Chapter 15
A Stochastic Weather Generator Model for Hydroclimatic Prevision in Urban Floods Risk Assessment in Abidjan District (Cote d'Ivoire)

Jean Homian Danumah, Samuel Nii Odai, Mahaman Bachir Saley, Joerg Szarzynski, Kwaku Adjei, and Fernand Koffi Kouame

Abstract Flood risk occurrence is very often related to heavy precipitation; and available future weather data is a potential source for long term flood risk prediction. The aim of this paper was to determine and analyze trends in rainfall, temperature and PET under present and future climatic conditions using Long Ashton Research Science-Weather Generator (LARS-WG) software, in prediction of flood risk occurrence in Abidjan. This work was based on the integration of Hydro climatic daily data within LARS-WG software. The processing steps are: (1) calibrating and validating the model using 50 years measured data, (2) generating baseline data for 50 years, (3) processing future scenario data based on baseline already set using HADCM3 and (4) Comparing baseline and generated scenario data. The resulting statistics show that temperature will increase by 0.32, 1.36 and 2.54 °C for the periods 2011–2030, 2046–2065 and 2080–2099 respectively. Then rainfall in the same period will increase by 4 %, 6 % and 10 % respectively. The mean and high flooding risk will then increase in long term within this urban area. Thus this future large extension of flooding occurrence imposes to take future weather scenario into account in prediction and management of flooding risk in Abidjan District.

Keywords Climate change • Flood risk • LARS-WG • Abidjan • Cote d'Ivoire

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Introduction

Climate change is considered to be the biggest challenge facing by the mankind in the twenty-first century (Osman et al. 2014). Climate change is a global issue and needs to be examined at global, regional and local scale. Population growth too with its demand and development has become a world issue on this century (Txomin et al. 2013). Population demand, green gas emission from industrialization and land use lead to severe climate variability (Yan et al. 2014) and change such as increases of extreme events (flood, drought, and tsunami) occurrence across the world and more specifically in West Africa.

More recently in Cote d'Ivoire, we have registered increasingly important phenomena of floods, with its effects such as death, properties damage and population exodus. Extreme rainfall is the main natural disaster which causes loss of many lives; destroy infrastructures, and displacement of people during the rainy season in Abidjan. Statistical analysis in 2013 shows that 26 % of the district of Abidjan is flood risk area and 21, 13, and 15 people died in 2009, 2010, and 2011 respectively due to floods. Besides, with a total of 80,000 people living in areas subject to risk of flooding in the district with 40,000 people in risk areas in Cocody, 12,500 people in Abobo, 10,000 in Adjame, 9500 in Yopougon and 8000 in Attecoube communes. However, the use of future scenario of weather data for understanding present condition and managing future hydrologic events in Cote d'Ivoire is practically non-existent. Weather data analysis for many years were based on determining break on the times series using some statically methods such as Pettit and Buishand test, application of Nicholson indices to bring out the wet and dry period in case on rainfall variability and shows general trend, inter-annual behavior (Brou 1997, 2005; Savané et al. 2001; Goula et al. 2006; Kouassi et al. 2008). Also assessing flood risk based on rainfall variability using remote sensing and GIS techniques in West, Southwest and South of Cote d'Ivoire (Savane et al. 2003; Saley et al. 2005, 2013).

Flood risk occurrence is very often related to heavy precipitation, which means that there is a need of knowledge about hydroclimatic variability for most reliable flood management and mitigation; then available future weather data becomes a potential source for short term and long term extreme rainfall prediction. For all that, general circulation models (GCM) has become an important tool to generate future scenarios and helpful to predict extreme rainfall under climate change. However, the output from Global Climate Models (GCMs) cannot be used directly at a site because of their very coarse spatial resolution (Semenov et al. 1998). Thus, weather generator can serve as a good computationally tool to produce at local scale (Abidjan site) specific climate change scenarios at the daily time-step with better resolution and fit reality.

