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EFFECTS OF CLIMATE CHANGE AND HUMAN ACTIVITIES ON WATER RESOURCES IN THE COMOE RIVER BASIN (WEST AFRICA)

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ABSTRACT

This study was carried out on the Comoe River Basin (78,000 km^2) in West Africa where climate change is supposed to affect many sectors like water resources, biodiversity, food, energy, housing, tourism, transportation and health. This study used the GR4J model and three RCM, namely, the COnsortium for SMall scale MOdeling (COSMO) Climate Limited-area Modeling-Community (CCLM4-8-17), the KNMI Regional Atmospheric Climate Model (RACMO) and the Rossby Centre Atmospheric model 4 (RCA4) to assess the robustness of a lumped hydrological model in modelling streamflow and to examine climate change effects on streamflow in the Comoe River Basin using the RCP 4.5 and 8.5 scenarios. Future period's streamflow were simulated under these scenarios using the GR4J model. The comparison of mean yearly discharge for 2041-2060 and 2081-2100 periods to 1981-2000 periods at M'Basso revealed that flows will decrease respectively for 2041-2060 and 2081-2100 periods about 41% and 45% according to the scenario RCP 4.5 KNMI-RACMO22T model. The decrease of flows following RCP 8.5 for the same periods is about 46% and 44%. High flow and low flow periods are quit the same for the three RCM. The two scenarios and the three RCM reveal an increase of temperature up to 5.6°C for 2041-2060 and 2081-2100 periods at Abidjan, Adiake, Dimbokro, Bondoukou and Bobo Dioulasso stations. Also, temperatures for 2081-2100 period are higher than the ones of 2041-2060 period. The highest values are generally observed in January. Findings from this study revealed an underestimation of mean annual rainfall, 0.4 to 0.6 for RCP4.5 and 0.5 to 0.8 for RCP8.5 for 2041-2060 and 2081-2100 periods. Whereas, SMHI-RCA4 and KNMI-RACMO22T are overestimating mean annual rainfall, 0.2 to 0.3 for RCP4.5 and 0.1 to 0.5 for RCP8.5. Hydrologic and climatic parameters comparison at M'Basso station for 1981-2000, 2041-2060 and 2081-2100 periods revealed an increase of potential evopotranspiration for the two horizons and for the three RCM and a decrease of discharge. The vulnerability of water users to climate change was assessed and communities' adaptation strategies were defined. Results revealed that 95% of water users are perceiving changes in climate. They have heard of climate change and they attested that there is an increasing occurrence of this phenomenon. Reduced water level in rivers, delay in cropping season, crop failure, new pests and diseases, drop in income and decline in crop yield, food insecurity, changes in economic activity and cropping pattern are different ways that they are experiencing climate change. Findings also revealed that water users use many adaptation strategies like agroforestry, substitution and calendar redefinition, increasing fertilizer application, crops diversification, borrowing from friends and money lenders.

Key words: Climate change, Vulnerability, Water user, Adaptation strategy, Comoe River Basin

SYNTHESIS

Résumé

Cette étude a été réalisée sur le bassin du fleuve Comoé (78 000 km^2) situé en Afrique de l'Ouest. Dans cette zone, les changements climatiques sont supposés affecter plusieurs secteurs tels que les ressources en eau, la biodiversité, la sécurité alimentaire, l'énergie, l'habitat, le tourisme, le transport et la santé. Pour évaluer la robustesse d'un modèle hydrologique global dans la modélisation des écoulements et examiner les effets du changement climatique à travers les scénarios RCP 4,5 et 8,5, cette étude a utilisé trois modèles climatiques régionaux (RCM) que sont le COSMO-CCLM4-8-17, le KNMI-RACMO22T et le SMHI-RCA4. La simulation des écoulements a été faite sous ces scénarios avec le modèle GR4J. La comparaison des débits moyens annuels pour les périodes 2041-2060 et 2081-2100 avec celle de 1981-2000 a révélé une baisse des écoulements pour ces deux périodes futures respectivement de 41% et 45% à la station de M'Basso selon le scénario RCP 4,5 du modèle KNMI-RACMO22T. La baisse des écoulements selon le scénario RCP 8,5 pour les mêmes périodes est de 46% et 44%. Les périodes des basses et hautes eaux sont quasiment les mêmes pour les trois RCM. Les deux scénarios et les trois RCM révèlent une augmentation de la température jusqu'à 5,6°C pour les périodes 2041-2060 et 2081-2100 aux stations d'Abidjan, d'Adiaké, de Dimbokro, de Bondoukou et de Bobo Dioulasso. Aussi, les températures de la période 2081-2100 sont-elles supérieures à celles de la période 2041-2060. Les valeurs les plus élevées sont généralement observées dans le mois de janvier. Les résultats de cette étude révèlent également une sous-estimation de la pluviométrie moyenne annuelle de 0,4 à 0,6 avec RCP 4,5 et 0,5 à 0,8 avec RCP 8,5 respectivement pour les périodes 2041-2060 et 2081-2100. Alors que SMHI-RCA4 et KNMI-RACMO22T surestiment la pluviométrie moyenne annuelle de 0,2 à 0,3 avec RCP 4,5 et 0,1 à 0,5 avec RCP 8,5. La comparaison des paramètres climatiques et hydrologiques à la station de M'Basso aux périodes 1981-2000, 2041-2060 et 2081-2100 a révélé une augmentation de l'évapotranspiration aux deux horizons et pour les trois RCM. Aussi, les précipitations et l'évapotranspiration sont-elles plus importantes que les débits qui sont très bas. Dans cette étude, la vulnérabilité des usagers de l'eau aux changements climatiques a été évaluée et des stratégies d'adaptation des communautés ont été définies. Les résultats ont montré que 95% des usagers de l'eau ont constaté que le climat a changé. Ils ont déjà entendu parler du changement climatique et ont certifié que ses effets se produisent de nos jours. Ils ressentent les effets des changements climatiques par la baisse des niveaux d'eau des fleuves, la perturbation des saisons, la destruction des cultures, les nouvelles maladies des plantes, la baisse des revenus et de la production agricole, l'insécurité alimentaire et l'abandon d'activités économiques. Les résultats ont également montré que les usagers de l'eau utilisent plusieurs stratégies d'adaptation telles que l'agroforesterie, la substitution de culture et la redéfinition du calendrier agricole, l'utilisation intensive de fertilisants, la diversification agricole et l'endettement usuraire.

Mots clés: Changement climatique, vulnérabilité, usagers de l'eau, adaptation, Comoé

Introduction

Le bassin versant de la Comoé est au carrefour de multiples usages des ressources en eau (agriculture, approvisionnement en eau potable, pêche, élevage, tourisme, etc.). Le contexte environnemental et socio-humain est changeant et en constante évolution. La compréhension de l'évolution des ressources en eau demeure, dans ce bassin, un défi scientifique certain. Dans cette étude, le diagnostic est posé à travers quatre questions scientifiques :

1. Quelle pourrait être la robustesse d'un modèle hydrologique agrégé dans la modélisation des écoulements ?
2. Comment évaluer les effets du changement climatique et des activités anthropiques sur les ressources en eau ?
3. Comment examiner les effets potentiels du changement climatique sous contrainte des scénarios RCP 4.5 et 8.5 sur les écoulements du bassin versant de la Comoé ?
4. Quelle est la vulnérabilité des usagers de l'eau face au changement climatique ?

La réponse à ces questions renvoie à l'objectif principal qui est d'évaluer l'impact du changement climatique et des activités humaines sur les ressources en eau du bassin versant de la Comoé. De façon spécifique, cet objectif principal se décline en quatre objectifs spécifiques en lien avec chacune des questions scientifiques posées ci-dessus.

La thèse est structurée en huit (08) chapitres. Le premier chapitre présente l'introduction générale à travers le contexte, les objectifs, les hypothèses de recherche et les résultats attendus. Le second chapitre présente le bassin versant de la Comoé, notre zone d'étude. Le troisième chapitre présente les données, matériels et méthodes utilisés dans cette étude. Les chapitres 4 à 7 présentent les quatre principaux résultats de l'étude. La conclusion et les perspectives constituent le chapitre 8.

Zone d'étude

Le bassin versant de la Comoé est situé en Afrique de l'Ouest. C'est un bassin transfrontalier, partagé par quatre pays que sont le Burkina Faso, la Côte d'Ivoire, le Ghana et le Mali. Il couvre une superficie de 78 000 km^2. Ce bassin est le siège d'un fonctionnement hydrogéologique différencié, d'un climat varié du Nord au Sud (climat semi-aride à savanes herbeuses au climat guinéen humide à savanes arborées et forêts denses) et d'un contraste de sensibilité à l'occupation des sols par les activités anthropiques. Ces spécificités à la fois climatiques et humaines rendent particulièrement fragile les ressources en eau de ce bassin versant.

Données, Matériel et méthodes

Les données météorologiques utilisées dans cette étude ont été fournies par la Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologie (SODEXAM) de Côte d'Ivoire et par la météorologie nationale du Burkina Faso. L'étude a été faite avec des données de vingt-trois (23) stations pluviométriques de plus de quarante (40) années d'observations par station.

Les données hydrométriques ont été fournies par les Services Hydrologiques Nationaux du Burkina Faso et de la Côte d'Ivoire. L'étude a été faite avec des données de six (06) stations hydrométriques de plus de quarante (40) années d'observations par station.

Les données de sortie de trois modèles climatiques régionaux, pour la période 1950-2100, ont été utilisées dans cette étude.

Résultats

Le Modèle du Génie Rural à 4 paramètres Journaliers (GR4J) a été utilisé pour reproduire les écoulements au niveau des cinq 05) stations hydrométriques que sont du Nord au Sud Folonzo, Yendéré, Sérébou, Akacomoékro, Aniassué et M'Basso. La calibration du modèle s'est faite avec des valeurs de Nash comprises entre 70 et 80% tandis que pour la validation ces valeurs varient de 50 à 80%. Les meilleurs résultats de robustness du modèle on été observés à la station de M'Basso. Les écoulements moyens mensuels sur les périodes 2041-2060 et 2081-2100 par rapport à ceux de la période de référence 1981-2000 ont été simulés à cette station de M'Basso.

Pour la vulnérabilité des usagers de l'eau face au changement global, une enquête socio-économique a été réalisée. Les résultats indiquent que 95% de la population a pris conscience de l'existence du changement climatique. Cette prise de conscience porte sur le retard dans le démarrage de la saison pluvieuse, la baisse de la pluviométrie et la récurrence d'épisodes de sécheresse. Par ailleurs, la majorité des sondés perçoivent également qu'il fait de plus en plus chaud et les vents de plus en plus violents. Les populations ayant un niveau d'instruction élevé expliquent ce changement par un changement dans les hauteurs de pluie et les séries de température par rapport au passé et celles n'ayant pas de niveau d'éducation indexent une sanction divine.

En termes d'impact socio-économique du changement climatique, l'agriculture, principale activité sur le bassin subit des rendements de plus en plus faibles. De nouvelles maladies des plantes (cacao, café, etc.) sont apparues et une recrudescence des maladies comme le paludisme sont à noter. A cela, il faut ajouter la baisse du niveau des cours d'eau et de la productivité de la pêche locale.

Face à cette situation, les populations ont développé des stratégies d'adaptation portant sur les méthodes culturales, le financement et les outils d'adaptation préventive.

Les méthodes préventives concernent la régulation des feux de brousse et la redéfinition des calendriers culturaux. Les stratégies d'adaptation financière sont celles qui permettent aux agriculteurs d'atténuer les effets des changements climatiques (baisse des rendements, baisse du pouvoir d'achat, etc.) en recourant à des finances. Il s'agit de l'endettement usuraire et de l'achat d'intrants.

Conclusion

Cette étude a permis d'affirmer la robustesse du modele hydrologique GR4J dans la modélisation des écoulements sur le bassin versant de la Comoé. Elle a également permis d'évaluer les effets du changement climatique et des activités anthropiques sur les ressources en eau. Les effets potentiels du changement climatique sous contrainte des scénarios RCP 4.5 et 8.5 sur les écoulements du bassin versant de la Comoé ont été examinés.

L'étude vulnérabilité des usagers de l'eau face au changement global a permis de tirer de nombreux enseignements concernant la vulnérabilité des populations rurales agricoles aux changements climatiques.

En premier lieu, les changements climatiques observés par les populations du bassin de la Comoé sont les perturbations saisonnières. Elles se caractérisent par une instabilité régulière de l'installation des saisons ; le raccourcissement des saisons de pluies et à l'inverse l'allongement des saisons sèches ; la baisse de la pluviométrie (82%) et partant celle du niveau des cours d'eau (29%). Les populations observent une fréquence d'évènements extrêmes tels que les vents violents (86%), les fortes chaleurs (95%), les sécheresses (27%), l'apparition de maladies sur les plantes (91%) et de façon exceptionnelles les pluies diluviennes et les inondations.

En deuxième lieu, les populations dans leur ensemble sont conscientes des changements climatiques et en ont une bonne connaissance. Toutefois, en raison du fort taux d'analphabétisme ne sont pas accoutumé au concept de changements climatiques, à la différence des personnes instruites. Ainsi, les perceptions qu'elles en ont sont fonction de ces statuts sociaux. En effet, certains analphabètes perçoivent les changements climatiques comme une sanction de la transgression des normes sociales par l'Homme contrairement aux autres et aux personnes instruites qui les attribuent aux activités anthropiques.

En troisième lieu, l'étude révèle que les impacts des changements climatiques dans le bassin de la Comoé ont un aspect économique et social. Sur le plan économique, les populations interrogées (95%) constatent une baisse significative des rendements agricoles. Elle est, au minimum, estimée de moitié. Les changements climatiques ont également entrainé un abandon d'activités économiques ainsi que la baisse de revenu des populations dans le bassin de la Comoé.

Sur le plan social, la diminution des ressources en eau dans le bassin de la Comoé causée les changements climatiques, crée une difficulté d'approvisionnement en eau pour les populations. Celle-ci est aggravée par l'insuffisance des ouvrages hydrauliques, dans les localités qui en possèdent. C'est ainsi que les populations consomment les eaux de surfaces (fleuves, rivières, marigots, etc.) dont les conditions de potabilités ne sont pas toujours réunies et partant sources de maladies. Il est à noter également des conflits récurrents antre usagers de l'eau autour des ressources en eau du bassin.

Face à cette nouvelle donne climatique, les populations adoptent diverses stratégies s'adapter. Ce sont des stratégies :

- préventives (interdiction des feux de brousse, redéfinition du calendrier agricole) ;
- relatives aux périmètres culturaux (agroforesterie, intensification et diversification agricole) ;
- relatives aux cultures (substitution, association, ou arrosage de cultures) ;
- financières (achat d'intrants, endettement usuraire).

