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# Climatic Variability Patterns Associate to Water Resource Management Systems

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**Abstract**

Patterns of climatic variability were established between 1977 and 2013, associated to water management systems, in the jurisdiction of the Bucaramanga Regional Autonomous Corporation (CDMB). Flow, precipitation and temperature data obtained from the CDMB and of the Hydrology, Meteorology and Environmental Studies of Colombia (IDEAM) were used. For the evaluation of the current water management system, the Management System Evaluation Index (IESG) was constructed, which evaluated the Regional Environmental Management Plan (PGAR), the Hydrological Basin Management and Management Plan (POMCA), and the Triennial Action Plan (PAT). A conceptual model of a management system supported by climatic variability was designed. It was found that during the first semester of the year, seasonal and inter annual temperature variations have a direct relation with precipitation and flow, and generally respond to the climatic conditions of the country. The current environmental management system responds to a compendium of norms and adaptations of instruments of the national order, mediated by the individual efforts towards the achievement of goals. The management model designed at a seasonal scale, has as a strength that is a support tool for making decision in the water management of the CDMB, which allows to differentiate between climatic times.

**Keywords:** management tool; environmental governance; water management; water planning.

## INTRODUCTION

Human development has always been a function of the availability of water. All civilizations have had their establishment, growth, and peak moments in terms of water resources management, effects on climate, watersheds, and human needs (1). However, inadequate practices and scientific development have shown that the management of water resources is an issue that does not support expected (2.1); resulting in a proper water management (3).

In water management, the most important activities are of municipal competence and related to the provision of public services based on water and land use: "the ... {integrated water management} must use many instruments, and in the local field, the most important is the composed of local water services the design; although it is not possible to ignore the physical planning functions, whether urban or environmental, as well as the norms that are approved for the use of the different natural resources, or including environmental education activities "(4.5). Therefore, a water management based on climate variability would make decisions based on real knowledge of river basins (6.3).

At the basin level, there are advances for the creation and operation of organizations based on water management. Governments through the environmental authorities are concerned to enhance manage water, but a large majority are even more focused on improving the sectoral uses of water. Thus, to ensure the proper use of water in a basin, no intervener should pass over the authorities responsible for this management. Thus, the environmental authority must guide, coordinate or joint such interventions, support and study the effects of interventions and potential conflicts in order to prevent and avoid or mitigate them(7,8).

The characteristics of a basin in addition to define their functions, identify the parameters of water demands consists of the water volume in cubic meters, used by socioeconomic activities in a given time and space (9), and corresponding to the sum of the sectoral demands. Thus, Bosch & Hewlett (10) studied basins of a wide range of surfaces and defined that in estimating water balances, scale is not a major problem, so it is possible to use results of experience of management within river of a few hectares, and extrapolate them to larger ones.

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Instead, aspects such as relief, soil characteristics, vegetation, geological constitution, and climate (11), have a marked influence on the storage capacity and the generation of water flows into air and drainage networks (12).

In Colombia, climate variability as described by Poveda & Mesa (13)

Mesa *et al.* (14), and Poveda *et al.* (15) is determined by: "(1) Its tropical situation (seasonal variability), under the influence of the trade winds and the Southern Oscillation of the Intertropical Convergence Zone (ZCIT), (2) Its proximity to the Pacific and Atlantic Oceans, in addition to being the sources of moisture penetrating into the interior of the country, are the scenarios (interannual variability) where the El Niño Southern Oscillation (ENSO) events are developed, and (3), Its physiographic conformation including the presence of the Andes across the country from southwest to northeast, with valleys and slopes of mountains with marked climatic differences". The influence of the exposed it can be better understood within the own climate dynamics of each region ( 13,14,6,15).

Water management in Colombia has had little relation with the concept of climate variability (6,15), because efforts have focused on organizing databases with information on sampling in the field, conducted in different climatic periods, but this doesn´t to be a loose and isolated exercise, so the formulation and application of a management system adjusted to local climatic conditions, is a task that belongs to everyone.

The first trials in the management of the water resource by the Regional Autonomous Corporation for the Defense of the Plateau of Bucaramanga (CDMB) developed with a macro approach. For example, the upper basin of the Rio Lebrija, between 1967 and 1969, was the subject of an in-depth and detailed study, which established a diagnosis and management plan for the area to be develop in 20 years.

In the area under study, the CDMB has carried out studies by sub-basins through the Diagnostic, Prospective and Formulation Phases (between 1999 and 2002): High Lebrija (Angula lajas, Honda and Boring microbasins), Río Suratára Tona, Vetas, Charta, Surata Alto and Bajo Rivers Microbasins); Gold River (Oro Alto Microbasins, Lato, Frio, Oreo Medio and oro Bajo Rivers), determining with them a regulatory policy system for each microbasins identified in this region (16).

It was establish patterns at some climatic stations in the Río de Oro Sub - basin, with historical data on flow, precipitation and temperature, climate variability that help support water management in the CDMB.

## EXPERIMENTAL

### *Information sources*

For the Rio de Oro Subbasin (Figure 1), flow, precipitation and temperature data were analyzed with variable periods of time (Table 1), which were acquired by climatological stations belonging to the CDMB and the Hydrology, Meteorology and Studies Environment of Colombia Institute (IDEAM).

