Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 11 (3): 512-519, 2011
ISSN 1812-5654 / DOI: 10.3923/jas.2011.512.519
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Improved Estimation of the Mean Rainfall and Rainfall-runoff Modeling to a Station with High Rainfall (Tabou) in South-western Côte D'ivoire

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Abstract: The annual rainfall series of Tabou remained stationary over the period 1922-2004 with the application of the segmentation test. However, a decrease of 10% over the 1990s is noted. The 1993-98 deficit sequence which is at the origin of this decline seamless stationarity is characterized by observations of average deficits of 30, 31 and 44% of the months of heavy rainfall in May, June and November. Also for the months of December, January and March of the long dry season with rainfall amounts recorded decreases of 36, 44 and 38% compared to the period 1922-1992. Estimates of monthly rainfall in Tabou over the period 2000-2002 with the usual stations are less effective than those conducted by kriging and inverse distance which improve on average 26-122% in the month and, thanks to increased density in rainfall stations. The introduction of these estimates obtained by spatial interpolation instead of rainfall depths known in proportions of 19, 39 and 58% as the input data is supported by the model GR2M in calibration and validation phases. Unlike those from the arithmetic mean that cause decreases in 9-21% of the coefficients of Nash which amplified in validation from 9 to 48% depending on the size of their proportions in the rain input.

Key words: Rain, deficit, stationarity, interpolation, validation

INTRODUCTION

Climate variability is usually an effect of natural environmental conditions (Refsgaard *et al*., 1989). It describes the fluctuation of the seasonal or annual climatic parameters in relation to the multi-annual mean of reference (Servat *et al*., 1999). Tropical Africa is characterized by high rainfall variability. Several authors have highlighted it including the detection of breaks in its temporal evolution. The period late 1960s-early 1970s is that which sees a decrease in rainfall in the majority of stations in West Africa (Hubert *et al*., 1998; Savane *et al*., 2001; Le Barbe *et al*., 2002; L'Hote *et al*., 2002; Paturel *et al*., 2004; Lay and Galle, 2005; Goula *et al*., 2009). This similarity of behavior of annual rainfall at the regional level shows the organization of the cumulative rainfall variability in tropical annual homogeneous spatial structures whose size is important in the tropics and subtropics. Hence the observation that the main factors involved in the genesis of rainfall anomalies are of regional or global scale. The modifications of the climate in Africa are strongly related to certain modes dominating the interannual variability of the thermal fields of the oceans (Janicot *et al*., 1998; Fontaine *et al*., 1999). Thus, the existence of significant relations is noted between the thermic anomalies of the tropical Atlantic Ocean and certain regional interannual evolutions of precipitations in Côte d'Ivoire (Bigot *et al*., 2002, 2005). Like the cooling of the temperatures of ocean surfaces in the Gulf of Guinea in May, at the beginning of the great rain season, which precedes a rise by precipitations on the littoral of the Côte d'Ivoire (Kouadio *et al*., 2002). However areas because of certain factors such as the importance of vegetation cover or topography does not always follow the regional climatic variations (Moron, 1996). The coastal region of Tabou in the South-western Côte d'Ivoire subject to the direct influence of the West African monsoon, where rainfall is significant, seems to have this feature. Its annual pluviometry remained surplus during the decades 1970 and 1980 in spite of the general dryness in West Africa (Fadika *et al*., 2008). The penetration of flow of trade winds strongly humidified coming from the southern hemisphere which this zone undergoes is under the influence of the displacement of the zone of intertropical convergence (Lebel *et al*., 2003; Sultan and Janicot, 2004).

The objective of this study was to estimate rainfall in the Tabou area by spatial interpolation using data from a neighboring area and to determine the effect of errors in the series of rain on the effectiveness and the robustness of a rainfall-runoff model. We begin first by showing the

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rainfall characteristics of Tabou in the context of decreasing rainfall in West Africa. Then estimates by interpolation of rain at Tabou station will be done using data from an adjacent area which has a good density of rainfall stations. Finally, we will determine the influence of previous estimates of rainfall data on the calibration and validation of rainfall-runoff GR2M model.