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LIST OF ACRONYMS

ANADER	:	Agence National d'Appui au Développement Rural
BMBF	:	German Ministry of Education and Research
CanESM2	:	Canadian Earth System Model
C3D+	:	Climate Change Capacity Development
CCPAN	:	Climate Change Philanthropy Action Network
CLMcom-CCLM4-8-17	:	Climate Limited-area Modelling-Community - COSMO (COnsortium for SMall scale MOdeling (COSMO) Climate Limited-area Modelling-Community
CMIP5	:	Coupled Model Intercomparison Project Phase 5
CNRA	:	Centre National de Recherche Agronomique
CNRM-CERFACS-CNRM-CM5	:	Centre National de Recherches Météorologiques - Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique – Coupled Model 5
CORDEX	:	Coordinated Regional Downscaling Experiment
CRB	:	Comoe River Basin
DEM	:	Digital Elevation Model
ECOWAS-SWAC	:	Economic Community Of West African States - States-Sahel and West Africa Club
ET	:	Evapotranspiration
ETM+	:	Enhanced Thematic Mapper Plus
FGDs	:	Focus Group Discussions
FIRCA	:	Fonds Interprofessionnel pour la Recherche et le Conseil Agricoles
GCMs	:	Global Climate Models
GRP	:	Graduate Research Program
GHG	:	GreenHouse Gas
GRP	:	Graduate Research Program
GR4J	:	Génie Rural a 4 paramètres Journaliers
HIRLAM7	:	High-Resolution Limited-Area Model, version 7
ICHEC		Irish Centre for High-End Computing
IFAD	:	International Fund for Agricultural Development
IIASA	:	International Institute for Applied Systems Analysis
IPCC	:	Intergovernmental Panel on Climate Change
ITCZ	:	Inter-Tropical Convergence Zone
KNMI-RACMO22T	:	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute) - Regional Atmospheric Climate Model
LULC	:	Land Use Land Cover

MDC	:	Monthly Discharge Coefficient
MICCA	:	Mitigation of Climate Change in Agriculture
MINEF	:	Ministère des Eaux et Forêts
MPI-M-MPI-ESM-LR	:	Max Planck Institute for Meteorology - Earth System Model – running on Low Resolution grid
NGOs	:	Non-Governmental Organizations
NSE	:	Nash-Sutcliffe Efficiency
PE	:	Potential Evapotranspiration
RCA4	:	Rossby Centre Atmospheric model 4
RCP4.5 and RCP8.5	:	Representative Concentration Pathways 4.5 and 8.5
RegCM3	:	Regional Climate Model system *version 3*
RNA	:	Recensement National de l'Agriculture
SAPH	:	Société Africaine de Plantations d'Hévéa
SMHI	:	Swedish Meteorological and Hydrological Institute
SPI	:	Standardized Precipitation Index
TM	:	Thematic Mapper
UH	:	Unit Hydrograph
WASCAL	:	West African Science Service Center on Climate Change and Adapted Land Use
ZEF	:	Zentrum Für Entwicklungsforschung

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CHAPTER 1: GENERAL INTRODUCTION

The first chapter of our study presents respectively the context and problem statement, the literature review, the thesis objectives, the research questions and hypotheses, the scope of the study and the expected results of our study.

1.1. Context and Problem Statement

Recurrent climate variability and change in West Africa has shown a decrease in rainfall since the seventies (Dezetter, Servat, & Mahe, 2005). It resulted in a reduction of streamflow and wetlands leading to severe droughts (KOUAKOU, 2011). In West Africa, the responses of local communities to the impacts of climate change have mostly been reactive instead of proactive due to unpreparedness. Sub-Saharan Africa is the most vulnerable to the adverse impacts of climate change and variability (Boko et al., 2008). It is predicted to experience considerable negative impacts of climate change.

Côte d'Ivoire has been one of the countries that are most affected by climate variability and change in West Africa (Bigot, Brou, Oszwald, & Diedhiou, 2005) (Bigot et al., 2005) and is committed to fighting this phenomenon. This has led to decrease in rainfall from 10% to 30% across the country (Goula, Savane, Konan, Fadika, & Kouadio, 2006).

Recent findings in the Comoe River Basin (CRB) show a reduction of streamflow from 43% to 54% in response to the deficits in precipitations (Kouakou Koffi Eugène, 2007). Water quantity and seasonality of flows have great influence on sustainable development of water supply for industrial and agricultural productions in the CRB (Kouakou Koffi Eugène, 2007). There is a need to understand hydrological changes in the basin and and to provide management strategies for sustainable catchment management

Therefore, in order to ensure sustainable catchment management strategies, need to be fully understood.

1.2. Literature review

Climate change and human activities are known to impact greatly water resources and hydrological process in river basins (Wang, Ishidaira, & Xu, 2012). This might be ascribed to population growth and economic and social development which have impacts on watersheds through land use/ land cover changes and disruption of the natural water cycle. Findings from many authors revealed hydrological processes such as evapotranspiration (ET), soil moisture and groundwater recharge are significantly affected by land cover and land use changes (Y. K. Zhang & Schilling, 2006).

Land cover changes, such as deforestation or afforestation, have led to increased or decreased streamflows in different areas depending on prevailing environmental conditions and climate (Y. Zhang et al., 2011). They have discussed the effects of climate change and human activities on runoff processes. But, most of them apply the hydrological model to analyze the responses of runoff processes to man-made climate change and different watershed scenarios. Although the hydrological model is a powerful tool for such research, the results of studies have numerous uncertainties caused by shortcomings in the structure, parameter calibration, and scale problem coupled with hydrology model. In view of these, the analysis of long-term records of hydrological data might show temporal variations in runoff influenced by climate and land cover changes. Detailed investigation of pattern and trends of such changes may give good insight into the rate at which some identified human factors influence the hydrological regime at basin scale. These have been proven through the use of some adapted statistical methods for identifying trend changes in specific catchments (Hamed, 2008). However, few studies have quantified the contribution of climate variability and human activities on the changes in streamflows (Li, Coe, Ramankutty, & Jong, 2007); (Y. Zhang et al., 2011).

Nowadays, weather disasters such as cyclones, floods and droughts, are increasing in number and intensity in many parts of the world because of climate change. Climate change refers to the persistent change in climate over long periods of time due to either natural or as a result of human activity. It is very important to assess the impacts of climate change and human activities on water resources. It is recognised that drivers of the hydrological cycle are potentially affected by climate change. Therefore, sectors which are partly or fully dependent on water might be affected. There is a need to assess hydrological processes to understand very well the causes of the decrease in rainfall, so that a development of a new vision for future water management in West Africa can be done. Hydrological changes caused by any long-term climate change will have ecological and socio-economic impacts that may affect the management of water resources (Cohen, S.J., Miller, K., Hamlet, A.F., Avis, 2000). This might be evident with the recent increase in number of water-related disasters and serious shortage of water resources, and has necessitated the study of the impact of climate change and human activity on hydrology and water resources. These hydrological impacts of climate change might however vary from place to place, and thus need to be investigated on a local scale.

Findings from many studies revealed that the practical superiority of distributed or semi-distributed approaches over lumped ones for streamflow simulation has not been clearly demonstrated yet (Charles Perrin, Michel, & Andréassian, 2003); (C Perrin, Michel, & Andre, 2001); (Mahé et al., 2009); (Thirel et al., 2016); (Yang et al., 2011); (Conway et al., 2009); (Gosling, Taylor, Arnell, & Todd, 2011).

Since the 1970s, Human activities have been found to have great impacts on hydrological systems by deforestation, farming practices and urbanization. Due to the growth in population, the development of industry and agriculture, and urban construction (Huo, Feng, Kang, Li, & Chen, 2008), such as irrigation and drainage, and hydraulic structures, the elements of the hydrological cycle have changed in terms of quantity and quality, both in time and space. There has also been a growing awareness about natural resources being limited and that future development must provide management strategies for their sustainable use.

In the CRB, the main socioeconomic activities are agriculture, livestock, fisheries, industry, energy, mining, river transport, tourism and the crafts. Combining physical science analysis of the system with investigation of the human component can provide a better understanding of sensitivity of water users to climate change in this region and the capacity of the coupled human–natural system to respond and adapt to the consequences of the environmental changes. Therefore, the joint analysis on the effect of climate change and human activities on water resources of the CRB is important for the appropriate use of water resources, environment protection and transboundary ecological security.

knowledge on climate change, access to appropriate technology, institutions, policies and perceptions influences people's perceptions of and capacity to adapt to climate variability and climate change (Nyanga, Johnsen, Aune, & Kalinda, 2011). Local people have knowledge about their location, the history of major local events and threats, and how their vulnerability to disasters and different climatic conditions has changed over time (Tiani et al., 2015). Their participation is essential in identifying adaptation strategies.

1.3. Research questions

The main research questions to be addressed in this study are:

a) What is the robustness of a lumped hydrological model in modelling streamflow?

b) How to evaluate the effects of Climate Change and Human Activities on Water Resources?

c) How to examine the potential effects of climate change under the RCP 4.5 and 8.5 scenarios on streamflow in the Comoe River Basin?

d) How vulnerable are the different water users to Climate Change?

1.4. Thesis objectives

1.4.1. Main objective

The main objective of our study is to assess the impact of climate change and human activities on water resources in the Comoe River Basin. This will help to put forward a decision-making tool to respond locally to the impacts of climate change.

1.4.2. Specific objectives

The specific objectives of this study are:

- To evaluate the robustness of a lumped hydrological model for modelling streamflow;
- To evaluate the effects of climate change and human activities on water resources;
- To examine the potential effects of climate change under the RCP 4.5 and 8.5 scenarios on streamflow in the Comoe River Basin;
- To assess the vulnerability of different water user groups to climate change and human activities.

1.5. Hypothesis

Based on the key research questions formulated, the following hypotheses were formulated:

a. A lumped hydrological model is robust in modelling streamflow;
b. Climate change and human activities are impacting negatively water resources in the CRB;
c. Climate change under the RCP 4.5 and 8.5 scenarios have potential effects on streamflow in the Comoe River Basin are examined;
d. Different water users are vulnerable to Climate Change in the CRB.

1.6. Novelty

This research will contribute to the understanding of different water user groups' vulnerability to climate change and human activities. It fundamentally links nature and society and provides key knowledge for resilience analyses and policy and management actions. As actions often take place at local scale, this research will help to identify sensitive areas critical for sustainable use.

Talking about climate change and the vulnerabilities created by this process in addition to all other shortcomings – economy, medical resources, etc. – represents a challenge for scholars and researchers around the world, particularly in assessing the impact of the climate change in an unstructured and unpredictable social environment.

1.7. Scope of the thesis

Climate change is defined as any long-term significant regional change in measures of climate (such as temperature, precipitation, or wind patterns). It is therefore any major long-term variation in the average weather that a given region experiences. These variations have to be statistically significant in measurements of either the mean state or variability of the climate for that region, whether due to natural factors or as a result of human activity. Consequently, climate change can be regarded as a change of climate, which is attributed directly or indirectly to human activity, and which alters the composition of the global or regional atmosphere, in addition to natural climate variability over comparable time periods (Hope, Sr, 2009).

Vulnerability is an important concept like climate impacts and adaptation, sustainability science, land change, natural hazards and disaster management, poverty and development, ecology, public health, secure livelihoods and famine. From a climate change perspective, according to the IPCC, vulnerability is “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes”. Vulnerability is a function of exposure, sensitivity and adaptive capacity. People’s vulnerability to changes in water resources depends on a range of social, economic and environmental factors that affect the ability to manage water resources. Within every river basin, those communities and locations which are most vulnerable need to be identified in order to prioritise mitigating and adaptation action.

Climate variability and change is impacting ecosystems, infrastructures and populations in least developed countries. These populations have low capacity to cope, to respond or recover from related impacts. Therefore, least developed countries are giving attention to the assessment of climate change vulnerability. This interest is creating a need for knowledge, skills and tools to support vulnerability assessment and adaptation planning.

1.8. Expected results and benefits

The expected results of our study are:

- the robustness of a lumped hydrological model for modelling streamflow is evaluated;
- the effects of climate change and human activities on water resources are evaluated;
- the potential effects of climate change under the RCP 4.5 and 8.5 scenarios on streamflow in the Comoe River Basin are examined;
- the vulnerability of different water user groups to climate change and human activities is assessed and adaptation strategies for the CRB are proposed.

The Comoe River Basin is one of the twenty eight transboundary basins in West Africa. Results from this study will benefit to stakeholders and researchers. The proposed adaptation strategies will help water users in Burkina Faso, Cote d’Ivoire, Ghana and Mali to cope with climate change.

1.9. Outline of the thesis

Eight chapters comprise this thesis. Chapter 1 presents the general introduction of the study including research questions and objectives. Study area is described in Chapter 2. Chapter 3 presents Data, materials and methods used in this study. Chapters 4 to 7 present the results and discussion. Chapter 8 presents the conclusion and the recommendations.

CHAPTER 2: STUDY AREA

This chapter presents the mains characteristics of the Comoe River Basin, namely, localization, relief, geology, hydrogeology, vegetation, climate, soil and land use, demography, social and economic activities.

2.1. Localization

The CRB is located in West Africa between longitudes 3° and 5°30 West and latitudes 5° and 11°30 North (Figure 1) . Comoe is the longest river of Cote d'Ivoire (1,160km). The basin covers about 78,000 km^2. It extends over four countries: two landlocked countries (Burkina Faso and Mali) characterized by a Sudano-Sahelian climate and two coastal countries (Ghana and Côte d'Ivoire) with a tropical and sub-equatorial climate.

Table 1 shows areas covered in each country.