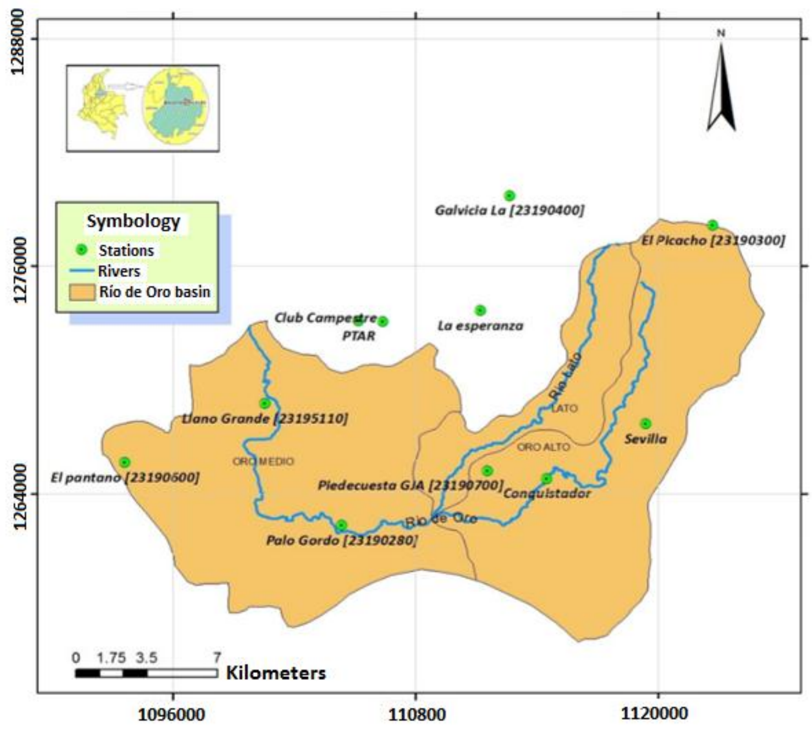


**Figure 1.** Spatial location of the stations used for the study.

**Table 1.** List of climatological stations used for the study.

| No. | Seasons | North | East | Variables | Owner | Registry |
|---|---|---|---|---|---|---|
| 1 | Llano Grande | 1268750 | 1100581 | P, T | IDEAM | 1970-2015 |
| 2 | Palo Gordo | 12 62336 | 1104369 | P | IDEAM | 1970-2015 |
| 3 | Piedecuesta | 1265208 | 1111578 | P | IDEAM | 1970-2015 |
| 4 | El Pantano | 1265634 | 1093619 | P | IDEAM | 1970-2015 |
| 5 | La Galvicia | 1279713 | 1112712 | P | IDEAM | 1970-2015 |
| 6 | El Picacho | 1278138 | 1122752 | P | IDEAM | 1970-2015 |
| 7 | Club Campestre | 1273072 | 1106399 | P | CDMB | 1982-2015 |
| 8 | Sevilla | 1267670 | 1119428 | P | CDMB | 1981-2013 |
| 9 | La Esperanza | 1273643 | 1111237 | P, T | CDMB | 1979-2004 |
| 10 | PTAR | 1273110 | 1105199 | P, T | CDMB | 1985-2012 |
| 11 | Conquistador | 1264794 | 1114531 | Q | IDEAM | 1978-2012 |

*PP: Precipitation, T: Temperature, Q: Flow rate.* Source. Authors Elaboration.

For the analysis of the flow, only the data of the Conquistador station (Table 1) located in the municipality of Piedecuesta (Figure 1) were used, because it was the only one in the upper middle that had extended and continuous records.

***Climate variability***

In order to analyze climatic variability, flow, precipitation and temperature data were used, and the pattern was established through the latitudinal migration of the ZCIT, while for the interannual, the analysis was supported by the occurrence of ENSO events, in their warm phases (cold) El Niño (La Niña). As an indicator of ENSO, oceanic El Niño Index (ONI was used www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml ), which is calculated by the National Center for Environmental Prediction of the Oceanic and Atmospheric National Administration (NOAA) of the United States of America.

The ONI corresponds to an index based on the three-month moving average of the +/- 0.5ºC threshold, in the Sea Surface Temperature (TSM) anomalies in the El Niño 3-4 region (5º North - 5º South, 120º - 170º West) for both ENSO phases. The occurrence of the event is consider when the threshold is presented for more than five consecutive months. For this study was use as study period 1977-2013.

The relationship between climatic variation (ONI) and the time series flow, precipitation and temperature was calculated, for this, variables were standardized (subtracting the mean and dividing by the monthly standard deviation), following the description in Mesa *et al.* (17), Poveda *et al.* (18), and Munera *et al.* (19). Standardization was do with the objective to remove the annually hydrological trends (20) and minimize bias when estimating the dependences opposite to the annual records.

***Current water management system***

Based on the documents published by the CDMB (2004, 2009, 2010), the exchange of information through institutional mails, and the interviews conducted with the Institution's Directors, the criteria for compliance with environmental regulations and effectiveness of management tools were evaluated: Regional Environmental Management Plan (PGAR), Hydrological Basin Management and Management Plan (POMCA), and Triennial Action Plan (PAT). These documents were summary in variables that allowed the analysis of regulatory compliance, having as a strategic line of interest the water resource.

The current management system was evaluated through Evaluation Index Management System *(IESG),* which was constructed by eight criteria defined separately for PGAR and joint for POMCA and PAT (Table 2). In turn, the criteria evaluated associated with the assigned qualifications (qualitative and quantitative), in each case add up to 100% in their weighting.

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**Table 2.** Evaluation criteria established to review the current management system and qualification given to each of them.

| No. | Evaluation Criteria | Environmental management tools | | | Weight range (%) | Rating | |
|---|---|---|---|---|---|---|---|
| | | PGAR | POMCA | PAT | | Qualitative | Value |
| 1 | Impact *(IM)* | X | X | X | NA | Positive | + |
| | | | | | | Negative | - |
| 2 | Objective *(OB)* | X | X | X | 8 | Not achievable | 0 |
| | | | | | | Achievable | 2 |
| 3 | Activity *(AC)* | | X | X | 25 | Not achievable | 0 |
| | | | | | | Achievable | 2 |
| 3 | Indicator *(IN)* | X | X | X | 8 | Quality | 1 |
| | | | | | | Performance | 3 |
| | | | | | | Tracing | 5 |
| 4 | Goal *(GO)* | X | X | X | 8 | Achievable | 0 |
| | | | | | | Not Achievable | 2 |
| 5 | Risk *(RI)* | X | X | X | 15 | Corrective | 0 |
| | | | | | | Preventive | 2 |
| 6 | Coverture *(CO)* | X | X | X | 10 | Punctual | 1 |
| | | | | | | Local | 3 |
| | | | | | | Regional | 5 |
| 7 | Strategic *(ST)* | X | | | 25 | Planning | 1 |
| | | | | | | Education | 3 |
| | | | | | | Conservation | 5 |
| 8 | Climate Variability *(CV)* | X | X | X | 26 | Not included | 0 |
| | | | | | | Included | 2 |

*NA: Not applicable. Source. Authors Elaboration.*

For the qualification of the criteria (qualitative and/or quantitative) they were take into account the guidelines established by the Ministry of Environment, Housing and Territorial Development (21), and it worked a matrix framework, milking pressure-state-impact-response. This tool allowed to organize the information, under a command and control scheme applied for the phases of diagnosis and water planning.

*IESG* construction was based on the methodology of environmental impact assessment by Diaz & corner (22) and two equations depending on the instrument to be evaluated (Table 2) were established: PGAR (Equ. 1); and POMCA and PAT (Equ. 2):

$IESG = \pm(OB + IN + GO + RI + CO + ST + CV)$, (Equ. 1)

$IESG = \pm(OB + AC + IN + GO + RI + CO + CV)$, (Equ. 2)

After obtaining the *IESG* ,this was normalized within a more appropriate scale for interpretation and analysis (values between 0 and 100), so that the Evaluation Index Management System Standard *(IESG $_{N}$)* was calculated through the Equation 3:

$IESG_N = \left[\frac{IESG - IESG_{mínimo}}{IESG_{máximo} - IESG_{mínimo}}\right] * 100$, *(Equ. 3)*

where $IESG_{minimum}$ and $iesg_{maximum}$ correspond to the minimum and maximum values of the *IESG* within the planning tool evaluated. With the results of Equation 3 in terms of climatic variability, a qualitative qualification associated with a color code was proposed (Table 3).

**Table 3.** Evaluation ranges proposed for the *IESG* $_N$ with their respective description.

| Rank | Rating | Description |
|---|---|---|
| 0 ≤ *IESG* $_N$ <25 | Irrelevant | The program and/or project is not relevant. |
| 25 ≤ *IESG* $_N$ <50 | Moderate | The program and/or project requires modifications (long term). |
| 50 ≤ $_N$ ≤ 75 *IESG* | Severe | The program and/or project requires modifications (medium term). |
| 75 ≤ $_N$ ≤ 100 *IESG* | Cr ítico | The program and/or project requires modifications (short term). |

*Source. Authors Elaboration.*

In addition, in the CDMB there are instruments such as the Regional Water Management Plan (PORH), the Environmental Observatory of the Environmental Management Plan (OASP), and the Annual Budget of Revenues and Expenditures, which were also revise to determine the appropriation degree and real implementation of the current management system.