MATERIALS AND METHODS

Presentation of the study area: The study area is composed of the Tabou area and an area of the Dodo River basin (Fig. 1) is part of the coastal zone of Côte d'Ivoire. The climate is of equatorial type with four seasons, two rainy seasons and two dry seasons. The evergreen forest and plains where the altitude does not exceed 200 meters characterize vegetation and terrain in southern Côte d' Ivoire. The coastline stretches over 500 km is composed in its Western half of rocky cliffs to the west of Sassandra and sandy clay to Cape Palmas (Liberia border). In fact, there are highly desaturated lateritic soils which cover much of southern Côte d'Ivoire. The drainage of the west coast consists of small rivers of which the most important are Tabou, Dodo, Nero and San Pedro.

Data rainfall: The monthly rainfall depth of Tabou precipitation station 1922-2004 and those of eighteen stations (HK1, HK2, HK3, KO1, KO2, KO3, SG1, SG2, SG3, BC1, BC2, BC3, DL1, DL2, DL3, KT1, KT2, KT3) from 2000 to 2002 belonging to the neighboring basin of the river Dodo are used (Fig. 1). This data was derived from the National Meteorology office and of a private company. In addition, Monthly potential evapotranspiration from 1977 to 2003 of Tabou Station are available as well as the mean monthly discharge of the river Tabou to its oufall Yaka Station (810 km^2) from 1963 to 2004.

Methods:

Stationarity of annual rainfall serie: The segmentation procedure (Hubert *et al*., 1998) is somehow a stationarity test whose null hypothesis is: The series of interest is stationary. If the time series being tested is not homogeneous (stationary), it is cut into as many subsets homogeneous as possible. The Scheffe (1959) allows determining the optimal segmentation and stopping the segmentation process with a significance level of 1%. The segmentation is applied with the Khrono Stat software.

Interannual variability of rain: The centered and reduced variable is the variation with the muti-annual mean of rainfall depth for one year on the standard deviation of the series. It highlights the surplus, deficit or normal character one year and therefore the fluctuation of annual rainfall.

Seasonal variations: The objective of this part is to identify possible changes in the distribution of monthly rainfall totals with the decrease in annual rainfall.

Influence of errors in input data on the calibration and validation of the GR2M model: In this section, the objective is to determine the influence of errors in the series of rain on the calibration and validation of the