Long Ashton Research Station-Weather Generator (LARS-WG) model which is a stochastic weather generator specially designed for climate change impact studies is one of the important general circulation models for future climate change. LARS-

WG is a numerical model which produces synthetic daily time series of a suite of climate variables, such as precipitation and temperature, with certain statistical properties (Semenov et al. 1998). LARS-WG has been tested for different sites worldwide and shown its ability to model rainfall extremes with reasonable skill (Semenov 2007). LARS-WG too has been used in various studies, including assessment of the impact of climate change (Goodarzi et al. 2014; Molanejad et al. 2014; Osman et al. 2014; Noori et al. 2013; Semenov 2007; Semenov 2014; Semenov and Brooks 1999; Trnka et al. 2014; Semenov et al. 1998; Rao 2014). According to Sobhany and Fateminiya (2014), high accuracy of climate data modelling in different climatic stations has been confirmed by many researchers using LARS-WG.

The significant lack of research gap identified by this study is that recent scientific work undertaken in the district of Abidjan concentrated on rainfall variability during past and current condition as flood risk drivers within two communes of Abidjan: Attecoube and Abobo (Savane et al. 2003 and Hauhouot 2008). This is a piece-meal approach and does not provide a solution to the problem of flood occurrence within the district. Other studies (Kouamé et al. 2013; Jourda et al. 2006; Ahoussi et al. 2013) in the district, not directly focus on extreme rainfall pointed out the inefficiency of the drainage network and impervious area which are part of the main drivers of floods. However, these studies are fragmented and did not consider the entire district and future scenario model to link climate change and natural disaster. Then, no studies have yet been undertaken to understand and analyze trends in weather data under present and future climatic conditions implications in urban flood risks at Abidjan.

The aim of this paper was to determine and analyze trends in hydroclimatic data (rainfall, temperature, solar radiation and PET) under present and future climatic conditions using Long Ashton Research Science-Weather Generator (LARS-WG) model, in prediction of flood risk occurrence in Abidjan. For this purpose, assessment process of observation and simulation data are conducted following three steps, calibration, validation and generating scenario using downscaling by SRA1B scenarios, HAdCM3 model of atmosphere general circulation models (GCM) in LARS-WG model.

Methodology

Study Area

The District of Abidjan is located in the south of Cote d'Ivoire between latitudes 5° 10 and 5° 38 North and longitudes 3° 4 and 5° 21 West (Fig. 15.1). It consists of 13 municipalities since 2001, 10 municipalities in Abidjan and 3 others communes namely Bingerville, Songon and Anyama and covers an area of approximately 2119 km^2. According to the statistic institution of the country records in 2013,

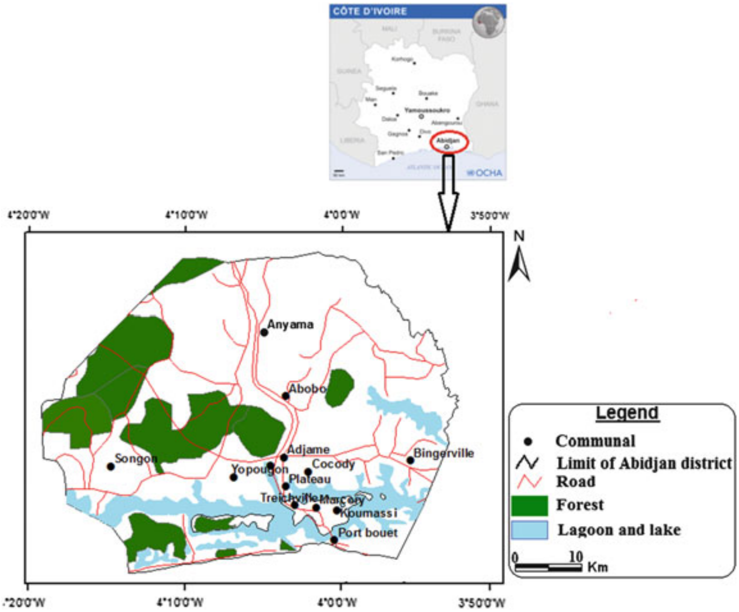


Fig. 15.1 Location of the study area (*Source*: Author)