### *Proposed water management system*

A conceptual model of a management system supported in the seasonal climatic variability was design with the results of the historical data and the current management system,. Thus, through the analysis of Pearson's multiple product-moment correlation and multiple regression, the relationships between the flow, precipitation, temperature and Real Evapotranspiration (ETR) variables were determined, and a linear equation was obtained for each of the four climatic periods that dominate much of the Colombian territory, as presented Mesa *et al.* (17): Dry Major (December-January-February, DJF), Rainy Minor (March-April-May, MAM), Dry Minor (June-July-August, JJA) and Rainy Major (September-October-November, SON ).

For calculating the ETR, the evapotranspiration Potential (ETP) was estimated by the empirical formula Thornthwaite (23), and with the precipitation data ETR was calculated through the Budyko equation (24,17).

For handling and storage of data, an Excel spreadsheet for Windows 2010 was use, while for the processing of the information, it was used the statistical package PAST (25) and ArcGis® software version 10.3.1 was used to determine precipitation and mean basin temperature.

## RESULTS

### *Seasonal and interannual climatic variability*

In the distribution of the data of the average flow, more than 80% corresponds to flows smaller than 2.23 m³/s and between May-June and October-November, the flow increases, with higher values in October (2.33 ± 0.92 m³/s), while between December-March and July-August periods of low water are registered, ie decrease in the flows (Figure 2), with lower values in the month of February (1.36 ± 0.37 m³/s).

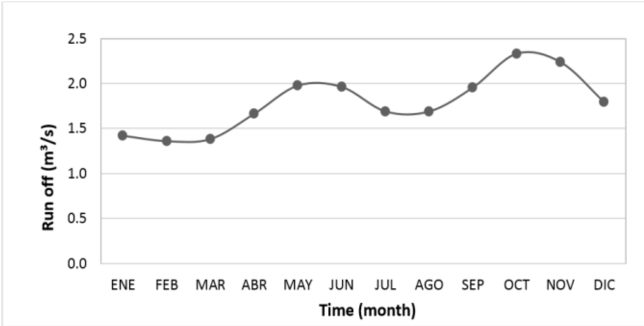


**Figure 2.** Seasonal flow cycle the mean precipitation of the Río de Oro Sub-basin.

During the period 1978-1983 (Figure 3), the behavior of greater variation in the flow with values between 0.64 and 5.58 m³/s was record; Between 1984-2006, the flow was more regular, although at the end of 2006, a flow of a similar magnitude occurred at the end of the 1970s. A negative trend was detect in the time series.

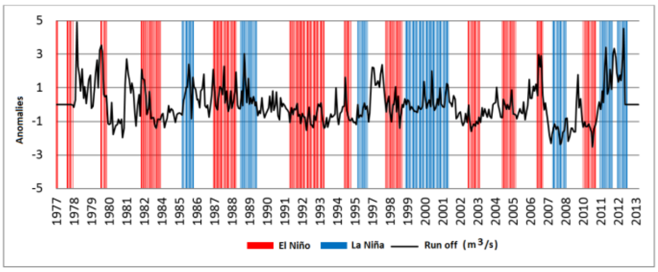


**Figure 3.** Interannual variability of the Rio de Oro flow in the upper-middle part of the basin.

As for the interannual flow variability, an association between negative (positive) anomalies and the occurrence of El Niño (La Niña) events with decreases (increase) in flow rates by direct influence of the macroclimatic event was find. However, several peak flows (positive anomalies) were detect between the years 1978-1980 and 2006-2007 that do not correspond to the occurrence of the El Niño event, therefore, this could be associated to other dynamics of the basin.

The cycle of precipitation is bimodal; it is observe that the maximum rainfall occurs in the first and second semester of the year towards the months of May and October, with the second semester being the rainiest (Figure 4). Then, when comparing the seasonal cycle of the flows with the precipitation, it is possible to show a lag of approximately one month, between the occurrence of the peak flows and the moment in which the precipitation is record. The precipitation data is below 203.93 mm.

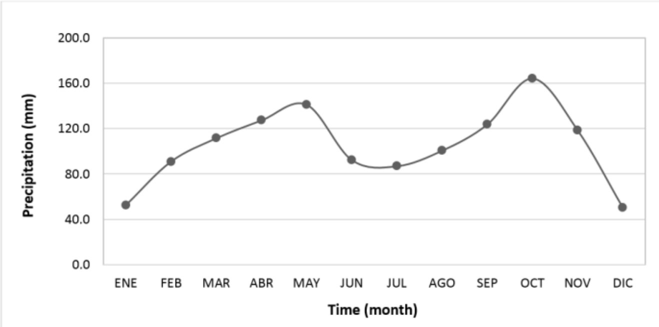


**Figure 4.** Seasonal cycle of the mean precipitation of the Río de Oro Sub-basin.

During the months of January, June and December there is a significant reduction in rainy events. As mentioned, May and October presented the highest rainfall 141.33 ± 35.43 mm and 164.42 ± 42.66 mm, respectively. For January, June and December, the driest month is December with 50.27 ± 28.34 mm, followed by January with 52.54 ± 22.72 mm and June with 92.51 ± 32.16 mm.

Reviewing the joint fluctuations of precipitation and flow during the study time period (Figure 5), the direct relationship between the two variables was confirm. However, in the years 1995-1996 and 2008-2009, there was an inversely proportional behavior, where the increase of the precipitation has little influence on the flow, which maintained low values, indicating in some way possibility of errors in the data.

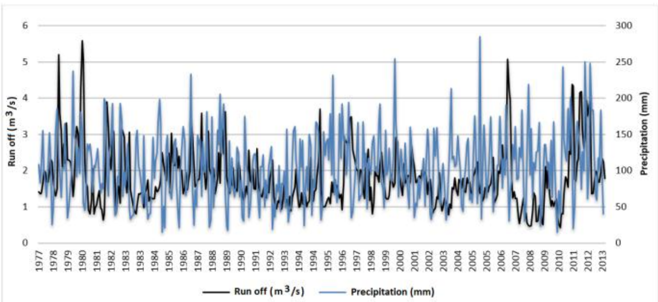


**Figure 5.** Time series of the precipitation and the flow of the Rio de Oro in the middle-upper part of the basin.

In Figure 6, the ENSO events and standardized precipitation *vs.* Flow data are compared, generally recording a directly proportional behavior between the hydrological variables and the positive (negative) anomalies during the occurrence of La Niña (El Niño). In this way it is demonstrated the dependence of the flow, as a function of the precipitation and in turn of the macroclimatic variables.

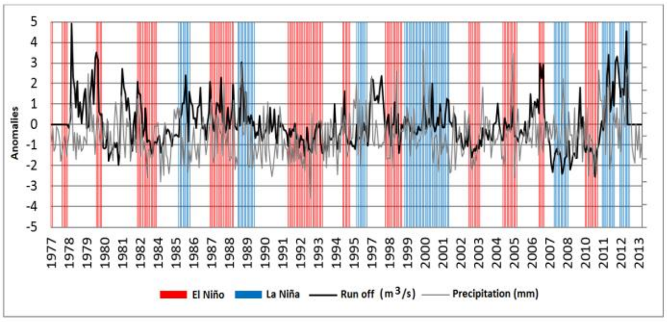


**Figure 6.** Interannual variability of the precipitation and the flow of the Rio de Oro in the middle-upper part of the basin.