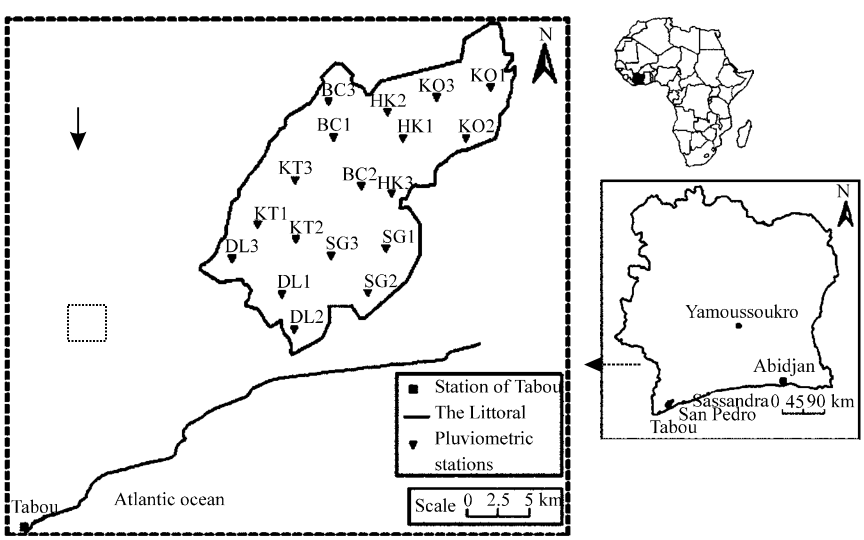

Fig. 1: Location of the study area

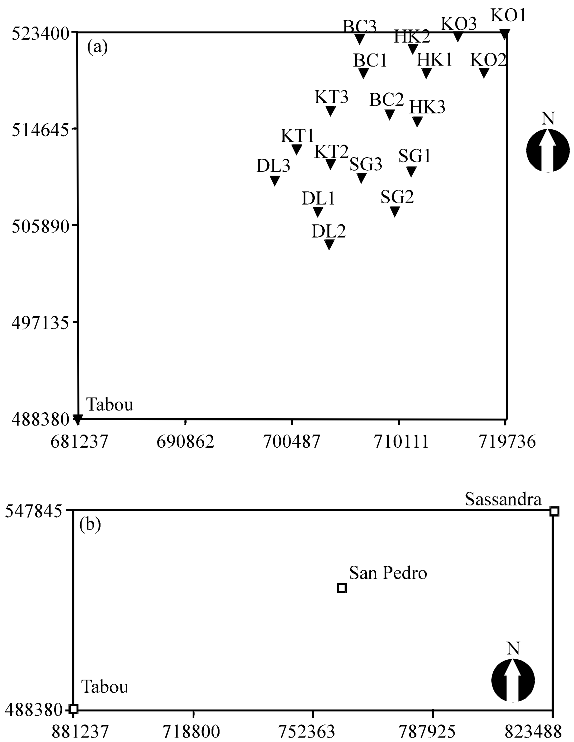

Fig. 2: Squares interpolation of rainfall including station and Taboo: Eighteen news other (a) and normal two stations (b)

GR2M (modèle du Génie Rural with 2 Monthly parameters (Mouelhi *et al*., 2006) Model parameters. In this context, systematic errors (for overestimation and/or under-estimation of rainfall) are intentionally introduced in the series of monthly rainfall amounts over the period January 2000 to December 2002 (36 months). Estimated rainfall by interpolation and arithmetic mean form the series of pseudo-monthly rainfall amounts. The kriging and inverse distance methods, which are two strong methods (Baillargeon, 2005) are used for interpolation of rain to the Tabou station. For this, the interpolation square (1356 km^2) includes eighteen other stations in the basin of the Dodo, that is to say a station for 71 km^2 (Fig. 2a). The estimates of rain per arithmetic mean are based on the data traditionally available in this zone i.e., those of San Pedro and Sassandra. Indeed, the stations eighteen located in the basin of the Dodo belong to a private entity. So, the users confronted with gaps in the Tabou series typically use these two stations, which is a station for 2862 km^2 (Fig. 2b).

The Nash coefficient varies consecutive to each of these changes compared to those obtained with the real rainfall amounts will determine the influence of errors in the rainfall depths input on the performance (efficiency and robustness) of the GR2M model.

RESULTS AND DISCUSSION

Stationarity of the annual series of rainfall: Applying the segmentation test to annual rainfall totals of Tabou shows that this serie is stationary over the period 1922-2004. The stationarity ruptures observed in general in West Africa in the period late 1960 early 1970s (Hubert *et al*., 1998; Servat *et al*., 1999; Paturel *et al*., 2004) indicating a decrease in rainfall do not appear in Tabou. The rupture indicating a change of average, that lets think that pluviometry is relatively remained abundant in the zone of Tabou. The Tabou area is wetter as it benefits from its position at the extreme western coast of which the provision is more perpendicular to the monsoon winds just like the eastern end of the Ivorian coast (Aubreville, 1949 cited in Eldin, 1971). The series of Taboo is different from those of other long-term stations of South-western Côte d'Ivoire as Grabo and Sassandra where ruptures are noted (Fadika *et al*., 2008). The rupture detected in 1995, by Goula *et al*. (2009), on shorter series of this station (1950-1997), proves to be therefore not significant with the lengthening of the series (1922-2004). It could simply reflect the observation of a short deficit sequence.

Interannual fluctuation and per decade: The annual rainfall totals vary greatly from one year to another. So the estate of more than three years of deficits, for example, appears only three times in the series, the sequence 1964-67, 1974-77 and 1993-98 (Fig. 3a). The latter is most important, thus the rainfall in the decade 1990-99 also recorded the largest deficit (10%) compared to the multi-annual mean (Fig. 3b). However, this deficit is lower than the average of 20-25% recorded in the humid zone of West Africa (Paturel *et al.* 1997; Servat *et al*., 1999). The absence of deficit phase of the late 1960s to early 1970s explains also that of stationarity breaks in this period in the annual series of Tabou.