Table 1: Areas covered by countries in the Comoe River Basin

	Areas (km^2)	**Percentage (%)**
Burkina Faso	16,900	22
Cote d'Ivoire	58,200	74
Ghana	2,200	3
Mali	700	1
TOTAL	78,000	100

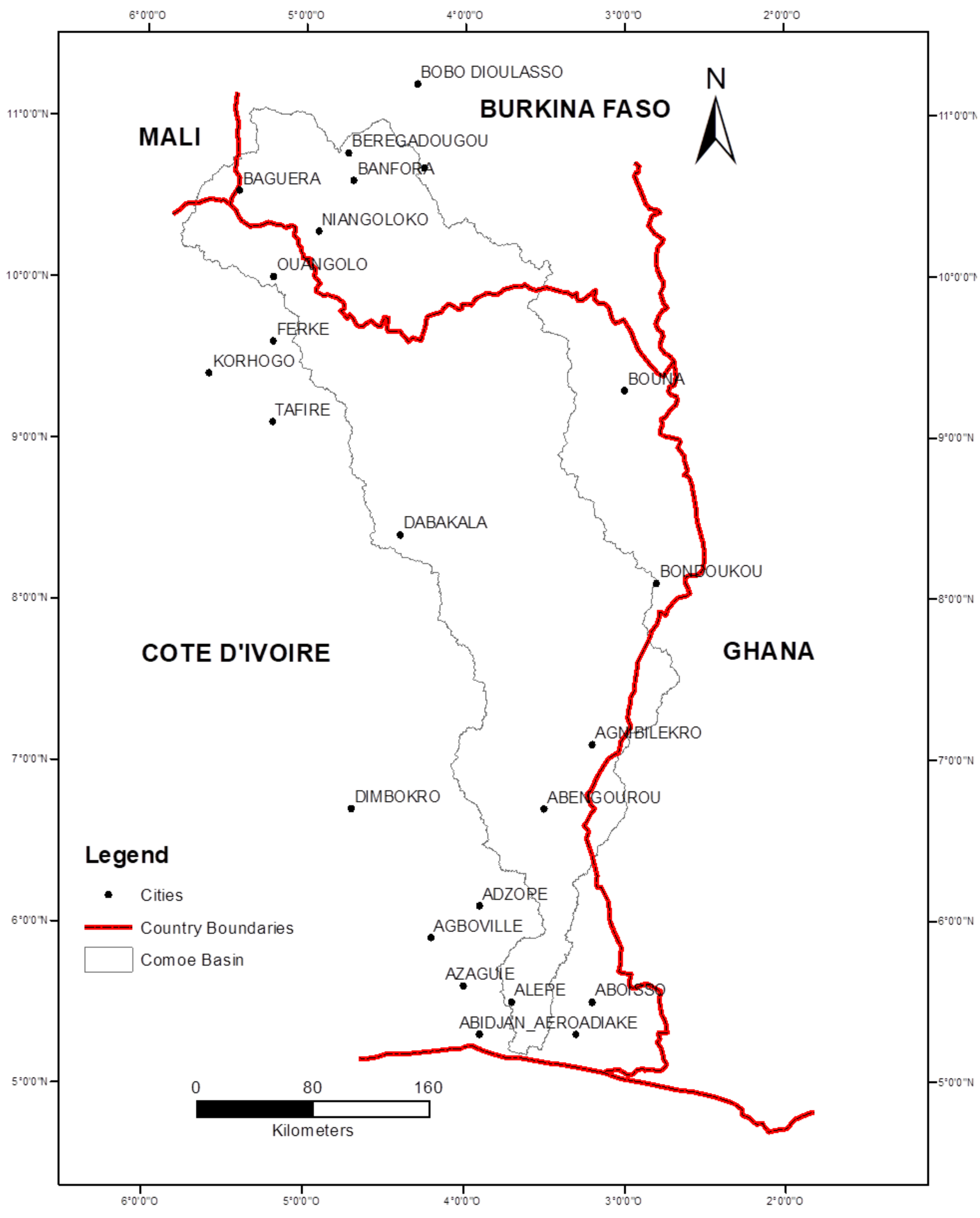


Figure 1: Comoe River Basin

2.2. Relief

The CRB in general has low relief with altitudes varying between 0 and 731 m above sea level. The highest elevation ranges are located north and east of the basin. The elevation decreases towards the south (Figure 2). The mean slope is about 0.7 m/km.

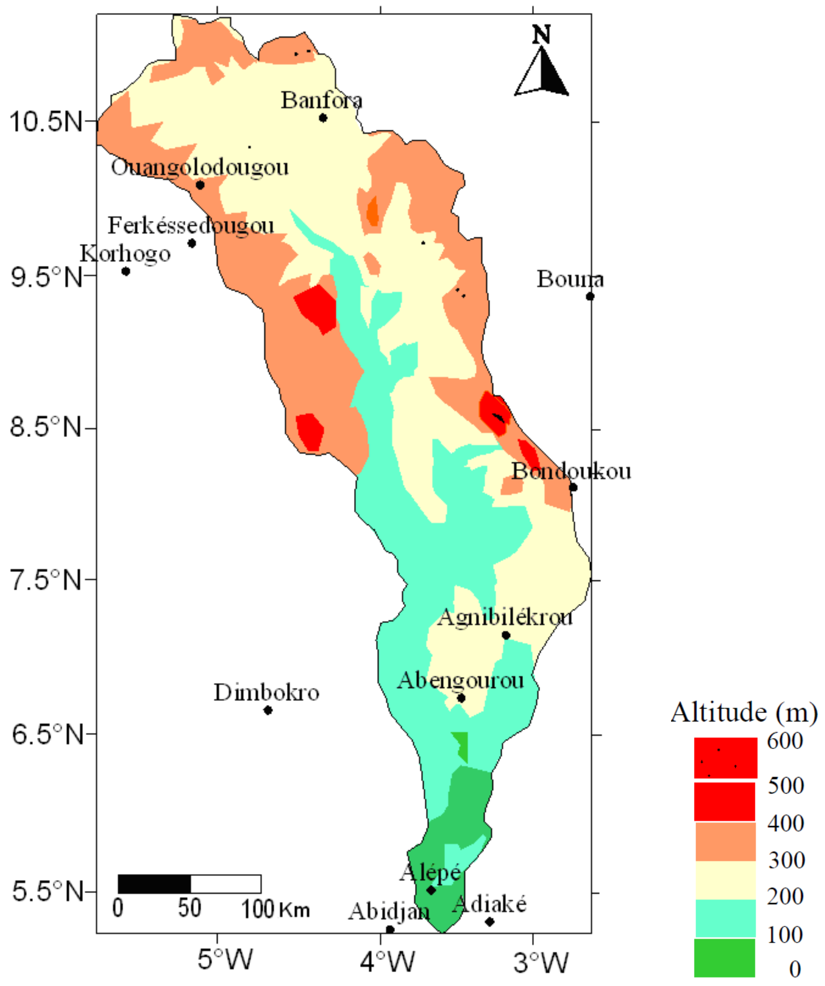


Figure 2: Relief of the CRB (KOUAKOU, 2011)

2.3. Geology

The basin overlies three main geological systems: a main Precambrian platform, Tertiary and Mesozoic era, and a Quaternary era (Devineau, 1984). Quaternary formations consist of sedimentary layers and are located in the south. Tertiary and Mesozoic formations are well represented in the southern part of the basin by sandy shale. Birimian complex and granitoid compose the Precambrian system in the northern and central parts of the basin. The basement or

Birimian complex consists of metamorphosed sediments intercalated with metamorphosed tuff and lava and intruded by batholithic masses of granite and gneiss. These dominantly argillaceous sediments have been metamorphosed to schist, slate, and phyllite, with some interbedded greywacke (Tastet & Guiral, 1994). Granitic formations are represented by mica and amphibole granites with sometimes seam of pegmatite (Figure 3).

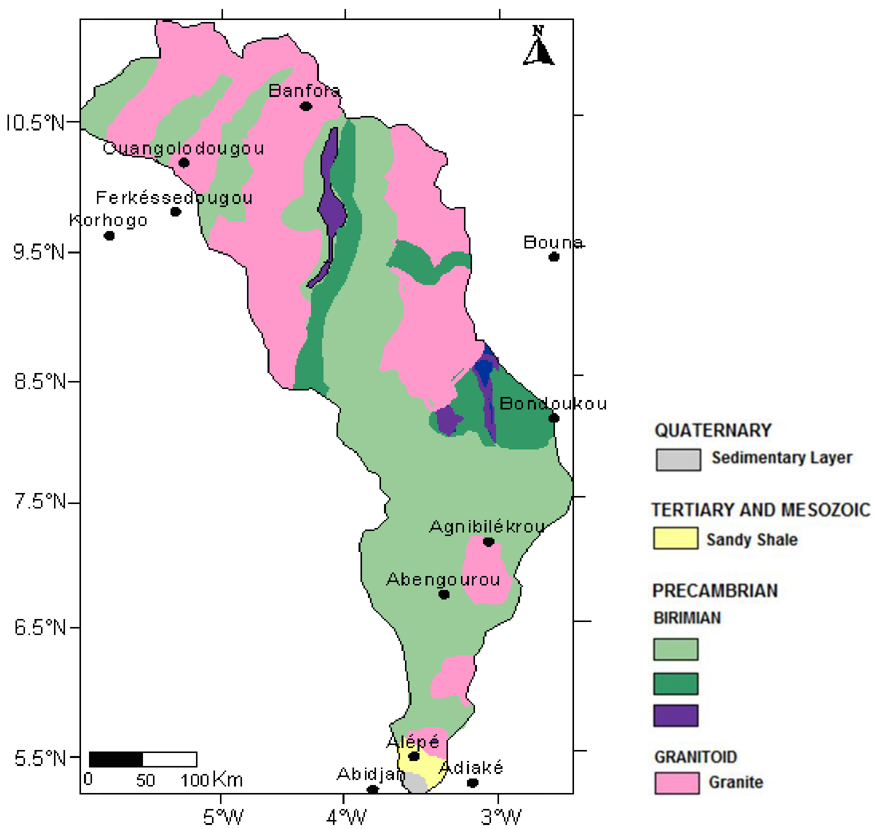


Figure 3: Geological map of the CRB (KOUAKOU, 2011)

2.4. Hydrogeology

The geological formations that underlie most parts of the Comoe Basin (Birimian rocks and Voltaian formation) have little or no primary porosity. The occurrence of groundwater in these formations is as a result of the development of secondary porosity from weathering, fracturing, jointing and shearing. Weathering is a consequence of circulation of water through joints, fractures, and quartz veins which had formed earlier in the rocks. The cartography of fracturing field of the Comoe River Basin was done with ten (10) TM and ETM+ of Landsat satellite images. It is about:

- 197-052 of November 17th, 2001;
- 197-053 of 31 January 31st, 2000;
- 197-054 of December 16th, 2001;
- 196-053 of November 7th, 2000;
- 196-054 of January 29th, 2000;
- 196-055 of January 26th, 2001;
- 196-056 of December 30th, 1990;
- 195-054 of February 2nd, 2000;
- 195-055 of February 2nd, 2000;
- 195-056 of February 2nd, 2000.

Figure 4 shows the global field of fracturing of the Comoe River Basin. Figure 5 shows the statistical analysis of fracturing map.

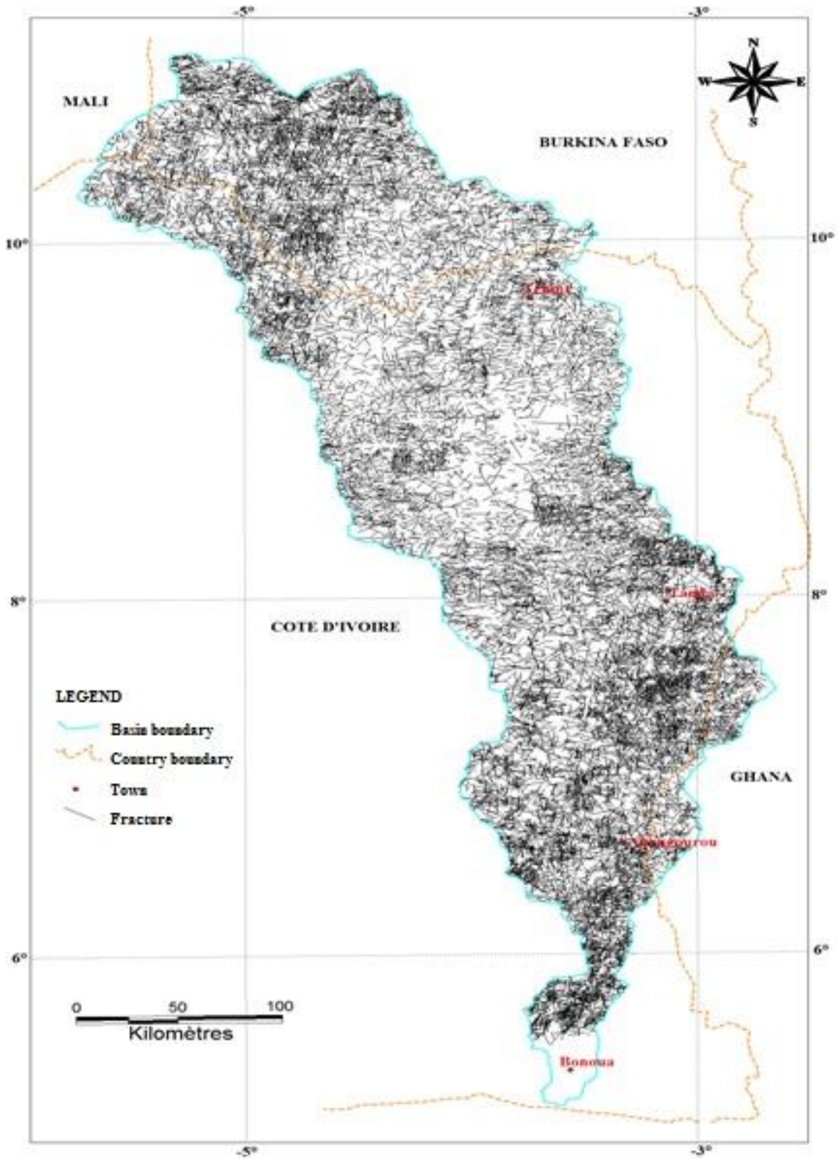


Figure 4: Map of fractures in the Comoe River Basin

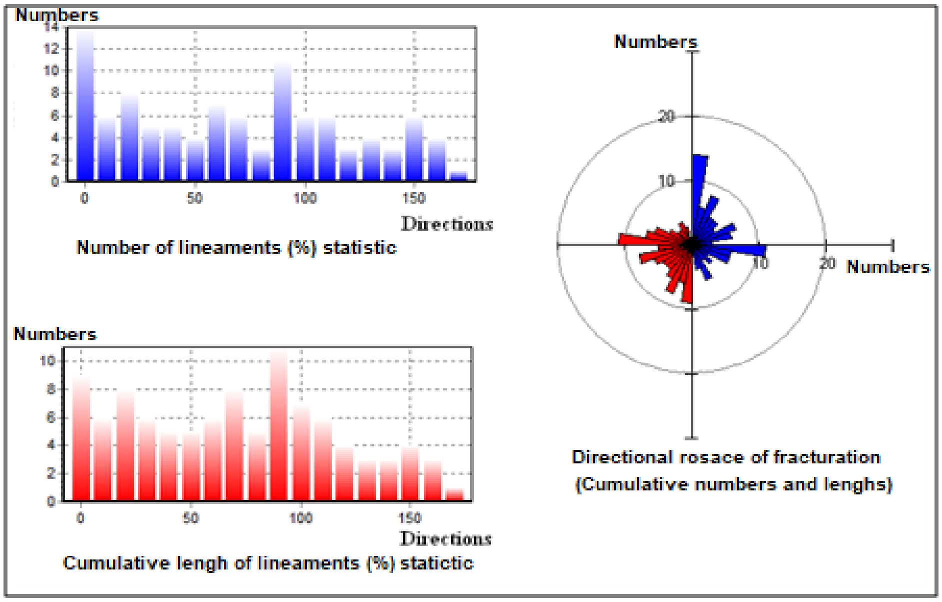


Figure 5: Statistical analysis distribution of global fracturing

The distribution analysis of orientation in terms of lineament number of the global fracturing field shows two (02) main directions: N0-10 and N90-100. 14% are in the direction N0-10 and 11% in the direction N90-100. There are nine (09) secondary directions: N10-20; N20-30; N30-40; N40-50; N60-70; N70-80; N100-110; N110-120 and N150-160. The percentages of these directions are between 5% and 8%. The percentage of the remaining directions ranges from 1% to 4%.