Abidjan district has an estimated population of 4,739,752 inhabitants in the metropolis, and 4,460,355 inhabitants in the city of about 5 million people or 20.3 % of the national population as at 2013. In addition, this population has a perpetual growth characterized by high industrialization and urbanization but also due to the political crisis through the country. It is limited (Fig. 15.1):

- To the south by the Atlantic Ocean
- In the southwest by the Department of Dabou
- To the west by the Department of Grand Lahou
- To the north by Agboville Department
- South-east by the Department of Grand-Bassam
- To the east by the Department of Alepe

Climatic Variability

The study area has an equatorial climate transition (Climate Attieen), characterized by four seasons: two dry seasons and two rainy seasons within the annual cycle:

- Long dry season from December to April
- Long rainy season from May to July

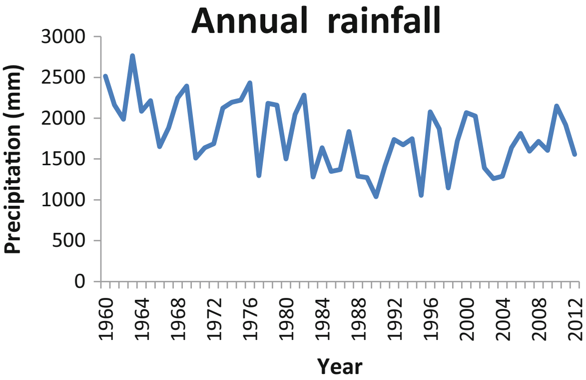


Fig. 15.2 Total annual rainfall variability of Abidjan from 1961 to 2012 (*Source*: Author)

- Short dry season from July to September
- Small rainy season from October to November

Abidjan district has three rainfall stations located at Bingerville, Adiopodoume and Abidjan airport. These stations can be measured on a daily and monthly basis the different climates. So we were able to collect temperature, rainfall and solar radiation data to Abidjan district station.

Precipitation

For the characterization of rainfall fluctuations that have affected the district of Abidjan, we conducted a study of spatio-temporal variation of monthly rainfall and annual rainfall totals (Fig. 15.2).

The high annual rainfall recorded in the district of Abidjan during the period 1960–2012 ranged from 2800 mm in 1963 to 1020 mm in 1990 with an average of 1910 mm. Generally in the 1960s, the annual rainfall ranged between 2000 and 3000 mm. After 1987, there was a drop of this rainfall has oscillated between 1500 and 2200 mm which is a reduction of more than 500 mm of rain compared to the 1960s.

Also, the observation of highest average monthly rainfall shows that June and sometime July are the rainiest month of the District of Abidjan (Fig. 15.3).

Temperature

The annual average temperature of Abidjan is around 26 °C. The temperatures in the district are higher from February to May and November. These temperatures are experiencing a slight decline during the months of June to October.

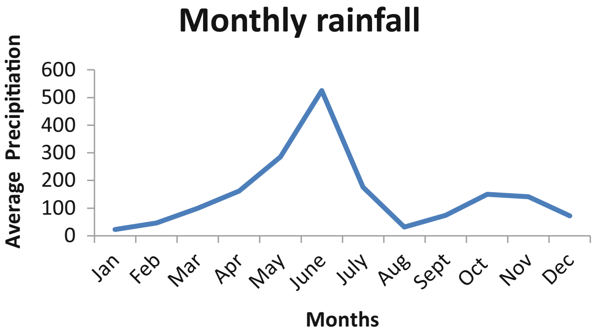


Fig. 15.3 Average of monthly precipitation of Abidjan from 1961 to 2012 (*Source*: Author)