It was possible to show how precipitation responds to seasonal and interannual variation scales, and their direct effects on flows. Likewise, the identification of the climatic quarters reveals that the territorial planning processes require the inclusion of climate variability in their strategies as a conditioning tool for environmental management systems formulated and applied by environmental authorities.

The seasonal temperature cycle presented in Figure 7 shows the different fluctuations that occur throughout the year. Like the seasonal cycle of precipitation, two high values are observe in the first (second) 23.03 ± 0.39 ° C (22.73 ± 0.37 ° C) semester of the year. When comparing the seasonal cycle of precipitation and temperature, a directly (inversely) proportional behavior was detected during the first (second) semester of the year.

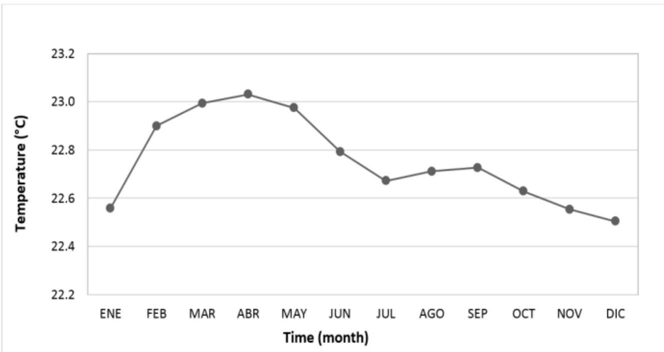


**Figure 7.** Seasonal cycle of the mean temperature of the Río de Oro Sub-basin.

In the data of the annual cycle of the temperature does not show significant variations throughout the year (less of 1 °C), and the values are around 22 °C, nevertheless, the maximum values are above the 23 °C. The months with the highest temperature are April (23.03 ± 0.39 °C), March (22.99 ± 0.42 °C) and May (22.97 ± 0.41 °C), while the months with the lowest temperature are December (22.50 ± 0.46 °C), January (22.56 ± 0.46 °C) and November (22.55 ± 0.40 °C).

The interannual variations in temperature show two different behaviors between the period 1970-1989 and 1990-2015, in which there appears a tendency of increase of approximately 0.5 °C with significant fluctuations. Throughout the series there were several peaks of increase in temperature, but they stand out those occurred in the year 1998 and 2003 being the highest recorded. In 1989, a peak of reduction in temperature of about 1.5 °C was observed in comparison with the normal values, and before this year the fluctuations oscillated between 22 and 23 °C; after 1989 an increasing temperature trend is marked (Figure 8).

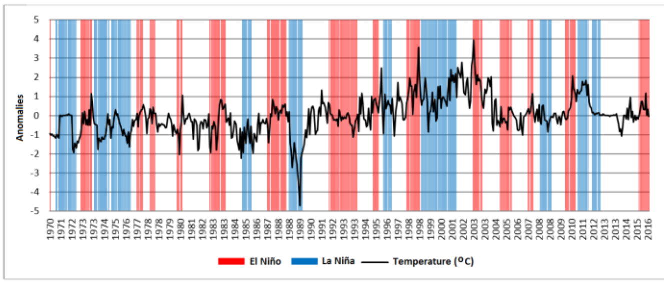


**Figure 8.** Interannual variability of precipitation and flow of the Rio de Oro in the middle-upper part of the basin.

According to the ONI, the direct influence of the macroclimatic events on temperature fluctuations over the period could be reveal. For this variable, a direct relationship between the positive (negative) TSM anomalies, the occurrence of El Niño (La Niña) events, and the positive (negative) temperature anomalies was find. The most marked negative anomaly occurred in 1989, when the La Niña event occurred.

***Current water management system***

Three planning instruments formulated by the CDMB were analyzed in the study region (28,29,30), and deficiencies and difficulties for their implementation in terms of climatic variability were identified. After the analysis it can be said that the CDMB's environmental management system is the result of a compendium of norms and adaptations of national instruments, and has been built through individual efforts towards the achievement of goals, without a proper representation to the regional reality, i.e., the activities in the planning processes respond more to the natural, water and geomorphological dimensions of the region, and not to the natural climatic variability, which should be the fundamental tool to apply, tending to the construction of processes, where the main goal is to preserve and make an integral management of the water resource.

Therefore, in the case of the CDMB and in the framework of the water management processes, both the PGAR, POMCA and PAT, which are existing instruments recognized by the Institution, define environmental actions related to administrative processes without involving the climatic variability. Thus, we have:

*Regional Environmental Management Plan (PGAR)*

The document was adopt in July 2014 and has a projection from 2015 to 2031. The work focused on the Alto Lebrija Basin, which includes the Río de Oro Sub-basin (Board of Directors Agreement No. 1113 of February 19, 2008). Thus, the numeral four point two (4.2) ***Strategic Lines: Integrated management of water resources,*** define within the pragmatic context a component of six programs: Offer water resources in the region (OWRR), demand of water resources in the region (DWRR), strengthening governance for water resource management (SGWR), quality of water resources in the region (QWRR), institutional strengthening for water resource management (ISWR), and integrated management of risks associated with supply and availability of the water (IMRW).

The PGAR assessment was done since the results of the numerical score obtained with $IESG_{N,}$ and presented in Table 4.

**Table 4.** Assessment of the criteria for the PGAR applying the methodology developed.

| Strategic Line | Program | IM | OB | IN | GO | RI | CO | S T | C V | *IESG* | $IESG_N$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Integral Management Water Resources** | ORHR | + | 0 | 3 | 0 | 0 | 5 | 1 | 0 | 0.99 | **0.00** |
| | DRHR | + | 2 | 3 | 0 | 0 | 5 | 1 | 0 | 1.15 | **100.00** |
| | FGRH | + | 0 | 3 | 0 | 0 | 5 | 1 | 0 | 0.99 | **0.00** |
| | CRHR | + | 0 | 3 | 0 | 0 | 5 | 1 | 0 | 0.99 | **0.00** |
| | FIRH | + | 2 | 3 | 0 | 0 | 5 | 1 | 0 | 1.15 | **100.00** |
| | GRDA | + | 0 | 3 | 0 | 0 | 5 | 1 | 0 | 0.99 | **0.00** |

*IM: Impact, OB: Objective, IN: Indicator, GO: Target, RI: Risk, CO: Coverage, ST: Strategy, CV: Climate variability.* Source. *Authors Elaboration.*

The results in Table 4 show that the *demand of water resources in the region* and *institutional strengthening for the management of water resources,* are programs that in a critical way (33.33%) require changes in the short term, and include climate variability as an essential component within them. The remaining four programs: *Offer of water resources in the region, Strengthening governance for the management of water resources, quality of water resources in the region, and comprehensive management of the risks associated with supply and water availability,* represent 66.67%; in this case the inclusion of the climatic variability is little relevant, being in the direction of the CDMB its respective incorporation.