Three main aquifer systems have been identified in the Comoe Basin, namely the altered rock, the bedrock and the sedimentary formations aquifer systems. Groundwater is abstracted from all the geological formations within the basin. Aquifer yields vary from one geological formation to another and across the basin. The mean yield of boreholes ranges from 2 m^3/h to 338 m^3/h in the sedimentary formations aquifer.

2.5. Vegetation

The natural vegetation in the Comoe Basin ranges from tropical humid forests, dry forests and savannah spanning from short grass at the northern part to humid rain forests at the south near the Atlantic coast (Figure 6). Two main types of vegetation can be identified in the Comoe Basin

(Pierre, 1971), savannah in the north and dense forest in the south with intermediary vegetation between the two. Additionally, a coastal ecosystem, containing lagoons and mangroves, can be found where the Comoe River flows to the sea with species *like Rhizophora racemosa, Avicennia Africana, Paspalum vaginatum and Acrostichum aureum*. In the dense forest, the following species are found: *Lophira alata, Uapaca guinéensis, Triplochyton scleroxylon (Samba), Mansonia altissima (bété), Celtis sp*. The woody and shrub savannah in the northern part of the basin is marked by forest galleries of thick vegetation along river channels where adequate moisture is available. The tall trees found in the forest galleries include the following: *Combretum Glutinosum, Gardenia Sobotensis, Vitex Cuneata, Terminalia, Diospyrus, Andropogon tectorum, Hyparrhenia chrysagyrea, Andropogon Calvescens, Andropogon Amplectens, Loudetia Phragmitoïdes and Phargmites Vulgaris*.

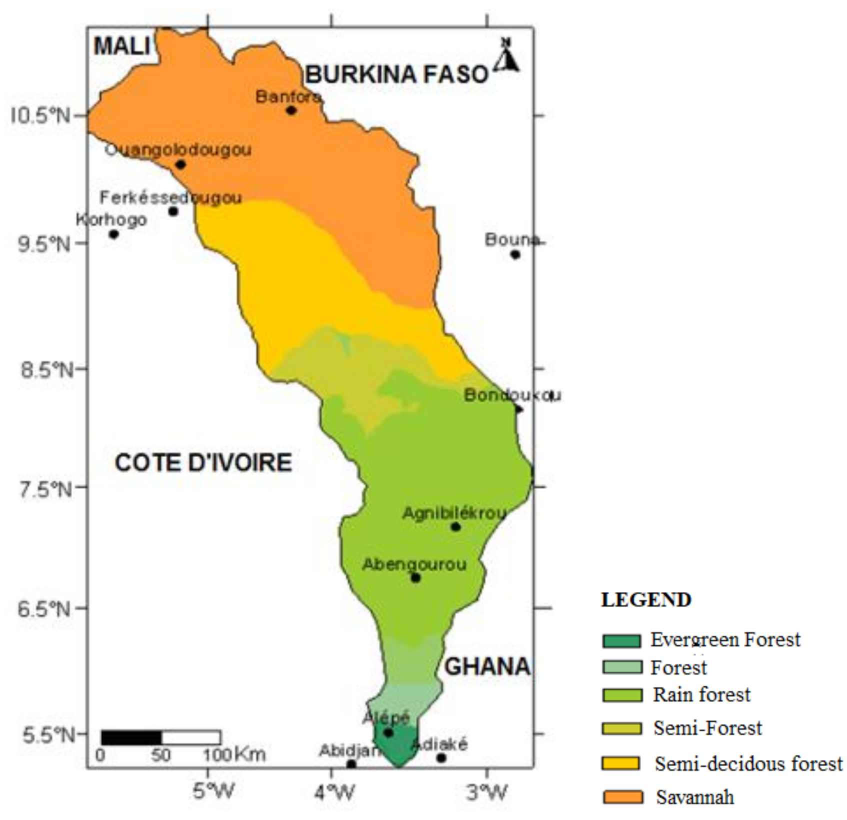


Figure 6: Vegetation types of the Comoe River Basin (KOUAKOU, 2011)

2.6. Climate

The climate of the region is controlled by two air masses: the North-East Trade Winds and the South-West Trade Winds. The North-East Trade Winds, or the Harmattan, blowing from the interior of the continent, are dry. In contrast, the South-West Trade Winds, or the monsoons, are moist since they blow over the seas. The interphase of these two air masses is called the Inter-Tropical Convergence Zone (ITCZ). There is a lot of convective activity in the region of the ITCZ, hence the region is associated with a considerable amount of rainfall. The ITCZ moves northwards and southwards and this movement determines the climate of four zones (Figure 7) (Goula et al., 2006).

- zone A: it extends over 400 km immediately in the south of the ITCZ with a climate characterized by a long dry season and many early-morning fogs;
- zone B: from 800 à 1000 km, it corresponds to a climate with two rainy seasons and a considerable amount of rainfall;
- zone C : it corresponds to the dry season with little sunshine and rare rainfall;
- zone H: it is located immediately in the north of the ITCZ where the Harmattan is occurring.

In January, the ITCZ reaches 5° of latitude north and in August, it reaches its northernmost position at about 17°N (Péné & Assa, 2003).

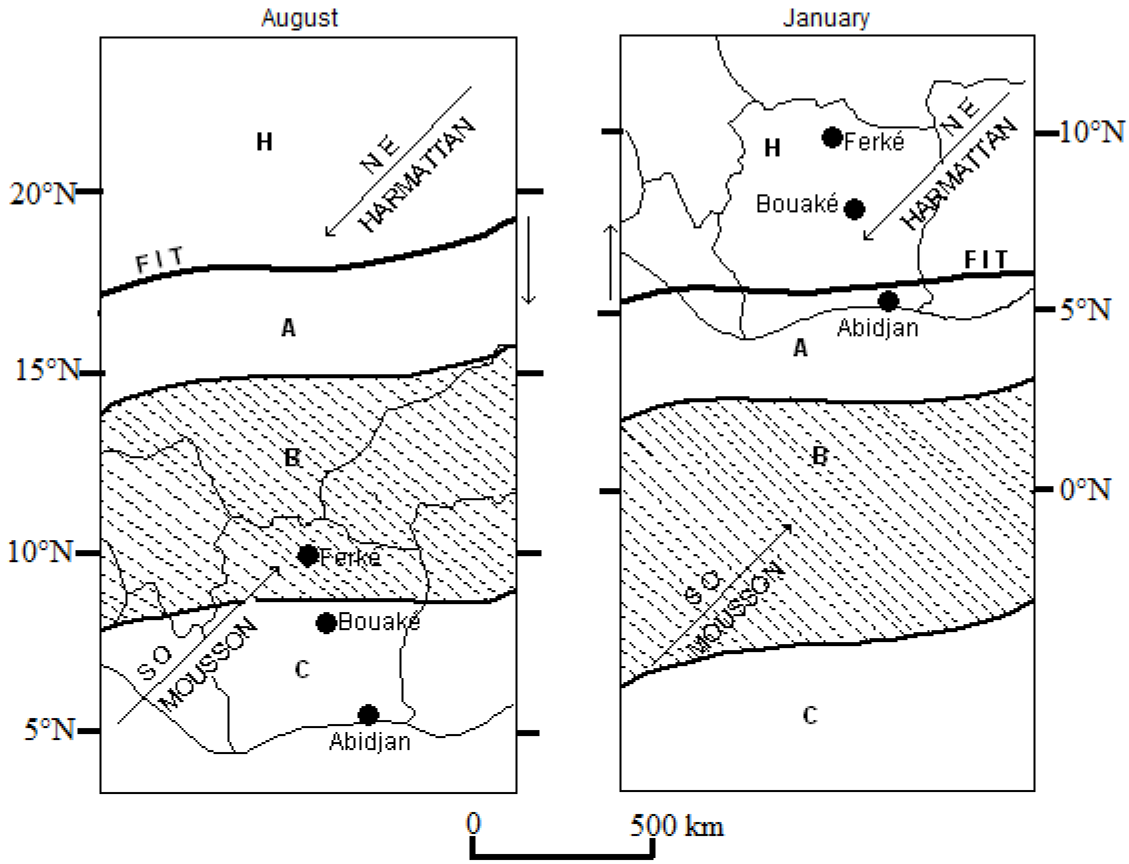


Figure 7: Seasonal variation mechanism in Cote d'Ivoire (J.M. Avenard, M. Eldin, G. Girard, J. Sircoulon, P. Touchebeuf, 1971)

Three types of climatic zones can be identified from north to south in the CRB (Figure 8): the transitional tropical climate "Sudanese Climate" covers, the attenuated transitional equatorial climate "Baouleen Climate", and the equatorial climate "Attieen Climate" (Girard et al., 1971).

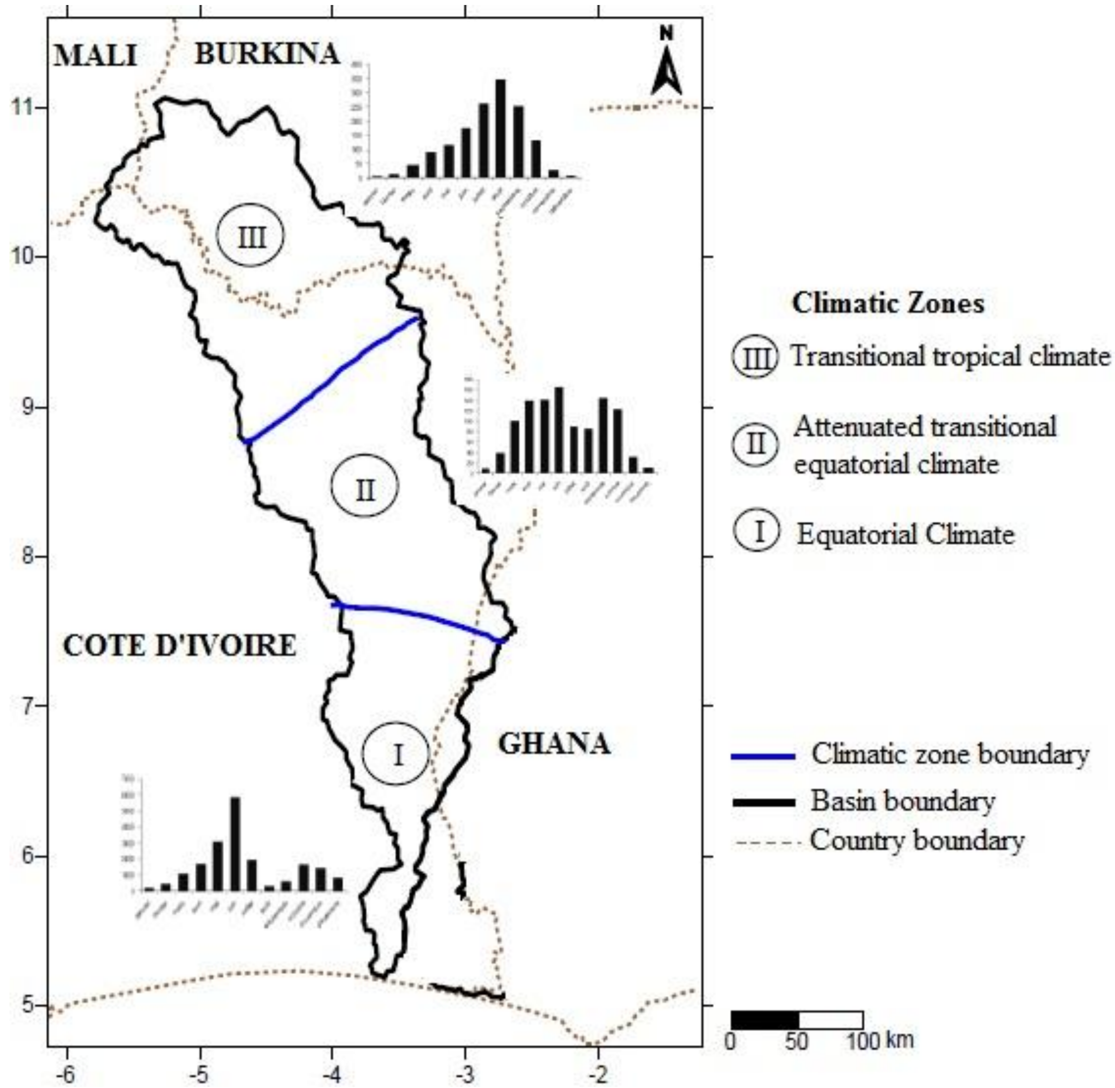


Figure 8: Climatic zones in the CRB (KOUAKOU, 2011)

2.6.1. Temperature

Daily maximum temperatures increase while daily minimum temperatures decrease in a south-north direction in the Comoe Basin. Historically, the minimum average temperature recorded is 18.8ºC, 20ºC, 22.1ºC in January, while the maximum average temperature is in February and March, 37.2ºC, 35.1ºC, 32.3ºC respectively at Bobo Dioulasso representing the transitional tropical climate zone, Bondoukou representing the transitional equatorial climate zone and Adiake representing the equatorial climate zone (Figure 9).

2.6.2. Rainfall

The three climatic zones are 1) the transitional tropical climate covering over one third of the basin (north of latitude 10° N) with one rainfall season peaking in August and average annual rainfall varying from 1250 to 1700 mm. The absolute driest period is November throughout March. 2) The transitional equatorial climate has a bimodal rainfall pattern characterized by two rainfall seasons very close to each other: a long rainy season (March to June) and a short rainy season (September to October). The driest period extends from November to February and average annual rainfall varies from 1100 to 1600 mm. 3) The equatorial climate in the southern part of the basin with two distinct rainy seasons (the first extends from June to July and the second from October to November) and two dry seasons (one occurs in August and September and the driest extends from December to March). Average annual rainfall varies from 1500 to 2500 mm. The timing of the onset and cessation of the rainy season is very important for crop management, and thus for food security. Furthermore, months with high rainfall variability are important to note, as this variability may have consequences for agriculture and other sectors. The survey sites lie within the equatorial climate zone (Girard et al., 1971). Figure 9 presents historical climate monthly averages for the three climatic zones.