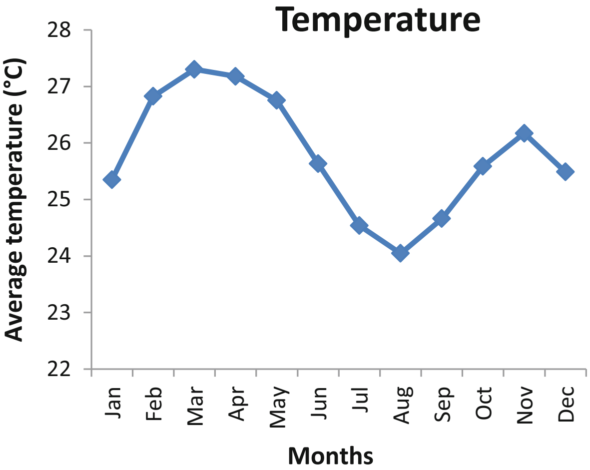


Fig. 15.4 Monthly temperature variability from 1961 to 2012 at Abidjan (*Source*: Author)

The curve show in Fig. 15.4 shows that the average monthly temperatures for the period of 1960–2012 fluctuated between 24 and 28 °C. The months March and April are the hottest months with a monthly average temperature above 27 °C. The months of July to September (rainy season) are the least hot, with a maximum temperature equal to 24.5 °C (Fig. 15.4).

After accomplishment of ombrothermic diagrams which shows comparison between temperature and rainfall charts of Abidjan (Fig. 15.5) over the period 1961–2012, we note that the temperatures are low during the months of heavy rainfall and strong during the months of low rainfall.

Analysis of the Annual Rainfall and the Heavy Rainfall Month

Graphical comparison applies between annual rainfall and heavy rainfall month of the Abidjan District to analyze the trends patterns from 1960 to 2012 bring out that

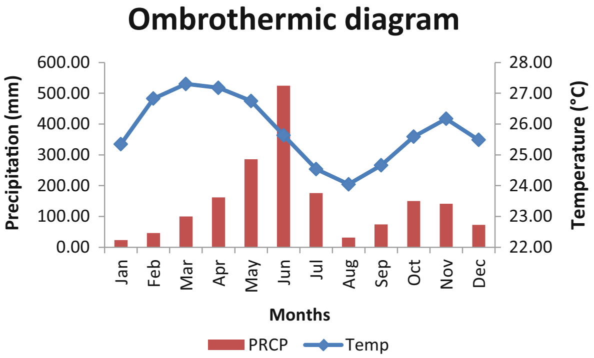


Fig. 15.5 Ombrothermic diagram of Abidjan from 1981 to 2012 (*Source*: Author)

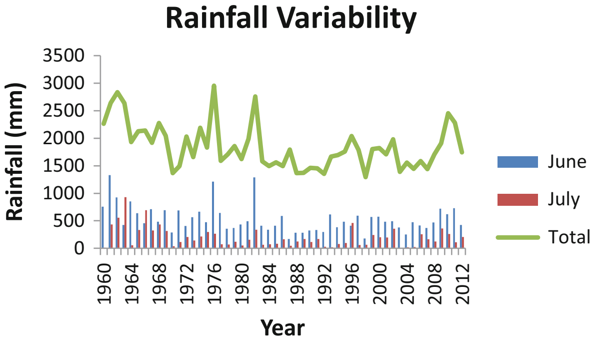


Fig. 15.6 Annual rainfall and heavy rain months of Abidjan from 1960 to 2012 (*Source*: Author)

in general the annual rainfall variability is based on the amount of rainfall in the month June because, it is the most important heavy rainfall month compare to July in the series (Fig. 15.6).

Data and LARS-WG Model Processing

In this study 50 years of observed daily weather data (precipitation, maximum and minimum temperature and solar radiation) have been used with LARS-WG (a stochastic weather generator model) and considered as baseline for the different process. Precipitation is considered as the primary variable in our case for analyzing flood event occurrence in the future and the other three variables come as secondary variables to obtain an overall understanding of future hydroclimatic events.