Thus, the 1970 is in excess of 2% compared to the multi-annual mean as the 1980s (5%). While the latter has seen, in general, an increased incidence of low annual rainfall in West Africa, (Ardoin, 2004). Through cons, the 1990s drought, which affects rainfall for the first time with the emergence of six consecutive years of deficits from 1993 to 1998. Not to the point of talking about rupture, the excess of 2% of the rainfall in the early 2000s confirmed (Fig. 3b).

Change of seasons: Averages of monthly rainfall totals over the period of study (1922-2004) and the phases that

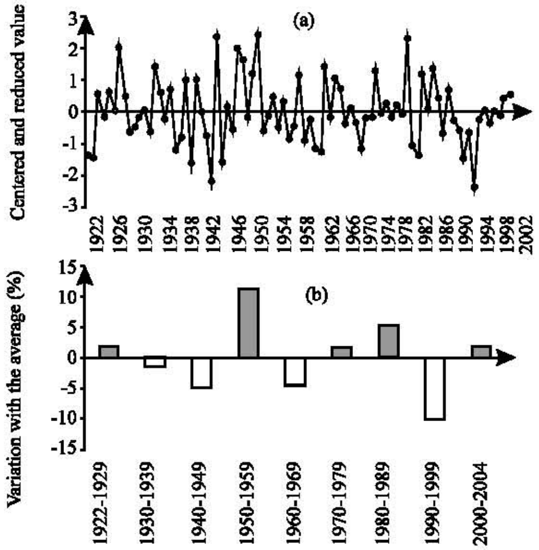

Fig. 3: Interannual (a) and decennial (b) variability of the rain at the station of Tabou

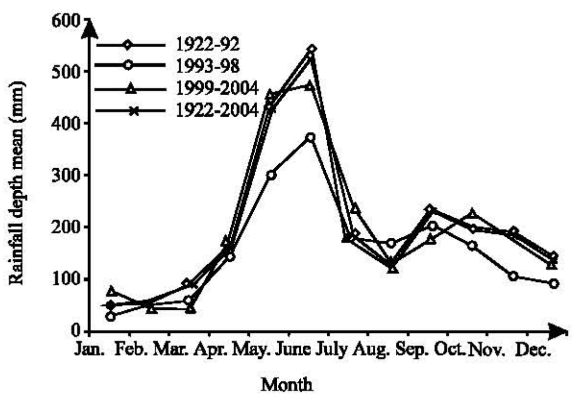

Fig. 4: Changes in periods of wet seasons and deficit

we consider to be wet or deficit make it possible to see time variation of the season (Fig. 4). Thus, the distribution of rainfall is organized in two rainy seasons alternating with two dry seasons. The big rainy season stood from April to July, the short dry season in August, the short rains from September to November and the long dry season from December to March. This distribution is also that of the wet period 1922-97 also remains the same during the deficit phases: 1993-98 and surplus: 1999-2004 but with decreases or increases in certain monthly rainfall depths. Thus, the decrease in total annual rainfall during the 1993-98 is characterized by the months of high rainfall and long dry season. For example 131 and 168 mm less for May and June of the big rainy season, 26, 32 and 88 mm less for September, October and November of the short rainy season and 50, 22 and 34 mm less for months

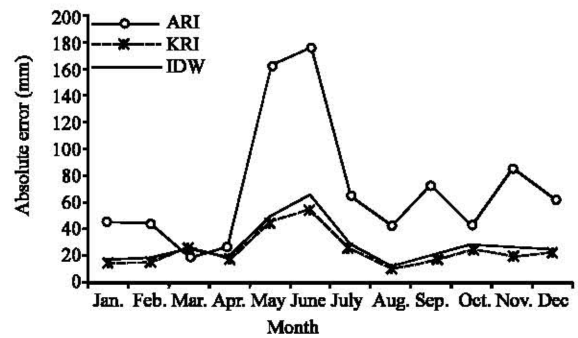

Fig. 5: Average absolute errors committed by estimating Monthly Rainfall depths at Tabou Station 2000-2002 by the methods of the arithmetic mean (ARI), Kriging (KRI) and the inverse distance (IDW)

December, January and March of the long dry season. Servat *et al.* (1999) have also noted in regions of West Africa, a decrease of rainfall recorded outside the rainy season. This marks a strengthening of the dry season, which contributes at the same time, lower annual precipitation and the clear perception of corruption by the people.