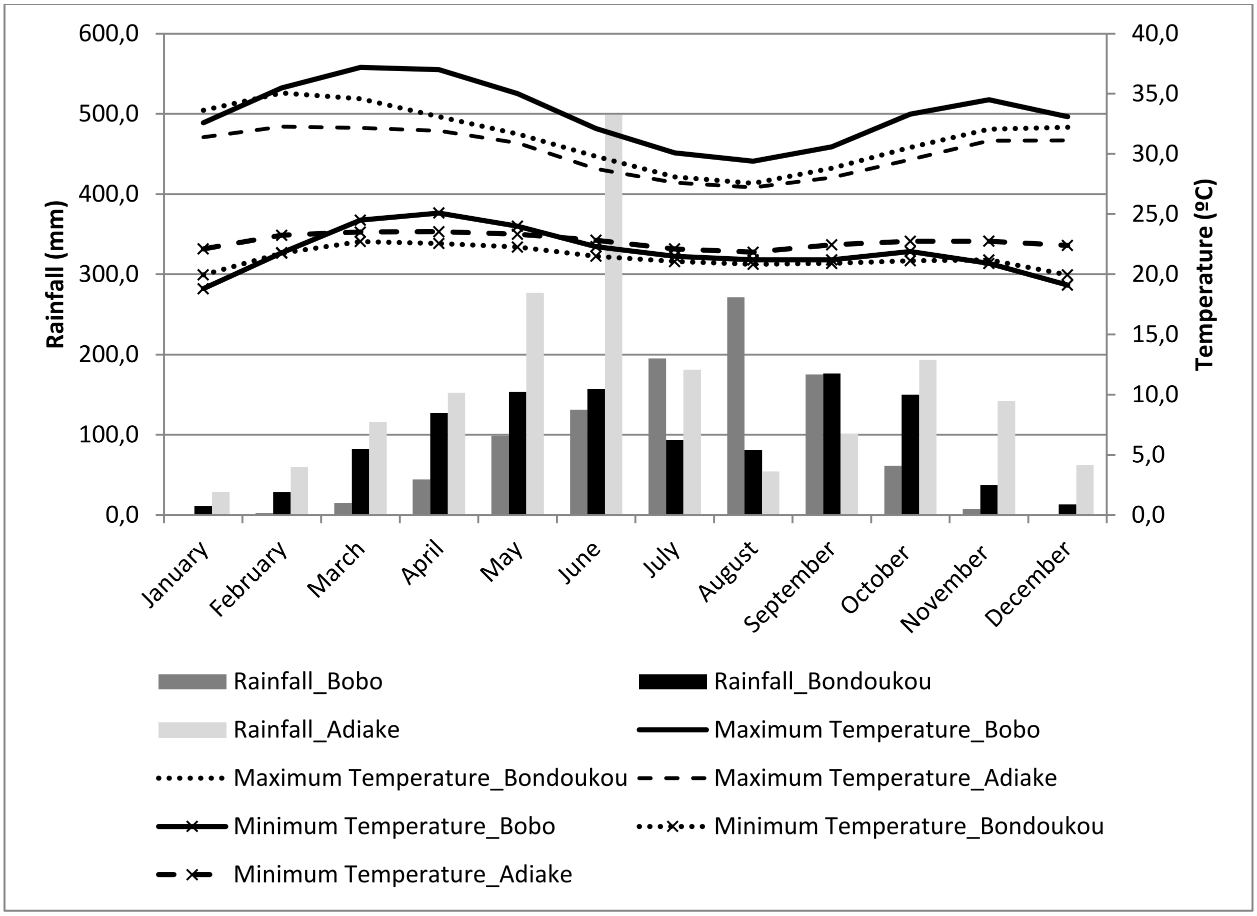


Figure 9: Historical climate monthly averages, Bobo Dioulasso, Bondoukou and Adiake stations, 1941-2010

2.7. Hydrography

The main characteristics of the Comoe River Basin are showed in Table 2.

Table 2: Geomorphological characteristics of the Comoe River Basin

Area (km^2)	Perimeter (km)	Equivalent rectangle		Compactness index of Gravelius	Type of hydrological network
		Length (km)	Width (km)		
78,000	1,981	904.1	86.4	1.98	Dendritic

With a length of 1,160 km, the Comoe River takes it source in Burkina Faso at Karfiguela at an altitude of about 420 m and flows through Burkina Faso and Cote d’Ivoire in north-south direction. The basin covers about 78,000 km^2 with 74% in Cote d’Ivoire, 22% in Burkina Faso, 3% in Ghana and 1% in Mali (Niasse, 2004). The basin is drained by several major rivers: the Yanon, the Ketéouro and the Kossa along the right bank; the Leraba, the Diore, the Ifou, the Béki and the Manzan along the left bank. Figure 10 shows the Comoe River network.

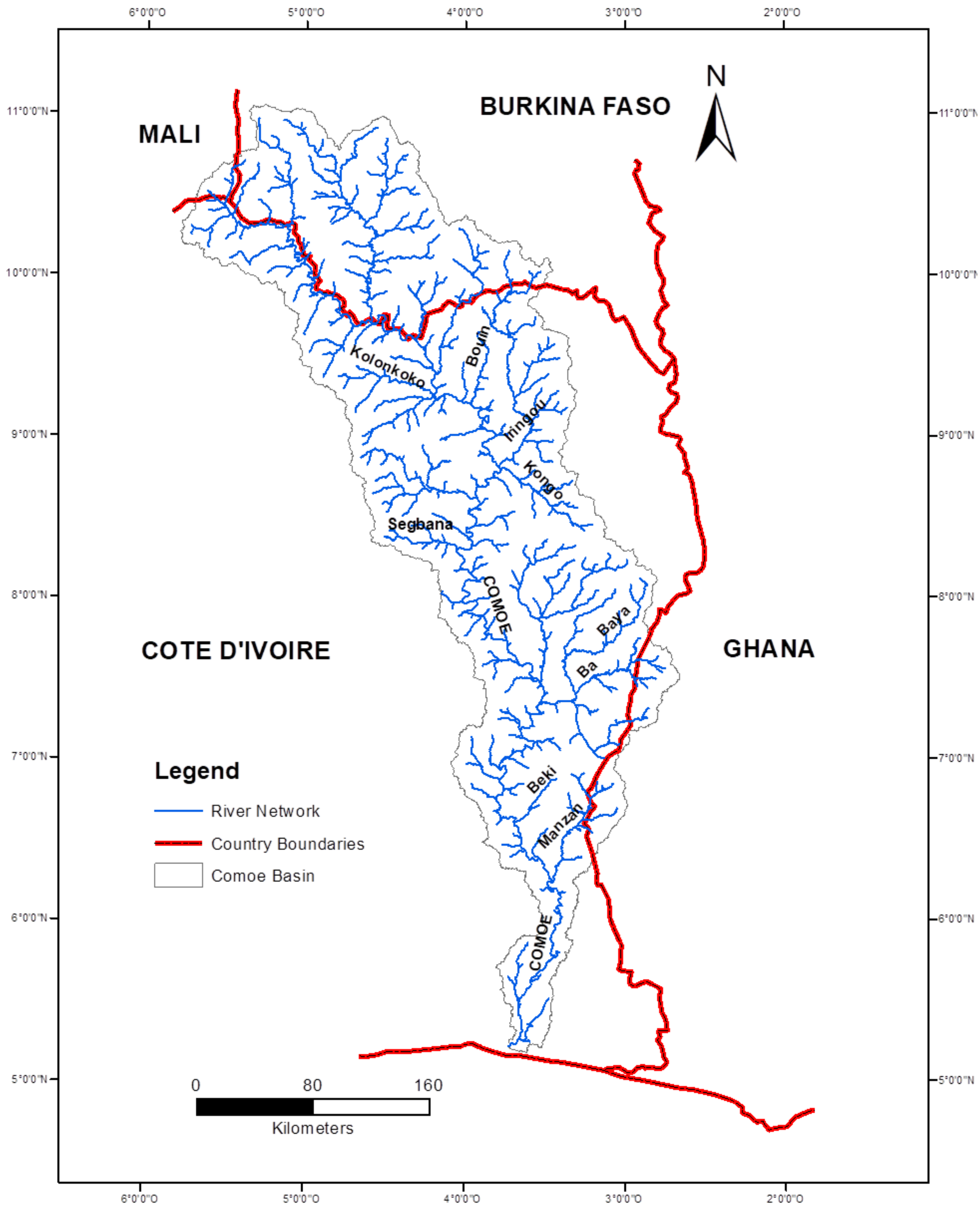


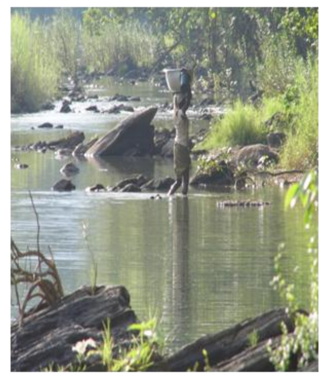
Figure 10: River network f the Comoe Basin

Communities in the Comoe River are using water for water supply, agriculture, fishing, washing, bathing, gold washing. Some of these uses are showed below in Figure 11.

Washing in the main river channel at Comoe N'Danou (May 2014)

Bathing in the main river channel at Comoe N'Danou (May 2014)

Water supply at Comoe N'Danou (May 2014)



Water supply at Logotan (May 2014)

Gold washing at M'Basso (May 2014)

Gold washing at M'Basso Comoe N'Danou (May 2014)

Figure 11: Water uses in the CRB

Apart from the huge network of rivers, the basin is dotted with ninety nine (99) dams (Figure 12).

Table 3 shows the use of these dams. In areas where surface water is inadequate, groundwater resources are used by the small communities for domestic and irrigation purposes.

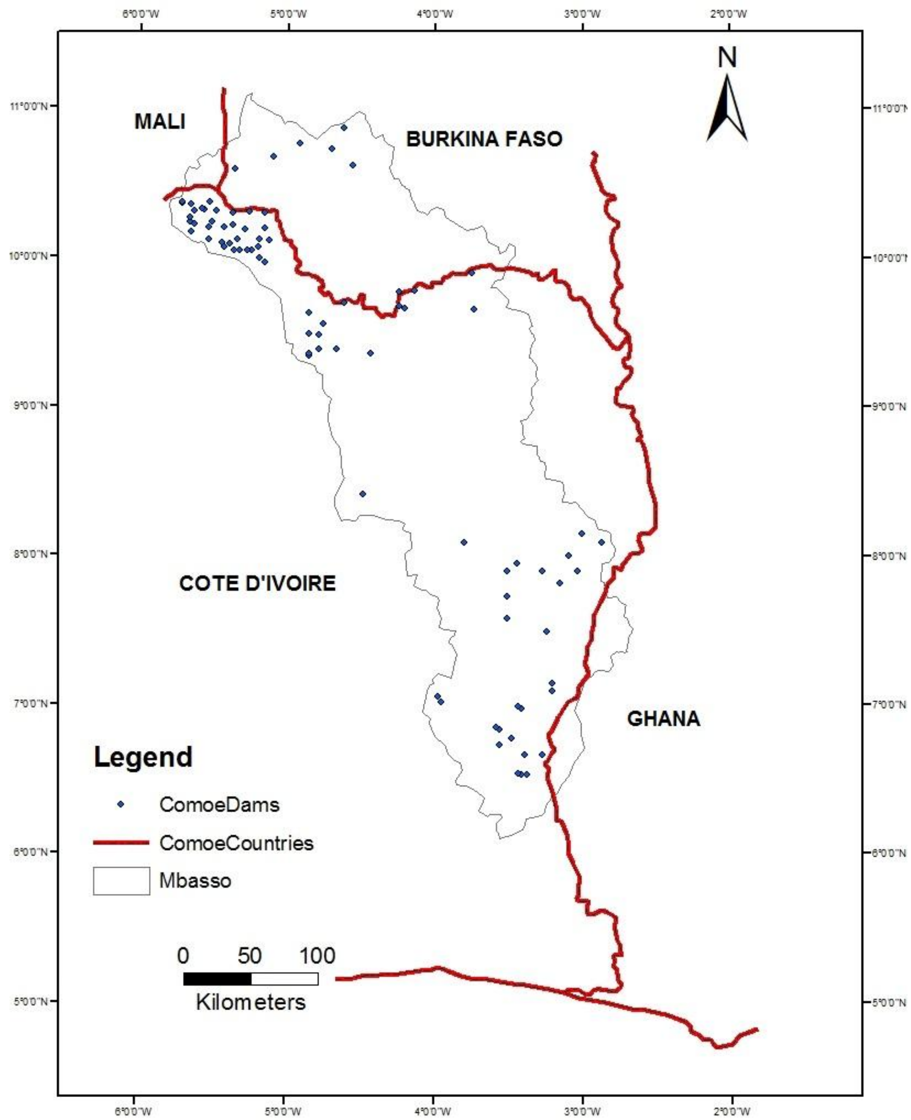


Figure 12: Dams in the Comoe River Basin

Table 3: Use of dams in the Comoe River Basin

Number	Storage capacity (10^6 m^3)	Water supply (%)	Rice Production (%)	Livestock (%)	Coffee (%)
99	37.3	3	13	82	1

2.8. Soil and land use

The geology, relief, and climate of locations interact to produce soils of typical characteristics. The major soil groups in the CRB are Gleyic, Ferric and Plinthic Luvisols; Eutric Cambisols; Dystric Fluvisols; Ferric, Plinthic and Orthic Acrisols; Xanthic Ferralsols (Figure 13).