In LARS-WG, the process of generating synthetic weather data can be divided into three distinct steps: calibration or site analysis, validation or Q-test and Generator or generation of future data based on normal distribution. The seasonal cycle of means and standard deviations was removed from the observed performance, and the residuals approximated by a normal distribution. These residuals were used to analyze a time correlation of each variable. Refer to software manual guide and Semenov and Barrow (1997, 2002), Semenov and Pierre (2010), and Semenov et al. (1998) for more detailed description of the modelling procedure.

- **Model Calibration**: Model calibration is done in LARS-WG by implementing SITE ANALYSIS which analyses observed daily weather data (precipitation, maximum and minimum temperature and solar radiation) of Abidjan to determine their statistical characteristics. The resulting information is stored in two parameters files and later used in the generation process.
- **Model Validation**: In this step, the statistical characteristics of observed data are compared with those of synthetic data generated using the parameters derived from the original observed data by applying the Q-test. Several statistical tests: chi-squared test, Student’s T-test and F-test are used in order to determine whether the distributions mean values and standard deviations of the synthetic data are significantly different from those of the original observed data set. Then, the ability of LARS-WG to simulate the data at the chosen site is assessed.
- **Generation of Climate Scenario**: LARS-WG model generates synthetic future weather data by combining a scenario file containing information about changes in hydroclimatic data (precipitation, minimum/maximum temperature, solar radiation and PET) based on baseline weather data (50 years of observed data) at Abidjan site. Baseline parameters are adjusted by the changes for the future period and the emissions predicted by IPCC Global Climate Model for each climatic variable of the grid covering the site. In our study, we used IPCC Global Climate Model: HadCM3 and SRA1B scenario to generate 50 future years predicted weather data for the periods of 2011–2030, 2046–2065 and 2065–2099.

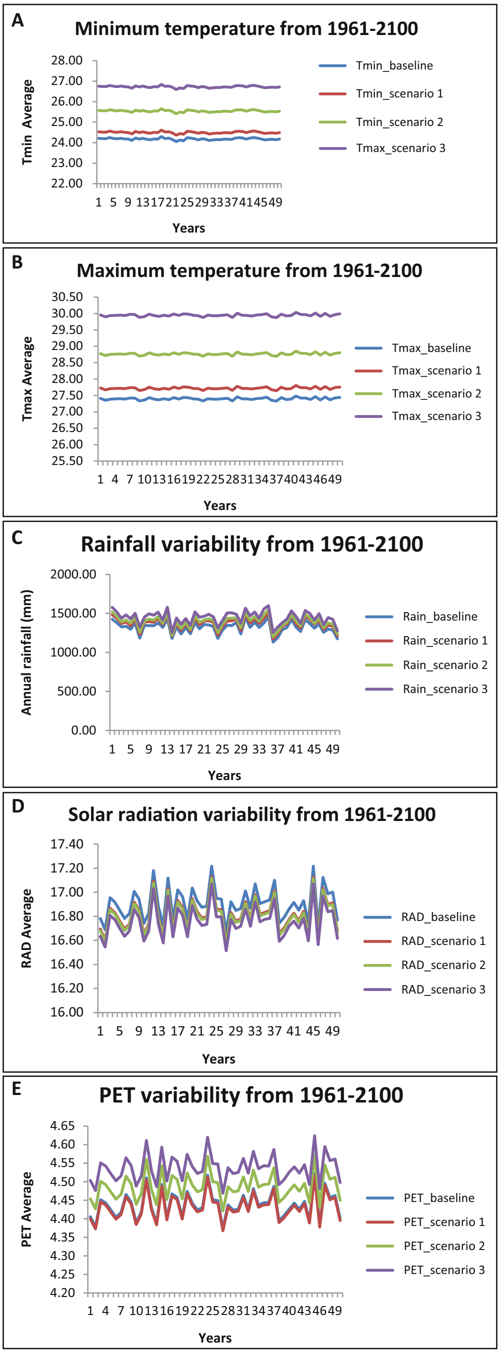
Results

The Table 15.1 shows how the minimum temperature, the maximum temperature, rainfall, solar radiation and the PET will change from the baseline (1961–2010) to three future scenarios 2011–2030 (scenario 1), 2046–2065 (scenario 2) and 2065–2099 (scenario 3). We also observe in Fig. 15.7, the trend variability and

