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ANALYSIS OF SEMI-DISTRIBUTED AND GLOBAL HYDROLOGICAL MODELS IN THE CENTRAL TROPICAL BASINS OF THE GULF OF MEXICO TO THE EFFECTS OF EXTREME HYDROMETEOROLOGICAL PHENOMENA

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ABSTRACT

The progressive change in weather conditions in the world, have caused an increase in the frequency and severity of hydrometeorological events, an example is what happened in the last 20 years in the southeast of Mexico, which left huge economic, social and environmental losses due to flooding, in addition to this problem, the lack of hydrometeorological information for the development of hydrological modeling. Therefore, it is necessary to have tools that allow decision making science-based, such as global hydrological models (GHM) currently a way to assess the effect of climate change on the hydrology of a watershed. The objective of this study was to adapt the Canadian GHM (MOHYSE) to tropical conditions, and determine the efficiency of its hydrological response through the Nash-Sutcliffe coefficient. Additionally, compared with a semi-distributed hydrological model (SDHM) to determine which of the models is more accurate to hydrograph observed in the study area. The results indicate that both models fit properly to tropical conditions, having MOHYSE a coefficient of Nash-Sutcliffe and Pearson correlation (0.5, 0.9) higher than MDSH coefficient (0.4, 0.8).

Key words: Watershed, flood, hydrologic modeling, tropics.

1. INTRODUCTION

During the last decades there have been extreme and unusual hydrometeorological events that have increased the vulnerability of the planet, so require a lot of attention due to the damage caused by floods. Mexico is frequently hit by extreme rainfall events, whether convective or cyclonic nature. An example of this is what happens in the central Gulf of Mexico basins that have supported 55.2% of total flooding of Veracruz from 1999-2013, leaving substantial economic, social and environmental losses [16].

Besides the risk in our country, there is not enough infrastructure for hydrometric measurement channels, rivers and watersheds since only greatest impact watersheds have this measurement system. Usually, the condition of the basins of southeastern Mexico (in terms of climatological and hydrometric data available) have few rain gauges are installed with about 30 years of observation, and as the number of weather stations in operation decreases by different reasons [3]. It is for this reason that predicting the temporal behavior of the maximum rainfall is a task that requires a deep research work.

Therefore it is necessary to develop tools scientifically supported for the correct prediction of floods and flooding, hence their forecasts have to be conservative in order to ensure the protection of human lives. An alternative to this problem is the use of hydrological simulation models for possible operation at low cost and reliability of the results projected [1]

Because of this, the objective of this research is to provide a tool for performing hydrological simulation studies in tropical countries using GHM. So GHM was adapted to tropical conditions, and its efficiency was determined in the hydrologic response through the Nash-Sutcliffe coefficient, its performance is also evaluated by comparing a SDHM (which is currently the most widely used in the world), additionally the potential of using the GHM in tropical conditions, and deficient regions of meteorological and hydrometric data [17]. was discussed.

It is very important in studies of this type, especially when there are insufficient data to calibrate the hydrological model to produce an analysis of the results of several simulations of events that may occur in the area to know the general characteristics of the watershed responses before those events, so you can make decisions based on the information of the rain is falling in a given region time [13].

2. METHODOLOGY

2.1 Data Collection

In this research, climatological data were obtained [5], of the National Weather Service for a period of 25 years (1982-2008) and hydrometric data from the National Water Commission [12], for the same period, The sample size was established by 7 stations that meet the criteria of seasonality and timing of a total of 15 stations in the study area, the digital elevation model (DEM) and the layers of type and land use was supplied by the National Institute of Statistics, Geography and Informatics [13].

2.2 Verification of Information, climate and hydrometric

The study of surface runoff requires, as a first step, evaluate the spatial and temporal behavior of rainfall in the study area. Initially, we proceeded with the adequacy and the homogenization of information rainy of the three selected meteorological stations (Figure 1), with influence in the catchment area of the river basin Actopan for a period of 25 years (1982-2008), which is the largest possible number of historical data with the least amount of missing values [2].