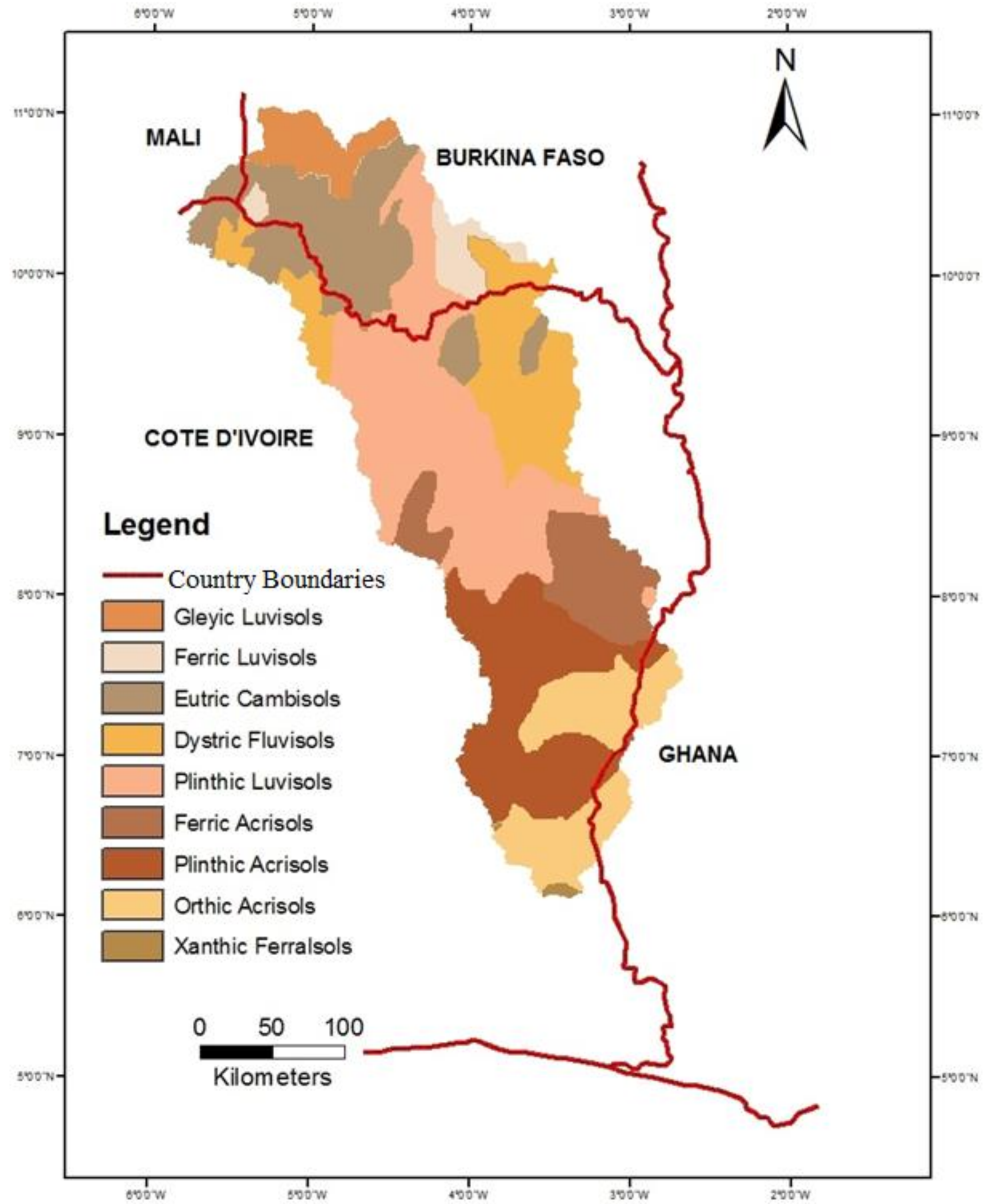


Figure 13: Soil map of the CRB

Agriculture remains the main engine for economic growth for most Sub-Saharan African countries, contributing around 40 percent (Oecd-, 2016) to their gross domestic product and employing more than half of their total labour force. Moreover, it serves as the main base for food security in this region. The dominant land use in the Comoe Basin is agriculture, which includes the cultivation of annual crops, tree crops, bush fallow and unimproved pasture (Figure

14). Agriculture in the basin is largely rain fed and essentially manual with the use of very few external inputs like tractors and fertilizers. Major crops cultivated include Coffee, Cocoa, Hevea, Cashew, Plantain, Yam, Pepper, Tomato, Gumbo and Aubergine.

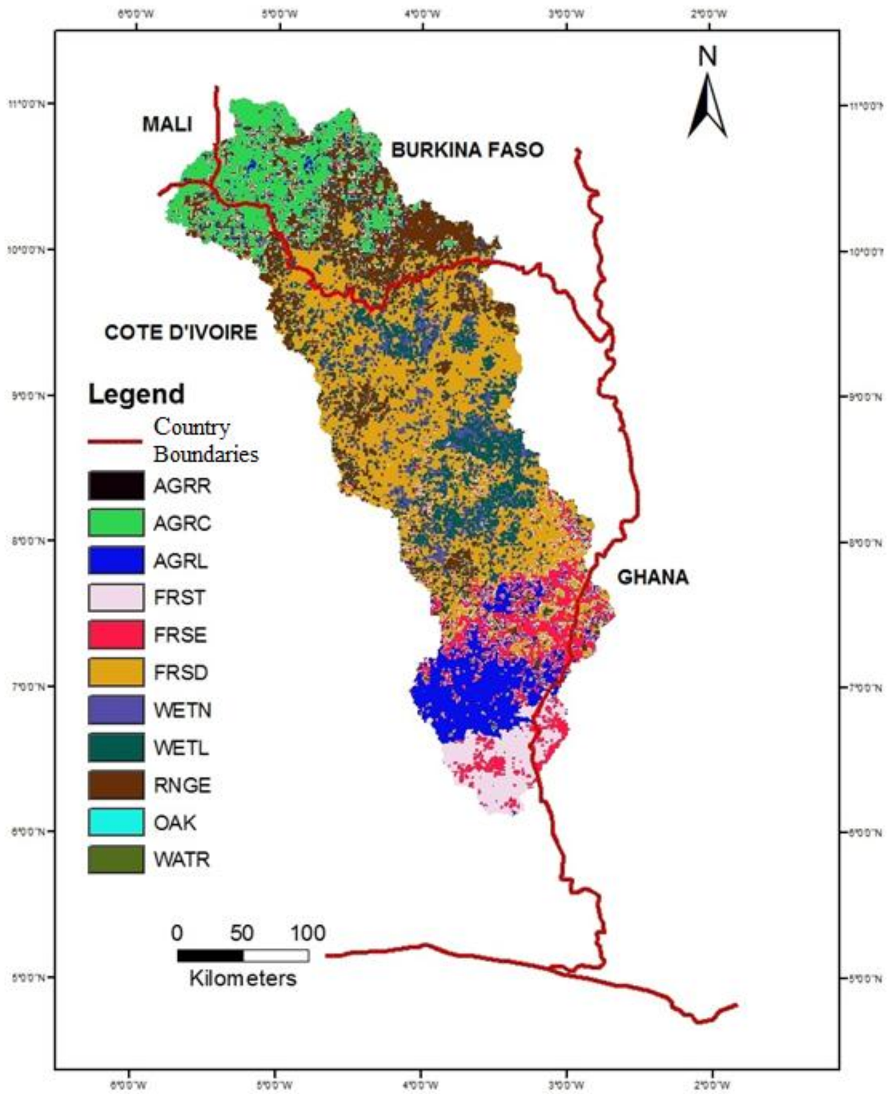


Figure 14: Land use in the Comoe River Basin

2.9. Demography and economic activities

The total population of the Comoe Basin is multiethnic and is estimated to 7.5 million. The main ethnic groups are:

- N'Zimas, Aboures, les Atties in the southern part of the basin;
- Agnis, Baoules, Abrons and Koulangos in centre;
- Djiminis, Djamalas, Senoufos, Malinkes, Lobis, Miniankas, Bambaras, Dogons, Peulhs, Bobos, Samogos, Fulfuldés, Mossis and Gouins in the northern part of the basin.

The geographic distribution of the population is quite variable, with the population density ranging from approximately 22 to 320 persons/km^2. The pressure on land and water resources is concentrated in particular areas where this density is high. The location of one of the largest parks in West Africa, the National Park of Comoe in the northern part of the basin, probably induces the low population density of that part of the basin. 12% and 4% of the population respectively in Cote d'Ivoire and Burkina Faso lives in the Comoe Basin.

Agriculture is the main socioeconomic activity with cash and food crops, fishing and livestock. Food crops are yam, plantain, cassava, rice, maize, sorghum and millet while cash crops are coffee, cocoa, hevea, cashew nut, cotton, palm oil. Livestock concerns cattle, sheep and pig. Table 4 shows the cultivated areas in the Comoe River.

Table 4: Cultivated area in the central part of the Comoe River Basin

Crop	Bondoukou (ha)	Bouna (ha)	Tanda (ha)	Ferke (ha)	Abengourou (ha)	Agnibilekrou (ha)	M’Bahiakro (ha)	Daoukro (ha)	Bongouanou (ha)	Grand Bassam (ha)	Aboisso (ha)	Agboville (ha)
cashew nut	23,611	20,113	10,226	25,720	105	2,445	3,800	17,170	536	75	29	-
Cassava	19,448	886	2,442	4,655	2,071	494	-	11	-	4,467	27,674	1,910
Yam	8,606	9,161	9,398	3,818	4,943	3,415	2,585	4,498	797	4,462	589	21,745
Millet	1,282	6,695	67	15,858	184	194	-	-	-	-	-	-
Maize	989	5,392	1,938	43,046	1,302	920	2,087	784	2,686	-	364	634
Groundnut	-	-	-	4,145	-	-	2,086	-	-	-	-	-
Banana	330	-	43	-	132	174	-	-	192		3,636	674
Mango	84	40	-	1,746	749	300	-	-	-	-	-	-
Pineapple	-	-	-		-	-	-	-	-	11,552	-	-
Cotton	-	175	-	49,461	-	-	30	-	-	-	-	-
Mango	-	-	-	-	-	-	187	114	-	-	-	617
Rice	-	319	38	7,805	973	-	5,145	621	-	-	459	574
Sorghum	-	-	-	24,342	-	-	-	-	5,164	-	-	-
Coffee	-	-	8,179	-	58,239	11,358	-	1,904	11,601	6,845	53,934	46,225
Cocoa	-	-	7,944	-	110,564	25,814	-	3,276	19,350	9,510	63,402	71,867
Hevea	-	-		-	852		-	202	287	11,262	648	365
Plantain	-	-	4,258	-	12,364	6,690	-	162	7,584		12,030	21,055
Coconut palm	-	-	209	-	-	-	-	-	-	12,169	585	2,801
Palm oil	-	-	-	-	41	-	-	47	950	22,862	14,909	239
Passion Fruit	-	-	-	-	1,635	1,118	-	84	-	-	1,229	217
Other	-	-	-	218	1,284	472	2,741	631	2,230	4,192	132	707
Total (ha)	**54,350**	**42,781**	**44,742**	**180,814**	**195,438**	**53,394**	**18,661**	**29,504**	**51,377**	**87,396**	**179,620**	**167,722**
	1,105,799											

CHAPTER 3: DATA, MATERIALS AND METHODS

This chapter presents data, materials and methods used in this study.

3.1. Data

3.1.1. Meteorological data

The Burkina Faso and Cote d'Ivoire meteorological agencies are the major source of the meteorological data used in this research. Most of the historical daily data has more than forty years recorded (Figure 15). Each meteorological agency operated two types of stations: 1) the synoptic stations; record data for temperature, relative humidity, sunshine duration and wind speed and 2) rain gauge stations that were installed around synoptic stations mainly to monitor rainfall amount over an area (Figure 16). The list of stations selected for this research (Table 5) shows locations at a range of different distances and elevations.