The decrease in rainfall during the rainy season in the deficit period was due a reduction in the number of rainy days (Houdenou and Hernandez, 1998; Lay and Galle, 2005) a relative drop in the number of rainfall events (Tapsoba *et al.*, 2002) and reduced the frequency of heavy precipitation (Assani, 1999). The increase in annual rainfall from 1999 to 2004 also saw one of those months with almost the same order as during the previous wet phase (1922-1997).

Comparison of the estimate of rain with the arithmetic mean and the spatial interpolation: Using three different methods to estimate the known values of monthly rainfall at Tabou station 2000-2002 let's show the absolute mean errors committed (Fig. 5). Both interpolation methods give similar results which are better than those of the arithmetic mean. This difference is accentuated during the months of heavy rainfall (May, June). Errors introduced in the data by using the arithmetic mean filling corrected for 26-122% by using kriging and 27-131% by the IDW is an average of 47% for both methods interpolation. These results were expected since the estimation with kriging takes into account the structure of spatial dependence of data (Baillargeon, 2005). While the arithmetic uses mean values of specific only two surrounding stations at some distance, so that there are three stations on 8587 km^2. Similarly, estimates at any point using the IDW are highly

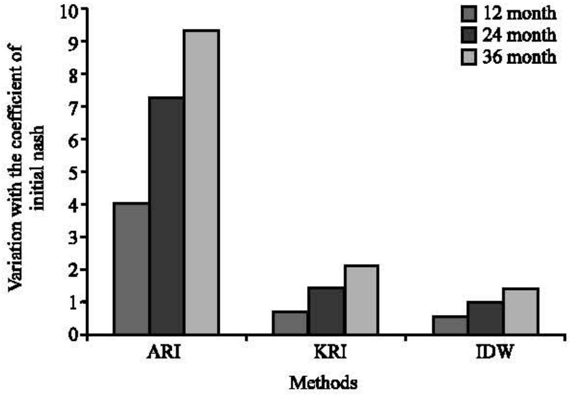

Fig. 6: Changes in coefficient of Nash with the replacement in the data input, 12, 24 and 36 months, with rainfall amounts by estimated by the arithmetic mean (ARI), Kriging (KRI) and inverse distance (IDW)

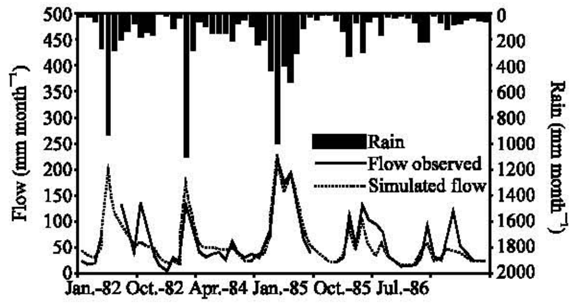

Fig. 7: Hydrographs obtained after GR2M model calibration over the period January 1982-April 1987

dependent on values of the three nearest points. Thus, the presence of nineteen stations over 1356 km^2 which is a much higher density than the previous one has favored these results. This confirms the assumption that errors in estimating basin rain increases with decreasing density of rainfall network (Robinson, 2005). Indeed, over the network is denser, it will likely capture the local intensity have significant weight in the final value of the basin rain (Bourqui, 2008).

Influence of estimates of rain on the calibration and validation of the GR2M model:

Calibration: The model calibration GR2M over 1998-2003 gives 44.2 as the coefficient of Nash. Variations in this ratio with the realization of substitutions of input rainfall amounts of 12, 24 and 36 months in the period 2000-2002 by others estimated provide evidence of the effectiveness of the GR2M model (Fig. 6). The effectiveness of the model drops for all three methods with increasing the length of new data.