*Plan of Management and Environmental Management Sub-basin of Rio de Oro (POMCA)*

The structure of the plan is defined considering as planning instruments at a higher level of importance, the National Development Plan 2002-2006 "Towards a Community State" and the PGAR 2004-2015 "A platform for a sustainable environmental reality", and this one (1) based on two objectives:

a) Recovery and conservation of the natural and regional base that contains two strategic lines: Integral water resource management and conservation or sustainable use of soil and biodiversity.
b) Impetus to sustainable Regional development.

The management methodology used responds to what was describe in Decree 1729 of 2009. The formulation of the general objective was make very macro, and it´s lost in the real context of what would be the achievement of programs and projects of the strategic line of the resource water. It was evidence a well coordinate proposal when it was done a documentary review, however when analyzing in detail the coherence between objectives, goals, activities, indicators and schedules; A guiding thread was not distinguished, for example the objectives do not lead to the achievement of the goal, and that in turn this can be measured, controlled and evaluated by an indicator, in the three periods of execution (long term, medium term and short term).

A POMCA documentary review of five related to the strategic line ***Integral management of water resources*** projects was made, thus have: protection, restoration, conservation and watershed management suppliers of water and production systems (PCSP), assessment, management, regulation and distribution of water resources (EORH), technical and economic support to the municipalities of the sub-basin for the management, treatment and final disposal of domestic wastewater (ATAR), control of dumping and monitoring of the quality of the sub-basin (CVCS) flows, use and efficient water saving (UAEA).

The results of *IESG $_N$* applied to projects are shown in Table 5. It was found that the proposed *use and efficient saving water,* proved to be the most critical (20% of total project) and therefore should be given greater attention (short term) in processes related to climate variability. In the medium term , the *Control of Dumping and quality monitoring of current sub – basin* project and in the long term the *Protection, recovery, conservation and management of supplying watersheds of aqueducts and production systems* project *,* involving in its water management system everything related to climatic variability, the above in order to guarantee the documentary coherence marked from the PGAR. While in the *assessment, management, regulation and distribution of water resources* project, the incorporation of climate variability it´s irrelevant.

**Table 5.** Evaluation of the criteria for the POMCA applying the methodology developed.

| **Programs** | **Projects** | **IM** | **OB** | **AC** | **IN** | **GO** | **RI** | **CO** | **C V** | ***IESG*** | ***IESG $_N$*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Integral Management Water Resource | PCSP | + | 0 | 0 | 5 | 2 | 0 | 3 | 0 | 0.86 | **39.02** |
| | EORH | + | 0 | 0 | 1 | 2 | 0 | 3 | 0 | 0.54 | **0.00** |
| | TIE | + | 0 | 0 | 3 | 2 | 0 | 3 | 0 | 0.70 | **19.51** |
| | CVCS | + | 0 | 0 | 5 | 2 | 2 | 1 | 0 | 0.96 | **51.22** |
| | UAEA | + | 2 | 0 | 3 | 2 | 2 | 5 | 0 | 1.36 | **100.00** |

*IM: Impact, OB: Objective, AC: Activity, IN: Indicator, GO: Target, RI: Risk, CO: Coverage, VC: Climate Variability.* Source. *Authors* Elaboration

**Table 6.** Evaluation of the criteria for the PAT applying the methodology developed.

| Program | Projects | IM | OB | AC | IN | GO | RI | CO | C V | *IESG* | *IESG* $_N$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Integral Management Water Resource | F EAM | + | 0 | 0 | 3 | 2 | 0 | 5 | 0 | 0.90 | **100.00** |
| | C MAJ | + | 0 | 0 | 3 | 2 | 0 | 1 | 0 | 0.50 | **0.00** |

*IM: Impact OB: Target, AC: Activity, IN: Indicator, GO: Meta, RI: Risk, CO: Coverage CV: Climate Variability.* Source. Authors' Elaboration.

<u>*Triennial Action Plan (PAT)*</u>

Regarding the PAT there is no strategic line, but the ***Integrated Water Resources Management*** Program, has two projects: formulation of strategies for environmental planning (FEAM), and watershed conservation and management of protected areas for the supply of environmental goods and services in the area of jurisdiction (CMAJ).

In Table 6, it can be seen that the *formulation of strategies for environmental planning* project accounting the 50.00% of the total, highlights the need to act immediately (short - term) in terms of climate variability resulting irrelevant, the action on *watershed conservation and management of protected areas for the supply of goods and environmental services in the area of jurisdiction* project. It is to clarify that the priority given by the *IESG* $_N$ it´s only positional and does not constitute an obligation to implement the projects.

In the formulation of the three instruments itself demonstrates the need to relate GO, AC and IN, from a clearly defined in space and time perspective. For its part, the OB are formulated in a global context, apart from the particular and inherent in the sub - basin under study. The ST actions and the evaluation of programs and/or projects, lack clarity and do not allow applying improvement actions related to the environmental dynamics owner of the basin.

***Proposed water management system***

As part of a proposal water management system based on climate variability, a conceptual making decision model was built (Figure 9), that has like inputs (inflows), the basis of weather data (national and international), as processes mainstreaming of climate variability on all instruments of the water planning and as outputs, programs and or projects based on the seasonal scale in the four climatic periods that dominate in Colombia (DEF, MAM, JJA and SON).