This is where the abstract should be placed. It should consist of one paragraph giving a concise summary of the material in the article below. Replace the title, authors, and addresses with your own title, authors, and addresses. Then they proceeded to fill in the values of missing precipitation, for which the interpolation method was used, which requires only information from the station under study and no adjacent stations, the equation used for the implementation of the method was the following [6]:

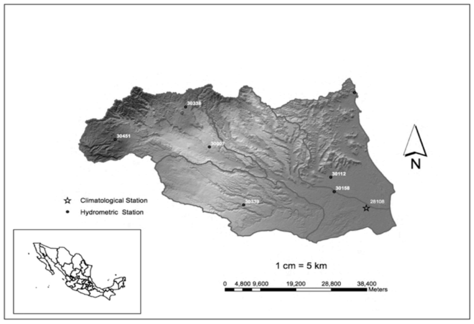

Figure 1. Location of the central Gulf of Mexico basins and climatological and hydrometric stations.

$$\frac{X_i}{N_i} = \frac{\sum_{i=1}^{n} X_i + \sum_{j=1}^{n} X_j}{P}$$

(1)

Unknown
Código de campo cambiado

In which:
Xi = Missing precipitation during the month i of year study.
Ni = Average rainfall during the month i for all years of record.
Xj = Existing precipitation during the month j of the year in study
P = Average annual precipitation for all years of record.

After applying equation (1), for each missing value was given an equation and solving the simultaneous system, the missing data for the period 1982 to 2008 were obtained.

2.3 Determination of morphometric parameters of the watershed using a GIS

From the digital elevation model (DEM) with the use of GIS ArcGIS 10 and their extensions (supplementary programs that provide specialized GIS functions): **SpatialAnalyst**y **HEC-GeoHMS,** are obtained eight sets of data describing patterns of drainage basin (Table 1), and allow the delineation of sub-basins and drainage network [7]. The HEC-GeoHMS tool has been developed as a group of hydrological geospatial tools for engineers and hydrologists with limited GIS experience. It is used to process the data in the basin after making initial preparation and compilation of field data [18]. This extension connects the GIS software with hydrologic simulation Hec-HMS.

2.4 Hydrological model to simulate rainfall-runoff SDHM

The HEC-HMS is a product of the Hydrologic Engineering Center of the Corps of Engineers U.S. Army (The Hydrologic Modeling System, HMS for its acronym in English), is a deterministic semi-distributed model. The SDHM is one of the models most known and used in the world *USACE et al* [21]. It is a free and broad international use computer program to study avenues, which provides a variety of options to simulate rainfall runoff processes and traffic flows [8].
Hydrological process was simulated using the HEC-HMS [18] model. The model HEC - HMS consists of three modules (Basin model, meteorological model and control specifications).

Table 1. Morphometric characteristics of the central basin of the Gulf of Mexico (CBGM). [1]Length of main channel, [2]Form coefficient, [3]Coefficient of compactness, [4]elongation index, [5] time of concentration y [6]Coefficient of massive.

Morphometry	**CBGM**	**Rating**
Perimeter (km)	**430**	**-**
LCP[1] (km)	**60**	**Large**
Average elevation (m)	**1586**	**Moderate**
Area (km^2)	**2538**	**Large**
Low altitude	**0**	**-**
High altitude	**3175**	**-**
ramp	**3175**	**High**
kf[2]	**0.57**	**Oblate**
kc[3]	**1567**	**Oblong oval**
I[4]	**2.1**	**Moderately elongate**
Order	**6**	**High**
Drainage density (km/km^2)	**5.56**	**High**
Pending the mainstem	**0.17**	**Strong**
Tc[5] (min)	**57.6**	**Moderate**
Population	**348.261**	**Moderate**
Km[6]	**78.1**	**Moderately Mountainous**

The spatial distribution of rainfall is interpolated by the method of the inverse square of the distance. The calculation of infiltration and rainfall-runoff transformation is determined by the number of the Soil Conservation Service curve [18], and for calibration was performed using as fit parameters of hydrologic curve number (CN), the lag time (T lag) and Index of abstraction (la). in an automated manner with an objective function.