These 12, 24 and 36 months respectively represent the proportions of 19, 39 and 58% for 62 months of monthly heights used as input data for calibration. The initial coefficient of Nash (44.2) shows a greater decrease with the rains from the arithmetic mean for which the gaps vary on average from 4 to 9.3 is from-9 to-21%. For cons the Nash coefficient varies less with the rain from kriging and IDW: 0.6 to 2.1 as deviations is from-1 to-5%. These findings corroborate those of Ardoin (2004) which also noted deterioration in the Nash criterion with relative errors in precipitation. Although variations of Nash from-65 to-203% with relative errors of ±30% rainfall is far superior to ours. This decrease Nash highlights the influence of network density on the effectiveness of a model. Uncertainties due to a poor estimation of the rain because of the low density of rain gauges are translated into a bad estimate (Bourqui, 2008). In fact, increasing the density of rain would lead to improved stability of the vectors of model parameters (Duncan *et al*., 1993; Anctil *et al*., 2006; Andreassian *et al*., 2001). In addition, they would adjust to errors in input data of precipitation with which models are effective (Troutman, 1983; Bell and Moore, 2000; Andreassian *et al*., 2001).). But this adaptability of models to errors in input data which depends on their structures is possible until a certain point and walk with those type as systematic over estimation or underestimation of rain (Oudin *et al*., 2006). It is this type of error that which has been committed with the estimates of the arithmetic mean, of kriging and inverse distance of our work. We deduce that the GR2M model could adapt to systematic errors introduced in the input data by kriging and IDW. But less than those caused by the arithmetic mean.

Validation: The GR2M model calibration over the period 1982-1987 gives 79.2 as the coefficient of Nash. The almost similar evolution of the flows simulated and observed confirms the good results of the GR2M model over this period (Fig. 7). The use, over this period, of the parameters obtained during the calibration phase in 1998-2003 produced a lower coefficient of Nash (66.2).

What causes the decrease of the coefficient of determination between series of observed and simulated flows from 0.76 to 0.54 (Fig. 8a, b). The calibration parameters obtained after made data substitutions in the previous section allows also appreciating the change in the robustness of the GR2M model. Indeed, by calculating the differences between the new coefficients of Nash and the first is to say 66.2 the Fig. 9 is obtained. It appears clearly with the three methods that the new Nash

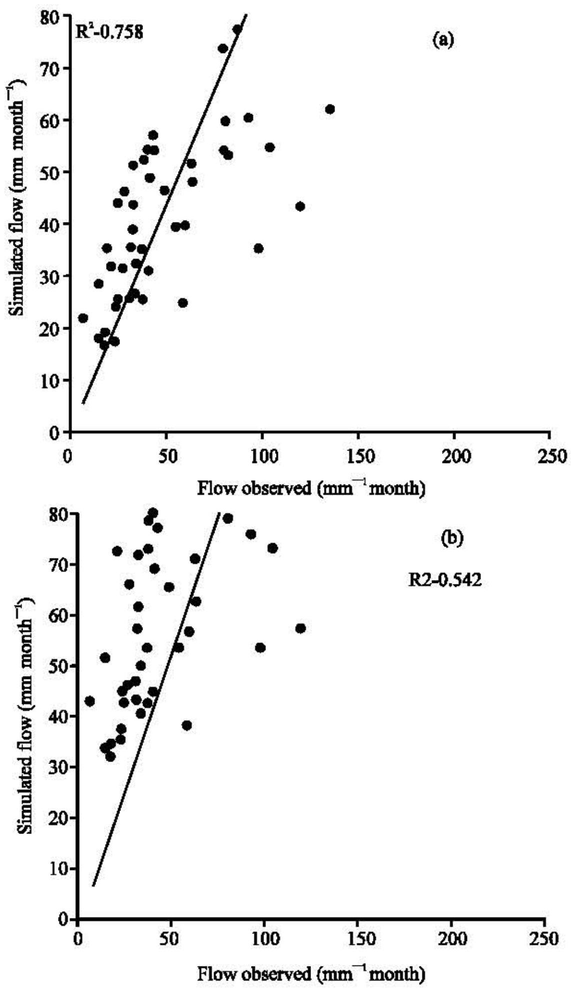

Fig. 8: Flow rates observed and simulated during the GR2M model calibration over the period January 1982-April 1987 (a) and during the validation of parameters for the period January 1998-April 2003 on the previous phase (b)

coefficients vary more than the old with the length of the integrated rainfall estimates. Also, as during the calibration, the parameters obtained with data containing values estimated by the arithmetic mean produce the lowest Nash. Hence larger variations of 6-32 or -9 to-48% which are much higher than those that give the other two methods. Indeed, the coefficients of Nash slightly increased and decreased, respectively from 0.3 to 0.9 for kriging and 0.9 to 3 for IDW. This provides variations of 0-1% for kriging and-1 to-5% for the inverse distance. Thus, the adaptation of GR2M model to the errors introduced into the input rains by the krigeage and the IDW is confirmed since they practically does not