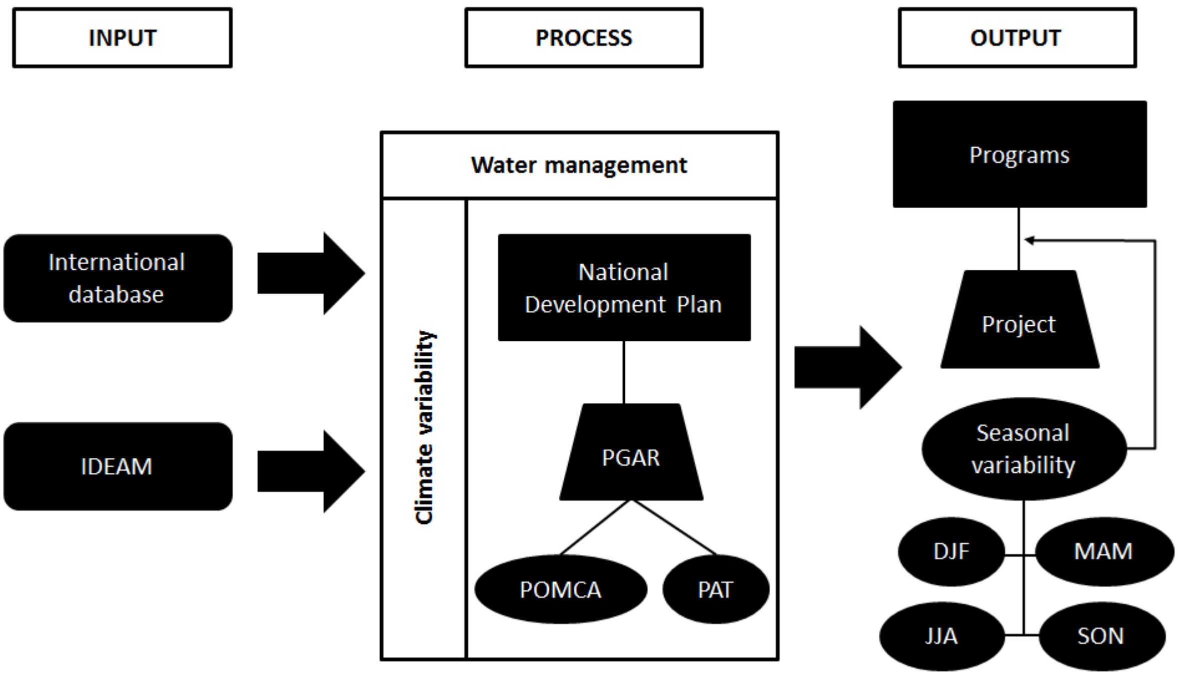


**Figure 9.** Conceptual model for water management proposed by CMDB.

**Table 7.** Correlation between variables in each of the climatic periods.

| Variables | Flow | Precipitation | ETR | Temp. | Flow | Precipitation. | ETR | Temp. |
|---|---|---|---|---|---|---|---|---|
| **DEF** | | | | | **MAM** | | | |
| Flow | 1.00 | 0.08 | 0.03 | 0.03 | 1.00 | 0.16 | 0.16 | -0.15 |
| Precipitation | 0.08 | 1.00 | **0.91** | -0.03 | 0.16 | 1.00 | **0.94** | -0.06 |
| ETR | 0.03 | **0.91** | 1.00 | 0.08 | 0.16 | **0.94** | 1.00 | 0.06 |
| Temperature | 0.03 | -0.03 | 0.08 | 1.00 | -0.15 | -0.06 | 0.06 | 1.00 |
| JJA | | | | | **SON** | | | |
| Flow | 1.00 | 0.25 | 0.21 | -0.21 | 1.00 | 0.42 | 0.38 | -0.17 |
| Precipitation | 0.25 | 1.00 | **0.97** | -0.15 | 0.42 | 1.00 | **0.91** | -0.15 |
| ETR | 0.21 | **0.97** | 1.00 | -0.07 | 0.38 | **0.91** | 1.00 | 0.07 |
| Temperature | -0.21 | -0.15 | -0.07 | 1.00 | -0.17 | -0.15 | 0.07 | 1.00 |

*Precipitation: Precipitation, ETR: Real Evapotranspiration, Temp. Temperature.* Source. Authors Elaboration.

Linear multivariate statistical model was contextualize in terms of flow as a dependent function of the precipitation, the ETR and temperature, as shown in equation 4.

$Q = f(P, ETR, T)$, (Equ. 4),

where $Q$ represents the flow in $m^3/s$, $P$ corresponds to the precipitation in mm, $ETR$ is the real evapotranspiration, in mm, and $T$ refers to the temperature in °C.

To obtain the model it was working with the registers of 46 years (1970-2015) of each of the variables mentioned above, and product-moment multiple correlation of Pearson (Table 7) was calculate. In this case, $p \geq 0.70$ indicates that the variables are correlate directly. Thus, the results in table 15 show in all climate periods, a significant direct relationship of precipitation with ETR (higher values to 0.90).

Given the above, it raised the multivariate linear statistical model using Equation 5, whose response variable is the flow and the explanatory variables: precipitation, temperature and ETR.

$Q = x_1 P + x_2 ETR + x_3 T + e$, *(Equ. 5)*

where $x_1$, $x_2$, and $x_3$ represent the regression parameters, and $e$ the error associated to the regression. The obtained results are present in Table 8.

**Table 8.** Results of regression parameters for each of the climatic periods.

| Variables | DEF | MAM | JJA | SON |
|---|---|---|---|---|
| Precipitation | 0.006298 | -0.0011553 | 0.01322 | 0.008968 |
| ETR | -0.012884 | 0.01092 | -0.020417 | 0.017004 |
| Temperature | 0.070087 | -0.16077 | -0.20586 | -0.28865 |
| Error | 0.15991 | 4.2321 | 6.6158 | 6.1497 |

In this way from Table 8, regression models that could support making decision for the granting of water in each climate quarter were raise. Therefore, the CMDB would have the tool to check the amount of flow available in terms of the seasonal variations owner of the Colombian Andes Region.

$Q_{DEF} = 0.006298P - 0.012884ETR + 0.070087T + 0.15991$, *(Equ. 6)*

$Q_{MAM} = -0.0011553P + 0.01092ETR - 0.16077T + 4.2321$, *(Equ. 7)*

$Q_{JJA} = 0.01322P - 0.020417ETR - 0.20586T + 6.6158$, *(Equ. 8)*

$Q_{SON} = 0.008968P + 0.017004ETR - 0.28865T + 6.1497$, *(Equ. 9)*

The regression models built, collect the historical memory of climate change and respond to the input data delivered in this case by the CMDB and IDEAM. So in its construction could be committing errors of judgment, but not procedural associated with the uncertainty of them. However the CMDB would be able to verify and implement through the established network monitoring a better management of them.

## DISCUSSION

The inadequate practices of management water resources that carried out in the basins, determined by the ratio supply-demand, demonstrate the reality of facing immediately the problems associated with the conservation and preservation of them (2 ,31,1) . Based on the above, advanced societies in environmental terms are increasingly demanding a water management more respectful of the natural environment, enable the enjoyment of intrinsic values increasingly appreciated, as the ecological, cultural, esthetic, sports and recreation (2,6). In this sense, it is necessary that water management is addressed with an integrated approach of its two facets like water reserve and environmental (1,9,32); with this premise, the implementation of an environmental management watersheds must be based on flow regimes (33,31) and the risk they represent on communities (34) .

Therefore, knowledge of the flow regime constitute a fundamental tool in watershed management plans, because they enable water management in a rational way, tailored to their different uses that preserve the functionality of the river ecosystem (31,1 , 9). Of this mode, for the basin under study data having influential variables as rainfall and temperature can be determined the effect of supply over demand in the sub-basin, and thus know the real possibilities of granting flows. Especially if you consider that there should be an ecological flow that meets the needs of human supply and agricultural and industrial supply (31,35,36).

They found more than 80% of the data flow are minor than 2.23 $m^3/s$, although there are above the ecological flow of 0.090 $m^3/s$ reported by the CMDB for 2004. This is to clarify that this is the source of supply of urban aqueduct of Piedecuesta (Santander), and for that same year the authorized concessions were 0.528 $m^3/s$ being available 0.411 $m^3/s$, which results are not enough to meet the demand of the urban population header projected for the year 2022 at 0.625 $m^3/s$ (28). This shows the urgency of implementing a water system planning adjusting to the real context.

In Colombia (32) according to the Article 21 of the project of law of the water, IDEAM design the particular guidelines for calculating the ecological flow, and is based on a hydrological process with a very simple design of the river, considered as ecological flow "... the permanence value in the source during the 90% of the time ...". For that, it was establish three methods: The 90th percentile curve duration, recurrence of 2.3 years, or the approximate percentage of 25% of the multiyear lower monthly average flow.

However, in practice the fixing ecological flow is done based on two types of criteria (32):

a) Analysis of Regimes Historical flows: Study especially periods of natural low water levels of the rivers, under the conception of those river communities have evolved subject to certain types of flow regimes, and thus their life cycles and ecological requirements are adapted to the seasonal variations owner of that regime.

b) Analysis of Variance habitat with circulating flows: Developed long time ago (35,37), is based on the RHABSIM methodology, and the use of it is widespread throughout the world. The conceptual basis of this methodology lies in knowing the circulating flow requirements of some species, or certain reofilas communities and their distribution in time, able to assess the flow requirements in order to maintain their populations.