2.5 Hydrological model to simulate rainfall-runoff GHM

The simplified to the extreme hydrological model (MOdèle HYdrologique Simplifié à l'Extrême by its French acronym) is a global deterministic hydrological model, developed from 2004 to 2006 by *Vincent Fortin and Richard Turcotte et al* [9].

2.5.1 Scheme MOHYSE production

According to *Fortin and Turcotte et al* [9], mention that the greatest success in hydrological modeling MOHYSEis divide the problem into a set of simpler sub-problems in defining the watershed, ie, divide it into a set of compartments where rainfall can stay before or be transported out of the basin, or whether it evaporate and thus return to the atmosphere.

The MOHYSE production scheme can be considered relatively simple as the authors mention, however is comparable in complexity to the models used for real applications. Its simplicity actually falls on modeling each of these compartments.

2.5.2 Methodology for implementing MOHYSE

EL MOHYSE requires an estimate of: the average temperature over a time interval (At) in Celcius, Rain (Pt) in mm / Δt and Snow (Nt) in mm / Δt, *Fortin et al*[10]. Where Mt = (Tt, Pt) is the vector of input variables of the model. Besides using the basin area (B) and the mean latitude (L), the model has ten parameters MOHYSE subject to modeling.

The parameters (Table 2) which takes into account the model, sorted into three parts, where the first two parameters are a function of snow water equivalent, the following six are part of the vertical balance and the last two are based on the hydrograph Unit (HU) [9].

Table 2. Model parameters MOHYSE (GHM). They are classified into three groups: The first is a function of snow water equivalent, the second and the third part of the vertical balance and unit hydrograph (UH).

Symbol	**Meaning**	**Unit**
C_{ETP}	Adjustment factor for potential evapotranspiration	mm/Δt
C_{TR}	Adjustment coefficient transpiration	$(\Delta t)^{-1}$
C_f	Melting speed	mm/Celsius/Δt
T_f	Melting temperature limit	Celsius
C_{inf}	Maximum infiltration rate	mm/Δt
C_{VA}	Drainage coefficient of the vadose zone to the aquifer	$(\Delta t)^{-1}$
C_V	Drainage coefficient of the vadose zone to the water course	$(\Delta t)^{-1}$
C_A	Drainage coefficient of the aquifer to the watercourse	$(\Delta t)^{-1}$
A	UH shape parameter	Adimensional
B	UH scale parameter	Adim

As for the output data produced MOHYSE at each time interval, in addition to the output flow (Qt) an estimate of: snow water equivalent of the snowpack (St) in mm, Water contained in the vadose zone (Vt) in mm, Water aquifer from the vadose zone (At) in mm, Production (HT) in mm / dt obtained from the sum of the surface runoff (Ht, 1), the flow hypodermic (Ht 2) and the base flow (Ht; 3).

2.5.3 Adaptation to tropical conditions MHG

The global hydrological model used for this study is a MOHYSE, *Fortin and Turcotte et al* [9], adaptation developed to despise the defrost output and modifying the model snow is modification was performed by programming in MATLAB, in the same way through the calibration Shuffled Complex Evolution (SCE) of the University of Arizona.

2.6 Comparison of GHM and SDHM modeling

In this investigation, the hydrological responses MHSD and MHG were quantitatively compared for four different criteria as shown below. This research focuses on the estimated by comparing the observed data (hydrometric 28030) results.

The most important criterion is the coefficient of efficiency (CE) or better known as the Nash-Sutcliffe coefficient.

(I) Coefficient of efficiency, CE, is defined by:

$$Ce = 1 - \frac{\sum_{i=1}^{N} |q(i) - \hat{q}(i)|^2}{\sum_{i=1}^{N} |q(i) - \bar{q}|^2} \tag{2}$$

where $\hat{q}(i)$, is the simulated runoff hydrograph for a period of time i (m^3/s), $q(i)$ s the observed runoff hydrograph for a period of time i (m^3/s). $\bar{q}$ represents the average observed runoff hydrograph for a period of time i (m^3/s) and N is the number of data. CE quantifies the goodness of fit between the estimated and observed hydrograph. For a better fit is indicated by a CE which is closest to the unit.