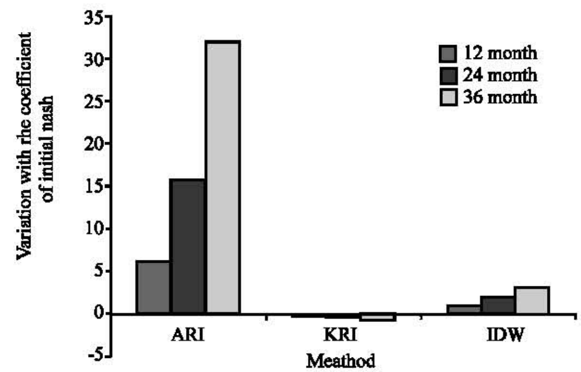

Fig. 9: Variation of Nash coefficients after validation of parameters obtained after the GR2M model calibration with data estimated over the period 2000-2002, the arithmetic mean (ARI), Kriging (KRI) and the inverse of distance (IDW)

influence the process of validation of the parameters obtained on another phase. Similarly, the difficulty in integrating those coming from the estimates by arithmetic mean of which the effect is accentuated during the validation especially with the length of the new data Ardoin (2004) also noted, with different basins of West Africa, an amplification of the initial error by the GR2M model as well in overestimated as in underestimation. In total, the filling of gaps, of monthly rainfall amounts, made by arithmetic mean values for neighboring stations available are not reliable as input to simulate rainfall-runoff. And this, especially if their length is more than 19% of the total rainfall input.

CONCLUSION

The station of Tabou recorded an important rainfall as benefiting from its position at the extreme south-western Côte d'Ivoire. The annual rainfall series of this station also has the peculiarity to have remained stationary from 1922 to 2004 in a general context of decrease in total annual rainfall since the late 1960s in wet Africa. It was not until the 1990s to record a first deficit sequence of five years from 1993 to 1998 thus where the largest deficit displayed by 10% this decade. This relative decline in annual rainfall over the period 1993-1998 is characterized by lower contribution to annual total of month of heavy rainfall compare to phase 1922-1992. Thus, the months of May and June ot the big rainy season have, on average, respectively 131 and 168 mm in less as 26, 32 and 83 mm less for September, October and November of the short rainy season. A strengthening of the long dry season also appears with decreases of 36, 44 and 38 mm of rainfall deph mean of December, January and March. The interpolation of rainfall by kriging and inverse distance highlights the reduction of estimation errors with increasing density gauges. Indeed, these two methods allows while based on a catchment area of eighteen gauges 350 km^2 respectively to improve, according to the month of 26-122 and 27-131% with an average of 47% for the both, the estimates made by the arithmetic mean of the observed rainfall at Sassandra and San Pedro, which are normally available. The introduction of these estimates of monthly rainfall of these three methods in proportions of 19-58% (12-36 months) in the input data from 2000 to 2002 reduced the effectiveness of the model with a decrease of Nash coefficient from 4 to 9.3 for the arithmetic mean. But the GR2M model is less sensitive to estimates of kriging and IDW, with only 0.6 to 2 drops of the Nash criterion. The validation of the parameters coming from the chock with the rains obtained by arithmetic mean causes an amplification of the fall of the coefficient of Nash from 6 to 32.Validation of parameters from calibration with rainfall obtained by arithmetic mean causes an amplification of the fall of Nash coefficient from 6 to 32. While those of interpolation methods generate light decreases of the Nash coefficient from 0.3 to 3.

In sum, Tabou serie notwithstanding the importance of its rainfall from the rest of South-western Côte d'Ivoire may suffer fillers with estimates from spatial interpolation of data from the vicinity of a fairly good density. These new rain could consist up to 58% of monthly rainfall input is reliable for a good simulation of the flow.

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