Table 15.1 Minimum/maximum temperature, precipitation, solar radiation and evapotranspiration change prevision at Abidjan

	T_{min}	T_{max}	Rain	RAD	PET
Baseline (1961–2010)	24.18	27.40	3.62	16.91	4.44
Scenario 2011–2030	24.50	27.72	3.75	16.82	4.43
Change	**0.32**	**0.32**	**0.04**	**−0.09**	**−0.01**
Scenario 2046–2065	25.54	28.77	3.82	16.81	4.49
Change	**1.36**	**1.37**	**0.06**	**−0.10**	**0.05**
Scenario 2080–2099	26.72	29.95	3.97	16.76	4.54
Change	**2.54**	**2.55**	**0.10**	**−0.15**	**0.10**

Fig. 15.7 Observed and future weather data variability from 1960 to horizon 2100. (**a**) minimum temperature, (**b**) maximum temperature, (**c**) Rainfall, (**d**) Solar radiation, (**e**) PET (*Source*: Author)



change between the baseline and the same future scenario of each weather data. These previsions are made using the global model HadCM3 and the optimistic emission scenario SRA1B.

Scenario 1: 2011–2030
The result of this analysis shows that, for the scenario 1 compare to the baseline, we will have an increase of 0.32 °C in both the minimum and the maximum temperatures, an increase of 4 % in the precipitation and a decrease of 0.09 and 0.01 in solar radiation and evapotranspiration respectively in the Abidjan district.

Scenario 2: 2046–2065
The second scenario shows an increase from the baseline of 1.36 °C of the minimum and 1.37 °C the maximum temperatures. For this same scenario, we also have an increase of 6 % in precipitation from the baseline and a decrease of 0.1 in solar radiation and an increase of 0.05 of the evapotranspiration.

Scenario 3: 2065–2099
The third scenario shows an increase from the baseline of 2.54 °C of the minimum and 2.55 °C the maximum temperatures. Then, we also have an increase of 10 % of the precipitation and a decrease of 0.15 of solar radiation and an increase 0.10 of the evapotranspiration compare to the baseline.

Globally the climate previsions for the locality of Abidjan show an increase compare to the baseline of the temperatures and the precipitation for short term and long term periods with the longer one being higher than the shorter one. For the PET, the short term previsions show a decrease when the long term prevision shows an increase. In contrast, the solar radiation shows a decrease for the short term and long term periods.

The implication of the different scenarios being modelled is that flood risk will occur more and more with high intensity due to the increase of precipitation in short and long term. This confirm that there is an urgency to put in place a strategy that will facilitate decision making for flood mitigation and better land use planning under changing climate in future at Abidjan.

Discussion

The methodology for analyzing the trend of weather data under present and future condition to predict future climate change in Abidjan using LARS-WG model to achieve it, is a real advantage. The reliability of these future scenarios are linked to the strength of input parameters, the observed daily data (temperature, rainfall, solar radiation) for 50 years were used without the need to generate data as baseline data due to large data availability in our case which reduced the reduced the range of uncertainty.

The HadCM3 model used in this study is from GCMs which is already part of LARS-WG model and subjectivity is also noted in the choice and range of data as input. This subjectivity is reduced by checking the consistency of observed data as baseline by doing calibration and validation of the data before generating the future scenarios which increases our confidence in the models' predictions and reduces the level of uncertainty.