(II) The total error volume (EV)

$$EV = \frac{\sum_{i=1}^{N} |\hat{q}(i) - q(i)|^2}{\sum_{i=1}^{N} q(i)} \tag{3}$$

where $\hat{q}(i)$ is the simulated runoff hydrograph for a period of time i (m^3/s), $q(i)$ is the observed runoff hydrograph for a period of time i (m^3/s). The EV is the average error between estimated and observed hydrograph. The EV value is positive when the average exceeds the estimated runoff hydrograph runoff observed and back. For a better fit is represented by a small absolute value of EV.

(III) The maximum error runoff, EQ_p %), is defined as:

$$EQ_p = \frac{\hat{q}_p - q_p}{q_p} \; x \; 100\ \% \tag{4}$$

Where $\hat{q}_p$represents the maximum simulated runoff hydrograph (m^3/s), and q_p is the observed maximum runoff hydrograph (m^3/s). EQ_p is positive, when the estimated peak runoff exceeds the maximum observed runoff. EQ_p is negative, when the estimated maximum runoff is smaller to the maximum observed runoff. For a better fit is represented by the smallest absolute value EQ_p *Kharkbaz et al,*[11].

(IV) The Pearson correlation coefficient

$$r_{xy} = \frac{\sum x_i y_i - n x_i y_i}{n S_x S_y} \tag{5}$$

Where S_x, is the typical standard deviation of variable X, S_y is the typical standard deviation of the Y Variable. Where if r is closer to unity, indicating a complete dependence between the two variables.

3. RESULTS AND DISCUSSION.

In order to describe the physical characteristics of the study area, morphometric analysis was conducted because it is a tool that allows us to establish performance evaluation parameters of the hydrological system of a region.

Table 3. Evaluation criteria for the simulated hydrologic response to GHM and SDHM. Coefficient of efficiency (CE), the total error volume (EV), the maximum runoff error, EQ_p , Pearson correlation coefficient (PC).

	GHM	**SDHM**
CE	**0.4**	**0.5**
EV (%)	**-6.14**	**-13.2**
Eqp (%)	**41.3**	**2.59**
PC	**0.8**	**0.9**

This tool can also serve as spatial analysis assisting in the management and planning of natural resources to allow, in the context of a well-defined landscape unit, make various components such as the size of the basin, the network drainage, the average slope, runoff, etc.

In the case of the central basin of the Gulf of Mexico we found (Table 2), which is a basin with an order of high current, which generally indicates the presence of structural controls of the relief and greater possibility of erosion or that the basin could be older. Its shape is moderately flattened and is located in a mountainous area, therefore, has a tendency to concentrate the runoff from heavy rain forming large floods easily, have a high altitudinal gradient difference, which shows a high climatic and ecological diversity, also have an elongated oval shape, which has a high density of drainage, increasing the hydrological response to the presence of rain. The time of concentration is moderate favoring the sediment transport capacity and increases the speed of the channel in case of storms.

For the fit obtained in the calibration and validation, four criteria are calculated coefficient of Nash- Stucliffeo efficiency coefficient, Pearson correlation coefficient, the total error volume (EV) andthe maximum runoff error (see Table 3), to evaluate the hydrological response of the two models (GHM vs SDHM), correlation coefficient Pearson for GHM (0.9) and SDHM (0.8) was obtained , which indicates that both models have a total dependency between the two variables (hydrograph simulated runoff and observed runoff hydrograph) . Based on the criteria of the EC, GHM (0.5) is greater SDHM (0.5) and according to the remaining two coefficients (the total error volume EV and the error of maximum runoff) shows that the GHM has superiority significant on SDHM. Based on input conditions identical data, the results indicate that both models adequately conform to the tropical conditions of the central basins of the Gulf of Mexico. However, MOHYSE earned best rates in its hydrological response regarding SDHM, although it is the first time that has been used in Mexico and in the tropics.