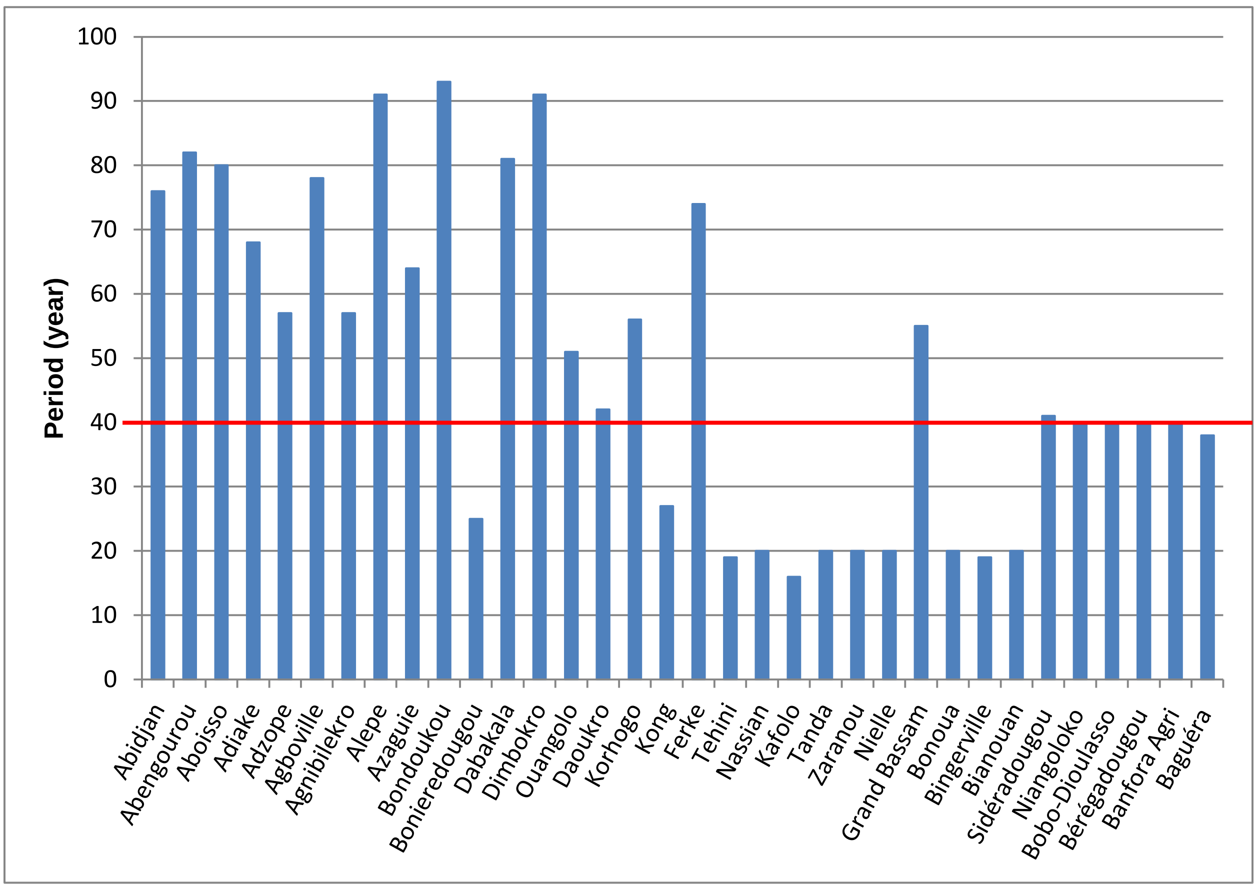


Figure 15: Recorded period of meteorological stations in the Comoe River Basin

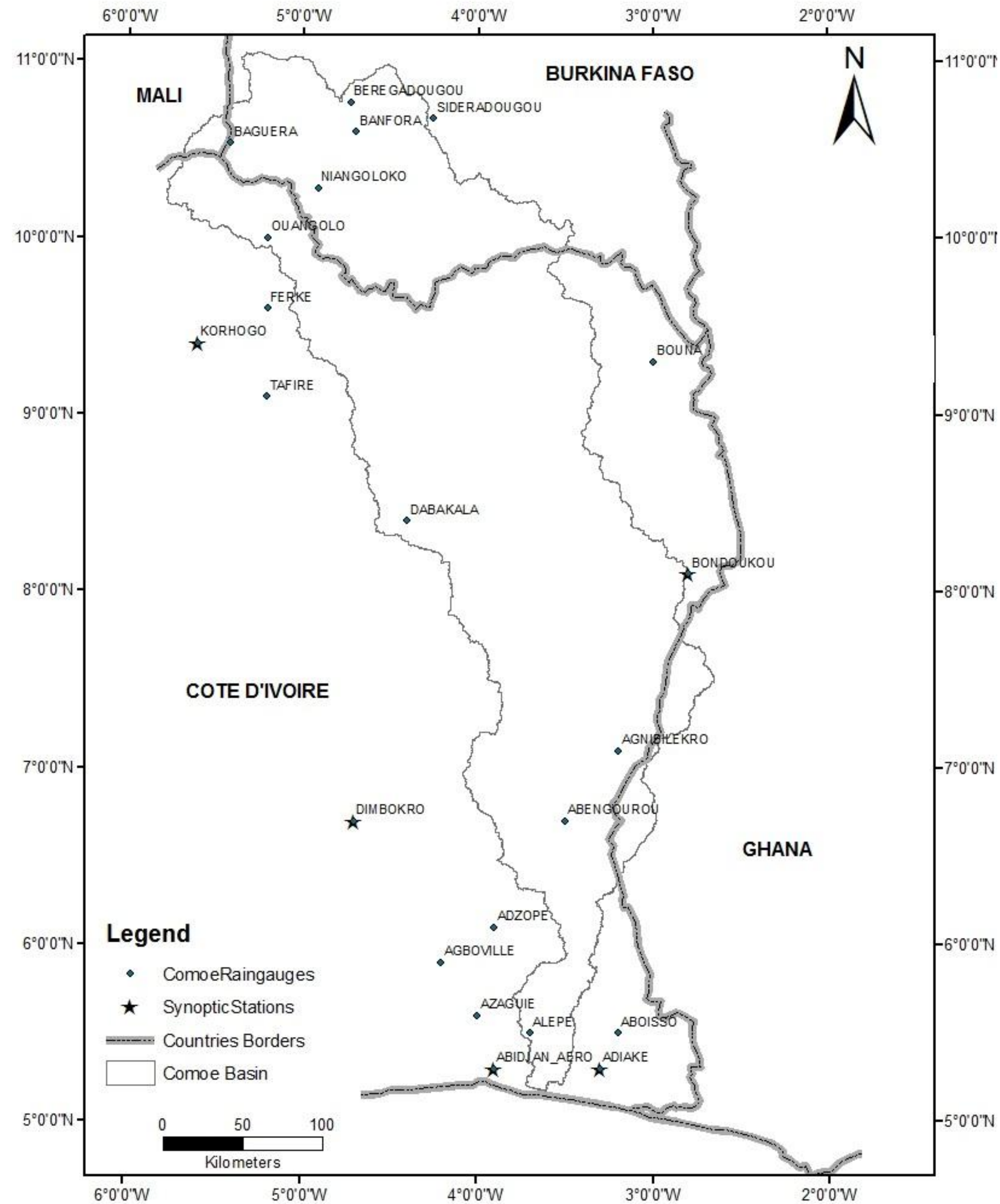


Figure 16: Selected climate station within the Comoe Basin

Table 5: Meteorological stations in the Comoe Basin

	Name	libtype	Period	Altitude	Longitude	Latitude
1	Abengourou - cnra	Agrometeorological	1919-2000	201	-3.4833	6.7167
2	Abidjan - aero	Synoptic	1936-2011	7	-3.56	5.15
3	Aboisso	Rainfall	1921-2011	34	-3.12	5.28
4	Adiake	Synoptic	1944-2011	35	-3.18	5.18
5	Adzope	Rainfall	1944-2000	125	-3.51	6.06
6	Agboville	Climatologic	1923-2000	54	-4.13	5.55
7	Agnibilekrou	Rainfall	1944-2000	221	-3.2	7.1167
8	Alepe	Rainfall	1919-2009	33	-3.6667	5.5
9	Azaguie	Rainfall	1933-2000	80	-4.1	5.38
10	Bondoukou	Synoptic	1919-2011	371	-2.8	8.05
11	Bonoua	Rainfall	1977-1997		-3.6	5.2833
12	Dabakala	Rainfall	1922-2002	258	-4.4333	8.3833
13	Daoukro	Rainfall	1955-1996	230	-3.95	7.05
14	Dimbokro	Synoptic	1921-2011	92	-4.42	6.39
15	Ferkessedougou	Agrometeorological	1927-2000	325	-5.14	9.35
16	Grand Bassam	Rainfall	1925-1980	5	-3.7333	5.2
17	Ouangolodougou	Rainfall	1950-2000	309	-5.15	9.9667
18	Zaranou	Rainfall	1976-1996		-3.3833	6.4333
19	Sidéradougou	Rainfall	1971-2012	319	-4.25	10.6667
20	Niangoloko	Rainfall	1971-2011	320	-4.9167	10.2667
21	Bobo-Dioulasso	Synoptic	1971-2011		-4.2833	11.1833
22	Bérégadougou	Rainfall	1974-2011	331	-4.7333	10.75
23	Banfora agri	Rainfall	1971-2011	270	-4.7667	10.6167
24	Baguéra	Rainfall	1974-2012	315	-5.4167	10.5333

3.1.2. Hydrological data

The Burkina Faso and Cote d'Ivoire hydrological agencies have provided the hydrological data used in this research. Most of the historical daily data has more than forty years recorded (Figure 17). Each hydrological agency installed staff gauges in streams (Figure 18) and manually measured the water level daily. Then, they use to calculate discharge for any water level by developing a stage discharge relationship which is expressed in an exponential rating curve. The list of stations selected for this research (Table 6) shows recorded periods and elevations.

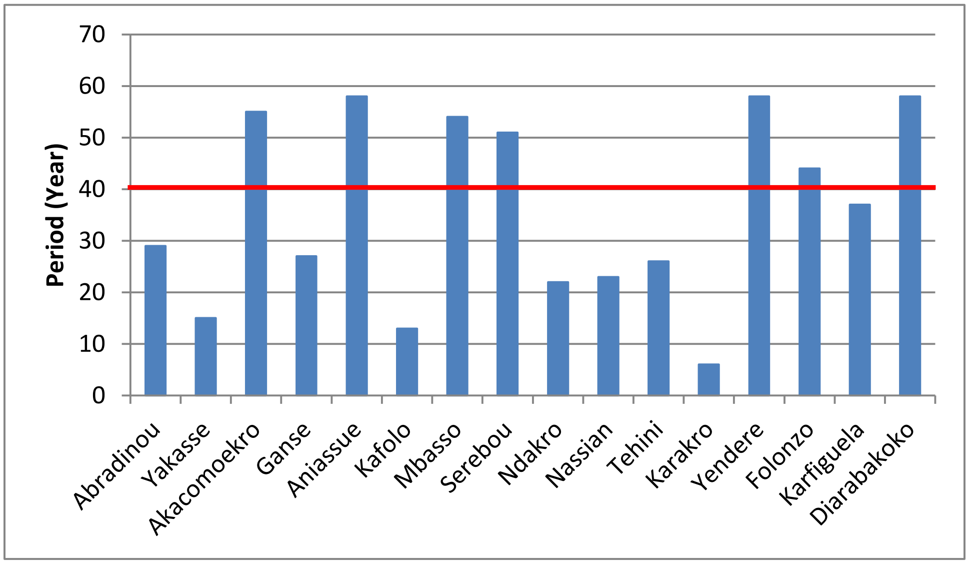


Figure 17: Recorded period of climate stations in the Comoe River Basin

Table 6: Hydrological station in the Comoe Basin

Coordinates	Longitude	Latitude	Altitude	Area	Period
Folonzo	04° 37' W	09° 54' N	299 m	9,480 Km^2	1969-2012
Yendere	05° 04' W	10° 10' N	264 m	5,930 km^2	1955-2012
Serebou	3°56'31" W	7°56'18" N	160 m	49,000 km^2	1954-2004
Akacomoekro	3°30'45" W	7°26'57" N	137 m	57,000 km^2	1956-2010
Aniassue	3°41'12" W	06°38'42" N	120 m	66,500 km^2	1953-2010
M'Basso	03°28'48" W	06°07'30" N	112 m	70,500 km^2	1955-2010

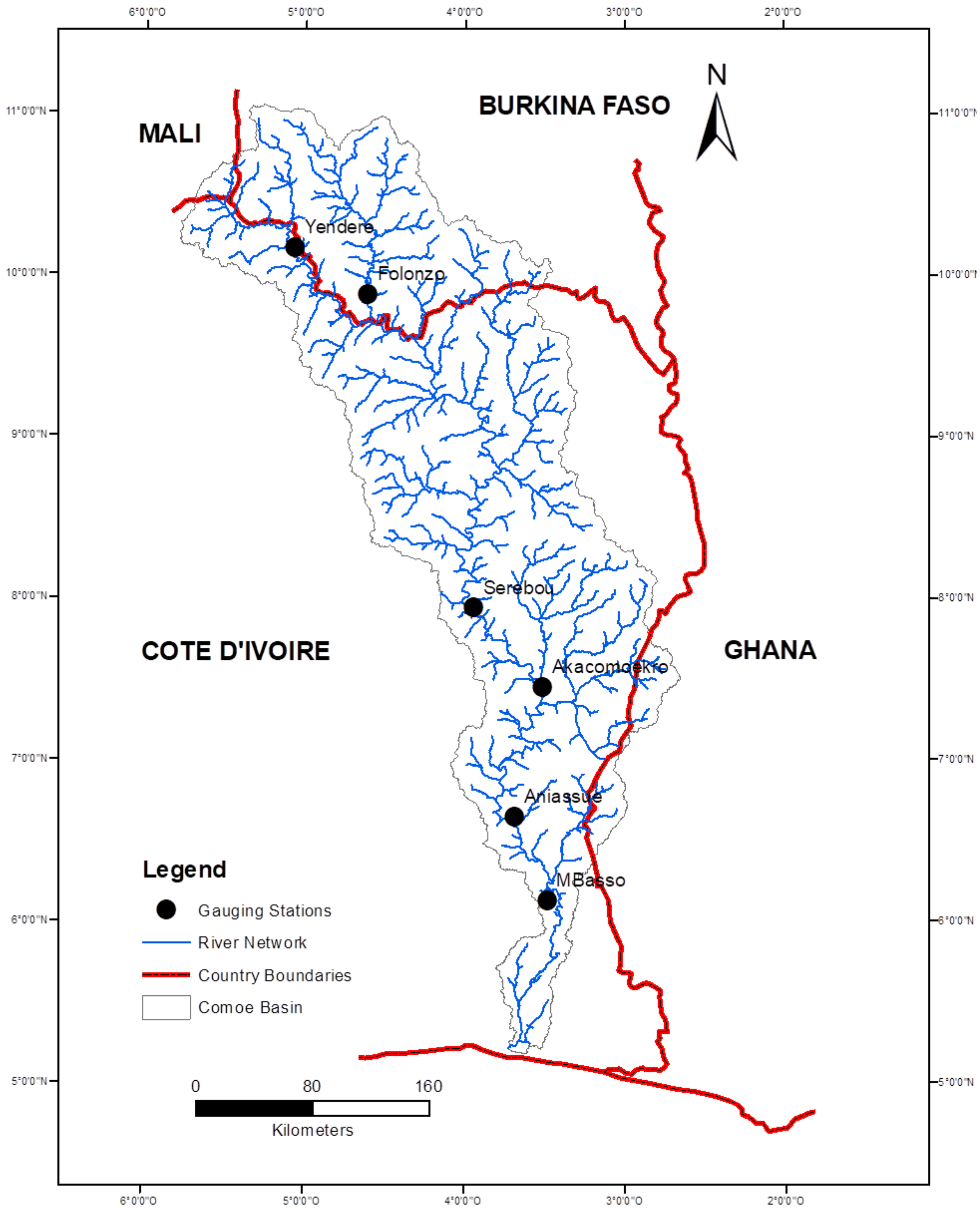


Figure 18: Selected hydrologic gauging stations in the Comoe Basin

3.1.3. Climate data

We used in this study three (03) Regional Climate Models (RCM) outputs for the period 1950-2100. Each file name provides information on Station, Variable, Domain, GCMModelName, Period, driving_model_ensemble_member, *RCMModelName, RCMVersionID, Frequency, StartTime* and *EndTime.*

3.2. Materials

3.2.1. Hydrological model

The GR4J (Modèle du Génie Rural à 4 paramètres Journaliers) model was used in this study. It is a daily lumped four-parameter rainfall-runoff model. It belongs to the family of soil moisture accounting models. Table 7 shows the characteristics of GR4J model used in this study.

Table 7: Characteristics of GR4J model

Model	Description	List of parameters	Reference
GR4J	Parsimonious model with two unit hydrographs and a groundwater exchange function	X1 (mm) capacity of the soil moisture store X2 (mm) groundwater exchange coefficient X3 (mm) capacity of the routing store X4 (days) time base of the unit hydrograph	Perrin et al. (2003)

GR4J is an empirical lumped model designed at the basin scale. It is not directly linked to physical aspects of the basin and uses stores to represent the overall water behavior. It makes flow simulations at the daily time step (Figure 19).

We choose the GR4J model for this study because of three reasons. Firstly, the model is a lumped one and it is taking the basin as a whole. A second reason is that each of the building blocks of any distributed model is itself a lumped rainfall-runoff model. Before gathering an ensemble of elementary models, it is worthwhile to improve the devices that will be used as constituents. Lastly, it has been giving good results in streamflow simulation.

To run the GR4J model, the Microsoft Office Excel software was used in this study. All the formulas – to run the model and calculate its efficiency - are put in different cells. The data are completed by the operator and the calculation is instantaneous. For Calibration, the solver tool was used.