However, GCMs and impact models are undergoing continuous development and improvement because some research have showed some uncertainty and limitations by applying Global Climate model at local scale due methodically model calibration. Thus, these results can be improved by integrating a comparison with others model which are or not statistic model, those from the hydrological modeling for the establishment of extreme events such as flood.

Conclusion

In this research, LARS-WG model has been used to generate specific climate change scenarios (weather data) for prediction of weather events at Abidjan site. HAdCM3 Model and the optimistic emission scenario SRA1B have been used. Integration of weather daily data: precipitation, minimum/maximum temperatures and solar radiation from 1961 to 2010 into the LARS-WG model as baseline data make robust the result. The HadCM3 model was then applied to 50 years observed data to generate 50 years of future daily weather data after calibration and validation for Abidjan site. The Results has shown that for the next 90 years, there will be an increase in short term and long term of minimum/maximum temperature and precipitation and inversely a decrease of solar radiation in Abidjan. In short, the LARS-WG model was proposed for realistic simulation of hydroclimatic data (precipitation, temperature, solar radiation and PET). And it was highly capable to generate future scenario and give better understanding and view concerning weather data variability in future more specifically rainfall in case on flood risk event. However, this study can still be improved for more details by coupling statistical and hydrological model. Finally effective preparedness strategies have to be developed to manage future extreme rainfall or floods occurrence within Abidjan district.

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References

Ahoussi KE, Loko S, Koffi YB, Soro G, Oga YM, Soro N (2013) Evolution spatio-Temporelle Des Teneurs en Nitrates Des Eaux Souterraines De La Ville d'Abidjan (CÔTE D'IVOIRE). Int J Pure Appl Biosci 1(3):45–60

Brou YT (1997) Analyse et dynamique de la pluviométrie dans le Sud forestier ivoirien: recherche de corrélations entre les variables climatiques et les variables liées aux activités anthropiques. Thèse 3ème cycle, Univ. Cocody, Côte d'Ivoire, 211 p

Brou YT (2005) Climat, mutations socio—économiques et paysages en Côte d'Ivoire. Rapport d'activités scientifique, pédagogique, administrative et publications. Memoire HDR, 106 p

Goodarzi E, Bavani MA, Dastorani MT, Talebi A (2014) Evaluating effect of downscaling methods; change-factor and LARS-WG on surface runoff (A case study of Azam-Harat River basin, Iran). Desert 19(2):99–109

Goula BTA, Kouassi VJ, Savané I (2006) Impacts du changement climatique sur les ressources en eau en zone tropicale humide: cas du bassin versant du Bandama en Côte d'Ivoire. Agron Afr 18(1):1–11

Hauhouot C (2008) Analysis of the rainfall risks in the precarious districts of Abidjan: Survey of cases in Attécoube. Geo-Eco-Trop 32:75–82

Jourda JP, Kouamé KJ, Saley MB, Kouamé KF, Kouadio BH, Kouamé K (2006) A new cartographic approach to determine the groundwater vulnerability of the Abidjan aquifer. In: Xu Y, Usher B (eds) Groundwater pollution in Africa. Taylor & Francis, London, pp 103–114

Kouamé KJ, Jourda JP, Saley MB, Deh SK, Anani AT, Biémi J (2013) Mapping of groundwater vulnerability zones to pollution in various hydrogeological environments of Côte d'ivoire by drastic method. Int J Sci Eng Res 4(5):9

Kouassi AM, Kouamé KF, Goula BTA, Lasm T, Paturel JE, Biémi J (2008) Influence de la variabilité climatique et de la modification de l'occupation du sol sur la relation pluie-débit a partir d'une modélisation globale du bassin versant du N'zi (Bandama) en Côte d'Ivoire. Rev Ivoir Sci Technol 11:207–229

Molanejad M, Soltani M, Saadat Abadi Ranjbar A (2014) Simulation of extreme temperature and precipitation events using LARS-WG stochastic weather generator. Int J Sch Res Gate 2 (3):121–129