Some basic ecological flows are obtained with any of the above criteria, variously known (minimum, desirable, optimum, of maintenance) according to the method used for its calculation, or level of ecological requirement. These flows represent estimates of the boundary conditions of tolerance to low flow, or thresholds community resilience (36). So, if the CMDB have a network monitoring more efficient that not depend on contractual processes operators, which will also increase the number of these considering each micro basin for their location, optimization and data quality obtained with a frequency collection increase to define collection process with results closer to the reality of each study area.

Therefore, activities in the planning processes should be the primary tool to implement, aimed at building processes, where the primary goal is preserving and make a comprehensive management of water resources, as recommended by García *et al.* (6) and Sedano-Cruz *et al.* (34) , who mentioned that in Colombia, it is necessary to strengthen the Integrated Risk Management in the management of land and water resources by the environmental authorities.

Given the influence that rainfall has on the behavior of flows (38,17) , coinciding with the four climatic seasons dominate in Colombia (14) , is posed a structure analysis which is an incorporation of climate information in management systems. For example, a lag of one month between the occurrence of the peaks of flow and when the rainfall occurs, as happens for the Cauca River (39,40).

Also it find an association between negative anomalies (positive) and the occurrence of El Niño (La Niña), it is feasible to decrease (increase) the flows by direct influence of macroclimatic event (14,17) . Relationship between years of El Niño and La Niña with flow has also been reported by Mesa *et al.* (14), Poveda (17) and Poveda *et al.* (15) , and it is the system response to ocean-atmosphere coupling (41,42) .

Despite the uncertainty on information currently available from the Corporations and IDEAM, wave the need to create policies that allow to give immediate responses to the water resources affectations(6,43) , therefore, the importance of interpreting these statistics from the context of climate variability, allows increase its functionality in making decision, for a variety of opportunities ranging from recognize the periodic fluctuations of the climate system and how can be the tool to predict restoration actions, maintenance, conservation and planning control.

The evaluation of the sub basin from the hydrological balance (44) determines the knowledge of all stakeholders, but especially the behavior of precipitation, the ETR and temperature to understand hydraulic runway. For the case study corresponds to a watershed, which aims should be collecting water from different sources of precipitation and at the same time generate water discharge as runoff, to ensure sustainability of the resource.

## CONCLUSIONS

Test results obtained in the flow analysis of the middle and upper basin showed that seasonal and interannual variability through migration of ZCIT, dominates the precipitation and affects the flow regime of subbasin. Once do, taking into account the availability of water resources and that the location of the cities creates a pressure on it, verification of ecological flow becomes an obligation that must be monitor in the lower basin.

It was evident as precipitation responds to the seasonal and interannual variation scales and its direct effects on flows. Through the identification of climate quarters it is necessary, in territorial planning processes, include climate variability as a conditioning tool of the environmental systems, formulated and applied as instruments management by the Corporation.

Seasonal and interannual variations in temperature has a direct relationship with rainfall and water flows, during the first half of the year, possibly associated with the type of convective precipitation, which is depends on the heating produced throughout the day in a given area in the troposphere. Meanwhile, as shown in the second half of the year may be a response of direct influence of the ZCIT and orographic precipitation.

System Environmental Management of CMDB forming as a result of the compendium of standards and adaptations of instruments at the national order, has been generated as individual efforts tending to meeting targets, without a representation according to the reality, that is, the regional activities in the Planning Process respond more to natural, water and geomorphology dimensions of the region, and not to natural climate variability, that should be the principal tool applying, aimed at building processes, where the important goal will be to preserve and do an integrated management of water resources, for this case Rio de Oro subbasin.

Regression models built respond to input data delivered in this case by the CMDB and IDEAM, so in its construction could be committing judgment but not procedural errors, associated with the uncertainty of them; however, the CMDB would be able to verify and implement across the established network monitoring a better management of them.

The consideration of the Environmental Management System based on climate variability allows better manage of the water resources, in this regard for Rio de Oro sub-basin, it proposes a review of the current planning instruments and the implementation of the Statistical Model to help in water concession process associated with the availability of natural resources.

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## REFERENCE

[1] Guerrero E, De Keizer O, Córdoba R. La Aplicación del Enfoque Ecosistémico en la Gestión de los Recursos Hídricos. Quito: UICN; 2006.

[2] Andrade-Pérez A, Navarrete-Le Bas F. Lineamientos para la aplicación del enfoque ecosistémico a la gestión integral del recurso hídrico Caribe ORpALye, editor. México D.F.: Programa de las Naciones Unidas para el Medio Ambiente; 2004.

[3] Rodríguez JP, García CA, Ruiz-Ochoa M. Integration of the stationality climate variability to a model of hidric environmental planning. International Journal of ChemTech Research. 2016; 9(12): p. 278-284.

[4] Jouravlev A. Los municipios y la gestión de los recursos hídricos Unidas N, editor. Santiago de Chile: CEPAL - Serie Recursos Naturales e Infraestructura 66; 2003.

[5] Rojas-Padilla JH, Pérez-Rincón MA, Malheiros TF, Madera-Parra CA, Guimarães Prota M, Dos Santos R. Análisis comparativo de modelos e instrumentos de gestión integrada del recurso hídrico en Suramérica: los casos de Brasil y Colombia. Ambi & Agua, Taubaté. 2013; 8(1): p. 73-97.

[6] García MC, Piñeros-Botero A, Bernal-Quiroga FA, Ardila-Robles E. Variabilidad climática, cambio climático y el recurso hídrico en Colombia. Revista de Ingeniería. 2012; 36: p. 60-64.

[7] Dourojeanni-Ricordi A, Oberti-Izquierdo L. Principios para elaborar un plan de protección de cuencas. Lima: Ministerio de Agricultura y Alimentación, Dirección General de Aguas; 1978.

[8] Araujo P, González M. Diagnóstico para el establecimiento de un plan de protección y conservación en la cuenca del río Omas–Asia. Revista Forestal del Perú. 1986; 13(2): p. 1-21.

[9] Gaspari FJ, Rodríguez-Vagaría AM, Senisterra GE, Delgado MI, Besteiro SI. Elementos hidrológicos para el manejo de cuencas hidrográficas. La Plata: Universidad

de La Plata; 2013.

[10] Bosch JM, Hewlett JD. A review of catchment experimentsto determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology. 1982; 55: p. 3-23.

[11] Gallart F, Llorens P, Latron J, Regüés D. Hydrological processes and their seasonal controls in a small Mediterranean mountain catchment in the Pyrenees. Hydrology and Earth System Sciences. 2002; 6(3): p. 527-537.

[12] Morejón Miranda YM, Vega-Carreño MB, Escarré-Esteve A, Peralta-Vital JL, Quintero-Silveiro A, González Piedra JI. Análisis de balance hídrico en cuencas hidrográficas de la Sierra de los Órganos. Ingeniería Hidráulica y Ambiental. 2015; 36(2): p. 94-108.

[13] Poveda G, Mesa O. Las fases extremas del fenómeno ENSO (El Niño y La Niña) y su influencia sobre la hidrología de Colombia. Ingeniería Hidráulica en México. 1996; 9(1): p. 21-37.

[14] Mesa O, Poveda G, Carvajal L. Introducción al clima de Colombia Medellín: Universidad Nacioonal de Colombia; 1997.

