3. The historical character of the whole, insofar as it is a process that is in constant development. This allowed us recognizing the history of the economic, social, cultural and natural development of the study area considered as ET since today is the result of yesterday and the history of tomorrow will depend on what is done today.

The aspects that characterize the ET and that respond to an environmental reality under study, reveals that this totality in construction is a holistic, systemic, continuous, dynamic, historical and concrete expression of the contradictory relationship between society and nature.

The new proposal of monitoring program included the need to quantify the pollutant loads of the tributary watersheds, the incorporation or elimination of some sampling points, the consideration of the vertical sampling (in depth and surface) due to the marked vertical haline stratification of this bay, as well as the decrease of the sampling frequency considering results of an analysis of the seasonal influence on the water quality of this bay (Seisdedo and Muñoz, 2005). As a result, 16 sampling points for the bay, 9 points for the main tributary sources (rivers, creeks and drainages of the Cienfuegos city) (Fig.1) and at least two campaigns per year in correspondence with the wet and dry periods were established.

A Water Quality Index (WQI) was proposed for estuarine systems such as the bay studied (Seisdedo and Muñoz, 2013), which considers some parameters related to the three categories mentioned above. After it's testing during the period 2010-2012, the obtained results showed a correspondence from a spatial point of view with the anthropogenic incidence reported previously (Seisdedo, 2006; Seisdedo and Arencibia, 2010), which allowed consider it as an effective scientific tool for the water quality management in this aquatic system. In addition, it allows numerous data to be summarized in the key information to evaluate the progress made with respect to the established objectives so that its use to date has been important. Besides, this WQI allowed identifying an improvement of water quality based on a change from mediocre to acceptable quality when the nutrient load incorporated from rivers decreased 310 ton of nutrients (N+P) in 2014 (Seisdedo *et al*., 2016).

The design of the conceptual and methodological tools for the water quality management from the trophic point of view in Cuban bays with estuarine characteristics such as Cienfuegos bay was based and characterized in the proposal of 10 identified indicators under the DPSIR framework (Seisdedo *et al*., 2016). These were concretized in contextualized assessment tools that allow orienting this environmental management through four stages: to prepare, to plan, to implement and to control-evaluate, in an appropriate way including participatory conception, which requires the strengthening of the relationships between the stakeholders and the training on IWCAM approach (León *et al*., 2013; Castellanos *et al*., 2009). The conceptual model of this environmental management in the Cienfuegos bay was validated considering the obtained values of Kendall coefficient (W) and significance obtained ($p<0.05$), which showed an appropriate association degree in the expert criteria. The methodology used to implement it included a set of procedures that ensured a logical, practical, simple and coherent sequence. With the application of them during the period 2013-2014, very favorable results related to the improvement of the water quality from the trophic point of view in the studied bay were obtained. These results showed that the nutrient loads incorporated into the bay and its water quality through the WQI showed the effectiveness of the actions designed to manage eutrophication. In addition, the socialization actions related to this process were increased, and stakeholders (government, communities and entities) were involved in this environmental management, as well as the applicability, adequacy to the context and effectiveness of the associated tools were verified.

The Integrated Management Program of the Cienfuegos bay allowed the definition of strategic actions corresponding to the period 2016-2020 based on the achievement of environmental training from decision makers and the general public, the reduction of interest conflicts generated by socio-economic activities, the improvement of participation mechanisms and integration of the key social actors in decision making, the improvement of socio-environmental conditions through the gradual solution of environmental problems identified in the territory from a contextual approach, promoting financial sustainability to guarantee the continuity and dynamics of the IWCAM process.

IV. CONCLUSION

The gradual assimilation of integrative approaches in the development of scientific tools to improve the water quality management in the Cienfuegos bay, for more than a decade, has generated some theoretical and methodological aspects. The importance of them is that have allowed to recognize the complexity of this process for Cuban bays with estuarine characteristics and contribute to the systematization and strengthening of inter-institutional and community relationships, as well as to the links between the

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processes of analysis and decision-making, with satisfactory results and possibilities of generalization in other bays with similar characteristics.

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