4. CONCLUSIONS

The GHM can be used in hydrological studies that do not have enough information for a DHM, as is the case in many basins of the country, you can use the MOHYSE obtaining reliable results.

The use of DHM and GHM can be performed to generate scenarios: once calibrated, you can explore the impacts that would have a number of alternative assumptions about future policies, hydrology, and climate. It also has a direct application in the creation of risk maps, urban planning, agro-hydrological management and promotes disaster risk reduction because it is an indispensable tool for promoting the welfare, protection of resources and the same so the methodologies developed in this research can be applied in other areas of the country with similar characteristics.

REFERENCES

[1] Argota, T. 2011, "Simulación Hidrológica de la cuenca del rio Amajac, Estado de Hidalgo, Aplicando el modelo SWAT", Tesis de Maestría, Instituto Politécnico Nacional, México.

[2] Carvajal, Y., Arango, D. 2007. Estimación de caudales promedios mensuales por subcuencas hidrológicas mediante modelación con HEC-HMS, EIDENAR, Facultad de Ing5eniería, Universidad del Valle.

[3] CENAPRED 2010, Centro Nacional para prevención de Desastres, México.

[4] Chow, V.T., Maidment, D. R., Mays, L. W., (1994) Hidrología Aplicada. Department of Civil, Environmental & Chemical Engineering, Youngstown State Uniuersity, Ohio. Colombia. McGraw-Hill Interamericana.

[5] Comisión Nacional del Agua, 2013 . (CONAGUA). Estaciones Hidrométricas y climatológicas.

[6] Fernandez, V. 2005. "Esquema Hidrometeorológico Intengral para HEC-HMS". Ponencia XVI Fórum de Ciencia y Técnica.EIPIH Raudal, Holguín, Cuba.

[7] Feldaman, A. D.(2000), "Hydrologic Modelling System HEC-HMS, Technical reference manual," U.S Army Corps of Enginering, Hydrologic Engineering Center, Davis, CA., 281.

[8] Forter Filion, T. C. (2009) Modélisation hydrologique simple appliquée à des bassins jaugés et non jaugés. Tesis de Maestría. Universidad de Quebec.

[9] Fortin, V., Turcotte, R. 2006. Le modèle hydrologique MOHYSE. Curso SCA7420, Departamento

[10] Khakbaz , B. 2012, From lumped to distributed via semi-distributed: Calibration strategies for semi-distributed hydrologic models. Journal Hydrology, USA.

[11] Instituto Mexicano de Tecnología del agua, 2009. (IMTA), Banco Nacional del Agua superficial (BANDAS), México.

[12] Instituto Nacional de Estadística y geografía, 2013. (INEGI). Cartas topográficas digitales, México.

[13] Magaña, V. 2010, " Guía para generar y aplicar escenarios probabilísticos regionales de cambio climático en la toma de decisiones", Centro de ciencia de Atmosfera, Universidad Autónoma de México (UNAM), México, (2010)

[14] Martínez, P. 2007. " metodología para el estudio de avenidas en Ramblas de cuencas mediterráneas utilizando sistemas de información geográfica y modelos semidistribuidos", Universidad politécnica de Cartagena. España.

[15] Nanía, L. S. 2007. "Manual Básico de HEC-HMS 3.0 y HEC-GEO- HMS 1.1". Universidad de Granda, Dpto. de Mec. de Estructuras e Ingeniería Hidráulica, Área de Ingeniería Hidráulica.

[16] Protección Civil, 2012, "Programa Veracruzano de protección Civil 2011", Lic. Noemí Zoila Guzmán Lagunés. Veracruz, México.

[17] Salgado, R. 2012. "Aplicabilidad de los Modelos Hidrológicos Distribuidos", Instituto Mexicano de Tecnología del Agua"; Morelos, México.

[18] USACE (2012)."Hydrologic Modeling System HEC-HMS". Hydrologic Engineering Center, recuperado (10/02/2013) http://www.hec.usace.army.mil, USA.