[15] Poveda G, Álvarez DM, Rueda OA. Hydro-climatic variability over the Andes of Colombia associated with ENSO: a review of climatic processes and their impact on one of the Earth’s most important biodiversity hotspots. Climate Dynamics. ; 36(11-12): p. 2233-2249.

[16] Pabón J, Eslava J, Gómez R. Generalidades de la distribución espacial y temporal de la temperatura del aire y de la precipitación en Colombia. Meteorología Colombiana. 2001; 4: p. 47-59.

[17] Poveda G. La hidroclimatología de Colombia: Una síntesis desde a escala inter-decadal hasta la escala diurna. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales. 2004; 38(107): p. 202-208.

[18] Álzate D, Rojas E, Mosquera J, Ramón J. Cambio climático y variabilidad climática para el periodo 1981-2010 en las cuencas de los ríos Zulia y Pamplonita, Norte de Santander, Colombia. Revista Luna Azul. 2015;(40): p. 127-153.

[19] Corporación Autónoma Regional para la Defensa de la Meseta de Bucaramanga (CDMB). Plan de Ordenamiento y Manejo Ambiental Subcuenca Río Suratá. Bucaramanga: CDMB; 2003.

[20] Poveda G, Vélez J, Mesa O, Hoyos C, Salazar L, Mejía J, et al. Influencia de fenómenos macroclimáticos sobre el ciclo anual de la hidrología colombiana: Cuantificación lineal, no lineal y percentiles probabilísticos. Meteorología Colombiana. 2002; 6: p. 121-130.

[21] Múnera J. Dinámica hidrológica de la Ciénaga Grande de Santa Marta mediante técnicas de sensores remotos. Posgrado en Aprovechamiento de Recursos Hidráulicos. Medellín: Universidad Nacional de Colombia, Escuela de Geociencia y Medio Ambiente; 2003.

[22] Betancur C, Sánchez L, Poveda G. Estimación de la escala de fluctuación de lluvias y caudales en Antioquia. Atmósfera. 1993; 20: p. 13-25.

[23] Ministerio de Ambiente y Desarrollo Sostenible. Guía Técnica para la Formulación de los Planes de Ordenación y Manejo de Cuencas Hidrográficas (POMCAS). Bogotá:; 2014.

[24] Díaz O, Rincón S. Diseño de una metodología de evaluación cuantitativa de impactos ambientales en la construcción y operación de rellenos sanitarios en Colombia. Bucaramanga: Unidades Tecnológicas de Santander, Programa de Ingeniería Ambiental; 2015.

[25] Thornthwaite C. An Approach toward a rational classification of climate. Geographical Review. 1948; 38(1): p. 55-94.

[26] Budyko MI. Evaporation under natural conditions, Gidrometeorizdat, Leningrad Jerusalem: English translation by IPST; 1948.

[27] Hammer Ø, Harper DAT, Ryan PD. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica. 2001; 4(1).

[28] CDMB. Plan de gestión ambiental regional 2004-2013. Participación concertada y proactiva. Bucaramanga: CDMB; 2004.

[29] CDMB. Plan de Acción ajustado 2007 - 2011. Bucaramanga:; 2009.

[30] CDMB. Plan de Ordenamiento del Recurso Hídrico Microcuenca Río de Oro Alto. Bucaramanga:; 2010.

[31] Díez-Hernández JM. Bases metodológicas para el establecimiento de caudales ecológicos en el ordenamiento de cuencas hidrográficas. Ingeniería y Competitividad. 2005; 7(2): p. 11-18.

[32] Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM). Estudio Nacional del Agua 2014. Bogotá, D.C.: IDEAM; 2015.

[33] Leduc C, Bromley J, Schroeter P. Water table fluctuation

and recharge in semi-arid climate: some results of the HAPEX-Sahel hydrodynamic survey (Niger). Journal of Hydrology. 1997; 188: p. 123-138.

[34] Sedano-Cruz K, Carvajal-Escobar Y, Ávila AJ. Análisis de aspectos que incrementan el riesgo de inundaciones en Colombia. Revista Luna Azul. 2013; 37: p. 219-238.

[35] Dourojeanni A, Jouravlev A, Chávez G. Gestión del agua a nivel de cuencas: teoría y práctica. Santiago de Chile: CEPAL - Serie Recursos Naturales e Infraestructura 47; 2002.

[36] Linsley BK, Zhang P, Kaplan A, Howe SS, Wellington GM. Interdecadal-decadal climate variability from multicoral oxygen isotope records in the South Pacific Convergence Zone region since 1650 AD. Paleoceanography. 2008; 23(2).

[37] Díez-Hernández JM, Payne TR. Actualización del Modelo RHABSIM 3.0 para estimación de caudales ecológicos. Ingeniería de Recursos Naturales y del Ambiente. 2011; 1(3),(3): p. 12-17.

[38] Montealegre J, Pabón J. La Variabilidad Climática Interanual asociada al ciclo El Niño-La Niña–Oscilación del Sur y su efecto en el patrón pluviométrico de Colombia. Meteorología Colombiana. 2000; 2: p. 7-21.

[39] Puertas-Orozco OL, Carvajal-Escobar Y. Incidencia de El Niño-Oscilación del Sur en la precipitación y la temperatura del aire en Colombia, utilizando el Climate Explorer. Ingeniería y Desarrollo. 2008; 23: p. 104-118.

[40] Puertas-Orozco OL, Carvajal-Escobar Y, Quintero-Angel M. Estudio de tendencias de la precipitación mensual en la cuenca alta-media del río Cauca, Colombia. Dyna. 2011; 78(169): p. 112-120.

[41] Webster PJ. The annual cycle and the predictability of the tropical couple ocean-atmosphere system. Meteorology and Atmospheric Physics. 1995; 56: p. 33-55.

[42] Webster PJ, Holland GJ, Curry JA, Chang HR. Changes in tropical cyclone number, duration, and intensity in a warming environment. Science. 2005; 309(5742): p. 1844-1846.

[43] Ávila-Díaz ÁJ, Carvajal-Escobar Y, Gutiérrez-Serna SE. El Niño and La Niña analysis influence in the monthly water supply at Cali Riverbasin. Tecnura. 2014; 18(41): p. 120-133.

[44] Castellanos Z. Balance hidrológico superficial de la cuenca Río Frío, Área Metropolitana de Bucaramanga. Bucaramanga, Santander: Unidades Tecnológicas de Santander, Programa de Ingeniería Ambiental; 2016.

[45] Birkmann J, Garschagen M, Kraas F, Quang N. Adaptive urban governance: New challenges for the second generation of urban adaptation strategies to climate change. Sustainability Science. 2010; 5(2): p. 185-206.

[46] Hawkins SJ, Sugden HE, Mieszkowska N, Moore PJ, Poloczanska E, Leaper R, et al. Consequences of climate-driven biodiversity changes for ecosystem functioning of North European rocky shores. Marine Ecology Progress Series. 2009; 396: p. 245-259.

[47] Programa de las Naciones Unidas para el Desarrollo (PNUD). Gestión del Riesgo Climático. New York:,. Buró de Prevención de Crisis y Recuperación, Buró de Políticas de Desarrollo, Grupo de Energía y Medio Ambiente; 2010.