Noori M, Sharifi MB, Zarghami M, Heydari M (2013) Utilization of LARS model for modelling of meteorological parameters in Golestan, province of Iran. J River Eng 1(1):5

Osman Y, Al-Ansari N, Abdellatif M, Aljawad SB, Knutsson S (2014) Expected future precipitation in central Iraq using LARS-WG stochastic weather generator. Engineering 6:948–959. doi:10.4236/eng.2014.613086

Rao CN (2014) Climate change analysis in southern Telangana region, Andhra Pradesh using LARS-WG model. Curr Sci 107(1):54

Saley MB, Kouamé KF, Penven MJ, Biémi J, Kouadio BH (2005) Cartographie des zones à risque d'inondation dans la région semi-montagneuse à l'Ouest de la Côte d'Ivoire: Apports des MNA et de l'imagerie satellitaire. Télédétection 5(1–2–3):53–67

Saley MB, Danumah JH, Sorokoby VM, Kanohin FO, Atcheremi D, Denean SP, Kouame FK, Djagoua VE (2013) Méthodologie pour la cartographie des zones vulnerables a l'inondation par systeme d'information géographique et analyse multicritère: application au bassin versant de la Davo a Sassandra (sud-ouest de la Cote d'Ivoire). Africa Geosci Rev 20(1):21–33

Savané I, Coulibaly KM, Gioan P (2001) Variabilité climatique et ressources en eaux souterraines dans la région semi-montagneuse de Man. Sécheresse 12(4):231–237

Savane I, Coulibaly N, Soro N (2003) Analyse multicritère spatiale pour l'identification de la vulnérabilité aux risques naturels d'Abobo (banlieue de la ville d'Abidjan, Côte d'Ivoire). Rev Ivoir Sci Technol 4:94–107

Semenov M (2014) Delivering CMIP5-based climate scenarios for impact assessments in Europe. In: EGU general assembly conference abstracts, 1

Semenov MA (2007) Simulation of extreme weather events by a stochastic weather generator. Clim Res 35(3):203

Semenov MA, Barrow EM (1997) Use of a stochastic weather generator in the development of climate change scenarios. Clim Change 35:397–414

Semenov MA, Barrow EM (2002) LARS-WG: a stochastic weather generator for use in climate impact studies, 28 p

Semenov MA, Brooks RJ (1999) Spatial interpolation of the LARS-WG stochastic weather generator in Great Britain. Clim Res 11:137–148

Semenov MA, Pierre S (2010) Use of multi-model ensembles from global climate models for assessment of climate change impacts. Clim Res 41:1–14

Semenov MA, Brooks RJ, Barrow EM, Richardson CW (1998) Comparison of the WGEN and LARS-WG stochastic weather generators for diverse climates. Climate Res 10:95–107

Sobhany B, Fateminiya FS (2014) Modelling of climatic parameters in province of Southern Khorasan. Phys Geogr 46(3):9

Trnka M, Rötter RP, Ruiz-Ramos M, Kersebaum KC, Olesen JE, Žalud Z, Semenov MA (2014) Adverse weather conditions for European wheat production will become more frequent with climate change. Nat Clim Chang 4:7. doi:10.1038/NCLIMATE2242

Txomin H, Luis RA, José LG-Y, Jorge AR, Josep EP-P (2013) Multi-level object-based urban mapping from remote sensing and GIS data. In: GIS Ostrava 2013 - Geoinformatics for city transformation, 10 p

Yan G, Qi F, Wei L, Aigang L, Yu W, Jing Y, Aifang C, Yamin W, Yubo S, Li L, Qianqian M (2014) Changes of daily climate extremes in Loess Plateau during 1960–2013. Quat Int 371:5–21. doi:10.1016/j.quaint.2014.08.052

Website

http://www.unocha.org/cotedivoire/maps-graphics/thematic-maps