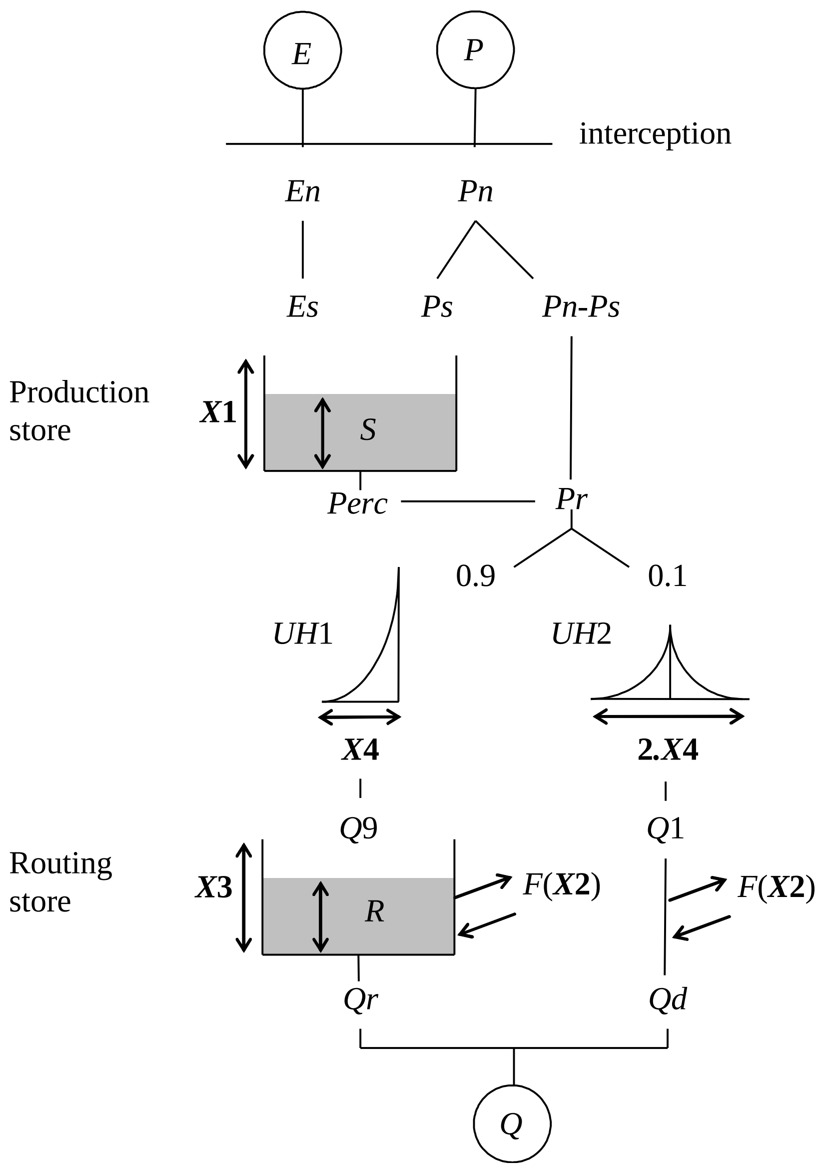


Figure 19: GR4J model structure (adapted from (Charles Perrin et al., 2003)).

3.2.2. Regional Climate models

Three (03) Regional Climate Models (the Rossby Centre Atmospheric model 4 (RCA4), RACMO22T and CCLM4-8-17) were used in this study (

Table 8). RCM outputs for the period 1950-2100 were provided by three institutes, namely, the Swedish Meteorological and Hydrological Institute (SMHI), the Royal Netherlands Meteorological Institute (Koninklijk Nederlands Meteorologisch Instituut (KNMI)) and the Climate Limited-area Modelling-Community (CLMcom) at a resolution of ~50km (0.44° * 0.44°). These Coordinated Regional Downscaling Experiment (CORDEX) simulations were respectively driven by three Global Climate Models (GCM), namely, the Centre National de Recherches Météorologiques - Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique – Coupled Model 5 (CNRM-CERFACS-CNRM-CM5), The Irish Centre for High-End Computing (ICHEC) EC-EARTH and the Max Planck Institute for Meteorology - Earth System Model – running on Low Resolution grid (MPI-M-MPI-ESM-LR). We used existing daily climate simulations of both the historical (1950–2005) and the projected (2006–2100) regional climate under the scenarios RCP4.5 and RCP 8.5. These RCPs were used by CORDEX to generate long term climate data for the African continent. Table 9 shows the main characteristics of the RCP4.5 and RCP8.5 scenarios. The RCP4.5 assumes an intermediate implementation of global climate change policies resulting in stabilization of atmospheric concentrations by 2100. (Cai, Huang, Tan, & Yang, 2011) compare the RCP4.5 to a number of climate policy scenarios and several emission reduction targets found in the climate literature. The RCP8.5, however, assumes that there will be no effective international action on climate change along with high population growth and lower incomes in developing countries, which would lead to higher emissions (thus concentrations) of air pollutants and greenhouse gases, unsustainable land use and less use of environmentally friendly energy sources. Therefore, the RCP8.5 should be considered as a pessimistic scenario, while the RCP4.5 would be an intermediate scenario that accounts for efforts to mitigate climate change.

Table 8: Details information on the three selected RCM

Institute	RCM	Resolution	Driving GCM	Source
CLMcom	CCLM4-8-17	~50km (0.44° * 0.44°)	MPI-M-MPI-ESM-LR	The Max Planck Institute for Meteorology, Germany
KNMI	RACMO22T	~50km (0.44° * 0.44°)	ICHEC-EC-EARTH	The Royal Netherlands Meteorological Institute
SMHI	RCA4	~50km (0.44° * 0.44°)	CNRM-CERFACS-CNRM-CM5	Swedish Meteorological and Hydrological Institute - Rossby Centre Atmospheric model 4

Table 9: Main characteristics of the RCP4.5 and RCP8.5

Scenario Component	RCP4.5	RCP8.5
GHG* emissions	Very low baseline; medium-low mitigation	High baseline
Agricultural area	Very low for both cropland and pasture	Medium for both cropland and pasture
Air pollution	Medium	Medium-high

*GHG: GreenHouse Gas

3.3. Methods

3.3.1. Assessment of climate variability impacts on water resources

3.3.1.1. Drought analysis

The Standardized Precipitation Index (SPI) method developed by (Mishra & Singh, 2011) is utilized to analyze the historical droughts occurring in the basin. The arithmetic average and the standard deviation of precipitation series are used to calculate the Standardized precipitation series. For a given X_1, X_2, X_n series, the standardized precipitation series, SPI_i, is calculated from the following equation:

$$SPI_i = \left(\frac{X_i - \bar{X}}{\sigma}\right) \quad \textbf{Equation 1}$$

Where $\overline{X}$, is the average and σ is the standard deviation of the precipitation series. Negative values obtained from this equation indicate precipitation deficit (drought events), while positive values stand for precipitation excess (wet events) compare to $\overline{X}$.

3.3.1.2. Relationship between rainfall and discharge

This is to assess the causal relationship between rainfall and discharge for the same period in basin's stations. According to (Kouakou Koffi Eugène, 2007), **t**he representation of rainfall (cause) and discharge (effect) on the same graph helps to determine the effects of climate change on water resources.

3.3.2. Assessment of the potential effects of climate change under the RCP 4.5 and 8.5 scenarios

3.3.2.1. Assessing model reliability

A climate model is reliable if it can correctly reproduce present climate. Several criteria can be used to assess the reliability of a fitted model. In this study, we made a comparison between observed and simulated temperature and precipitation data for the reference period (1981-2000).

The following equation tells us if the model is overestimating or underestimating climate parameters values:

$$\boldsymbol{E_r = 100 \times \frac{(X_{sim} - X_{obs})}{X_{obs}}} \qquad \textbf{Equation 2}$$

Where:

X_{sim} is simulated parameter value

X_{obs} is observed parameter value

E_r is the relative error

If $E_r > 0$ the model is overestimating the simulated parameter value

If $E_r < 0$ the model is underestimating the simulated parameter value

3.3.2.2. Parameters range and rate variation

Because of biases in RCM simulations data, we used two equations to correct the mean bias of the model in the temperature and precipitation data. Temperatures and rainfall are respectively expressed in °C and mm as shown below:

$$\boldsymbol{T_{direct,daily} = T_{future,daily} + (\overline{T}_{observed} - \overline{T}_{control})_{monthly}} \qquad \textbf{Equation 3}$$

$$\boldsymbol{P_{direct,daily} = P_{future,daily} \times (\overline{P}_{observed} / \overline{P}_{control})_{monthly}} \qquad \textbf{Equation 4}$$

Where T is temperature (°C), P is rainfall (mm), observed is the observed time series, control is the RCM output of the reference period, future is the RCM output of future scenario.

3.3.3. Evaluation the robustness of a lumped hydrological model for modelling streamflow

3.3.3.1. Total runoff

The total runoff is important to appreciate surface water potentiality in a river basin. It is expressed in mm as shown below:

$$\boldsymbol{R = 365 \times 86.4 \times \frac{Q}{A}} \qquad \textbf{Equation 5}$$

Where:

R is the total runoff (mm)

Q is the discharge (m^3/s)

A is the area (km^2).

3.3.3.2. Monthly discharge coefficient

The Monthly Discharge Coefficient (MDC) was used to determine the periods of low flows and peak flows. It is expressed by the following equation:

$$\boldsymbol{MDC = \frac{Q}{Qmean}} \qquad \textbf{Equation 6}$$

Where Q is the mean monthly discharge and $Qmean$ is the mean discharge of a given period. $MDC \geq 1$ Corresponds to peak flows period and $MDC < 1$ corresponds to low flows period.

3.3.3.3. Water balance

The majority of water that discharges from the basin outlet originated as precipitation falling on the basin. The water balance for our river basin is given by the following equation:

$$P = Q + ET + \Delta S + G \qquad \textbf{Equation 7}$$

Where:

P is precipitation (mm);

Q is surface runoff (mm);

ET is the evapotranspiration (mm);

ΔS is storage change in the basin and;
G is groundwater runoff.

3.3.3.4. Use of hydrological model

3.3.3.4.1. Calibration

The GR4J model is first calibrated against the observed streamflow data and is then driven by the historical and future climate data with the same optimized parameter values to model the historical and future runoff. The simulated future and historical runoff are then compared to estimate the climate change impacts on the runoff. The four parameters of the GR4J model have to be optimized:

X1: maximum capacity of the production store (mm)

X2: groundwater exchange coefficient (mm)

X3: one day ahead maximum capacity of the routing store (mm)

X4: time base of unit hydrograph UH1 (days)

X1 and X3 are positive, X4 is greater than 0.5 and X2 can be either positive, zero or negative.

In order to find the combination that reaches the best fit between the simulated and the observed water flows, the 4 parameter values were optimized using the Solver tool in Excel. Several evaluation criteria exist to assess this fit between the 2 ranges of data (Charles Perrin et al., 2003). We used the Nash-Sutcliffe Efficiency (NSE) expressed by (Nash & Sutcliffe, 1970) as follow:

$$NSE = 1 - \frac{\sum_{k=1}^{n}\left(x_{0,k} - x_{s;k}\right)^2}{\sum_{k=1}^{n}\left(x_{0,k} - \mu_0\right)^2}$$ **Equation 8**

Where n is the number of values, $x_{0,k}$ is the observed value at time k (the observed flow), $x_{s;k}$ is the simulated value at time k (the simulated flow), and μ_0 is the mean of the observed values. NSE is often given in %.

NSE varies between -∞ and 1. If it is negative, then the simulated results are worse than the mean observed values and a constant would give better results than the model which is thus considered useless. If $NSE = 1$ then the observed and simulated values are equal. Thus during the calibration process, one must try to reach an NSE as close as possible to 1 i.e. as high as possible. In this case the calibration process is an optimization of the 4 parameters X1, X2, X3 and X4 to maximize NSE.

Other criteria exist using, for example, the square root or the logarithm of flows in the NSE formula as observed and simulated values.

3.3.3.4.2. Validation

In the validation process, the same criteria or new ones can be used to assess the quality of the calibration of our 4 parameters on a new data set. Several criteria can be used at that step - whereas the calibration is generally made to optimize one criterion only even if, nowadays, more and more studies develop a multi-criteria approach.

3.3.3.4.3. Precipitation and Evapotranspiration

In this study, the Thiessen polygons were generated using the spatial analyst tool of ArcGIS and manually overlapped with the delineated subwatershed.

Precipitation (P) and potential evapotranspiration (ET) are inputs to the model. P is an estimate of the areal basin rainfall that has been computed by the Thiessen interpolation method from available raingauges. ET is evapotranspiration. All water quantities (input, output, internal variables) are expressed in mm.

The net precipitation Pn is equal to 0 if ET>P and equal to P-ET otherwise. The net evapotranspiration ETn is equal to 0 if P>ET and equal to ET-P otherwise.

3.3.3.4.4. Recharge and Discharge

If Pn>0, the net rainfall water is then divided and a part of it will go in the production store, if En>0 water is taken from this production store. This store stands for the humidity or moisture of the basin and is often confused with the soil although there is no direct link. This store allows to separate the rainwater - in a part that will actually reach the rivers and a part that will go back to the atmosphere by evapotranspiration or percolate later - by taking into account the past conditions over the basin (past precipitations and evapotranspiration). The production store is basically a stock of water S (in mm at the beginning of day k) that will increase or decrease due to rainfall and evapotranspiration. Part of this water will also percolate to the rivers.

3.3.3.5. Interfacing between RCM and GR4J model

Equations 2 and 3 were used in this study to correct the mean bias of the model of the temperature and precipitation data. Figure 20 describes procedures to use bias corrected RCM in the GR4J model.

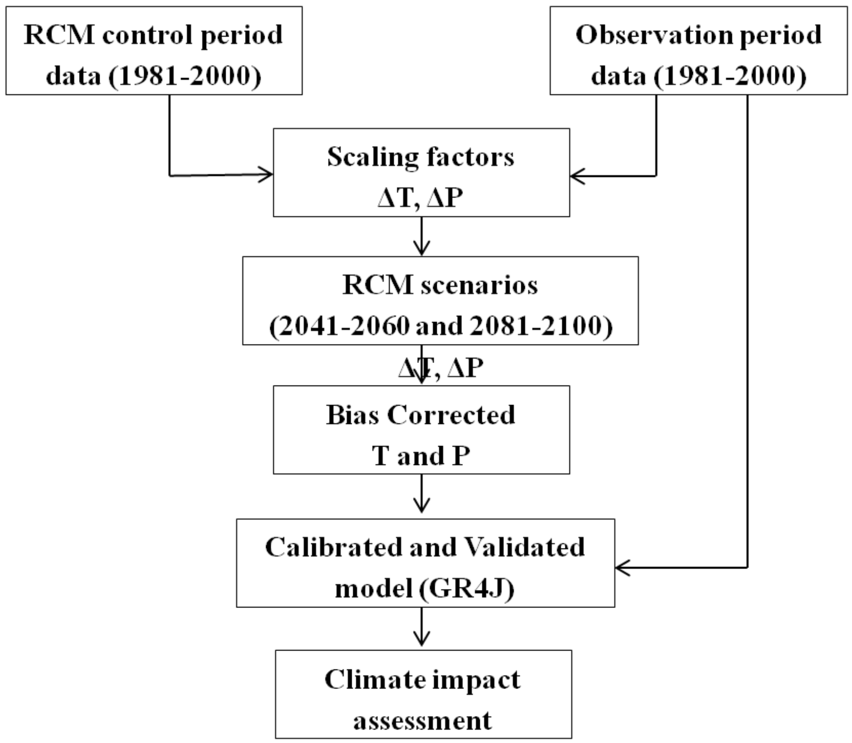


Figure 20: Simple scheme to use bias corrected RCM in GR4J model (Fiseha, Setegn, Melesse, Volpi, & Fiori, 2014)

3.3.4. Vulnerability assessment

A survey to assess the vulnerability of communities to climate change was conducted in the southern part of the Comoe River Basin in Côte d'Ivoire. Four (4) regions (Indenie-Djuablin, Me, Gontougo and Iffou) and twenty-one (21) villages which are in close proximity to the Comoe River were visited (Figure 21).

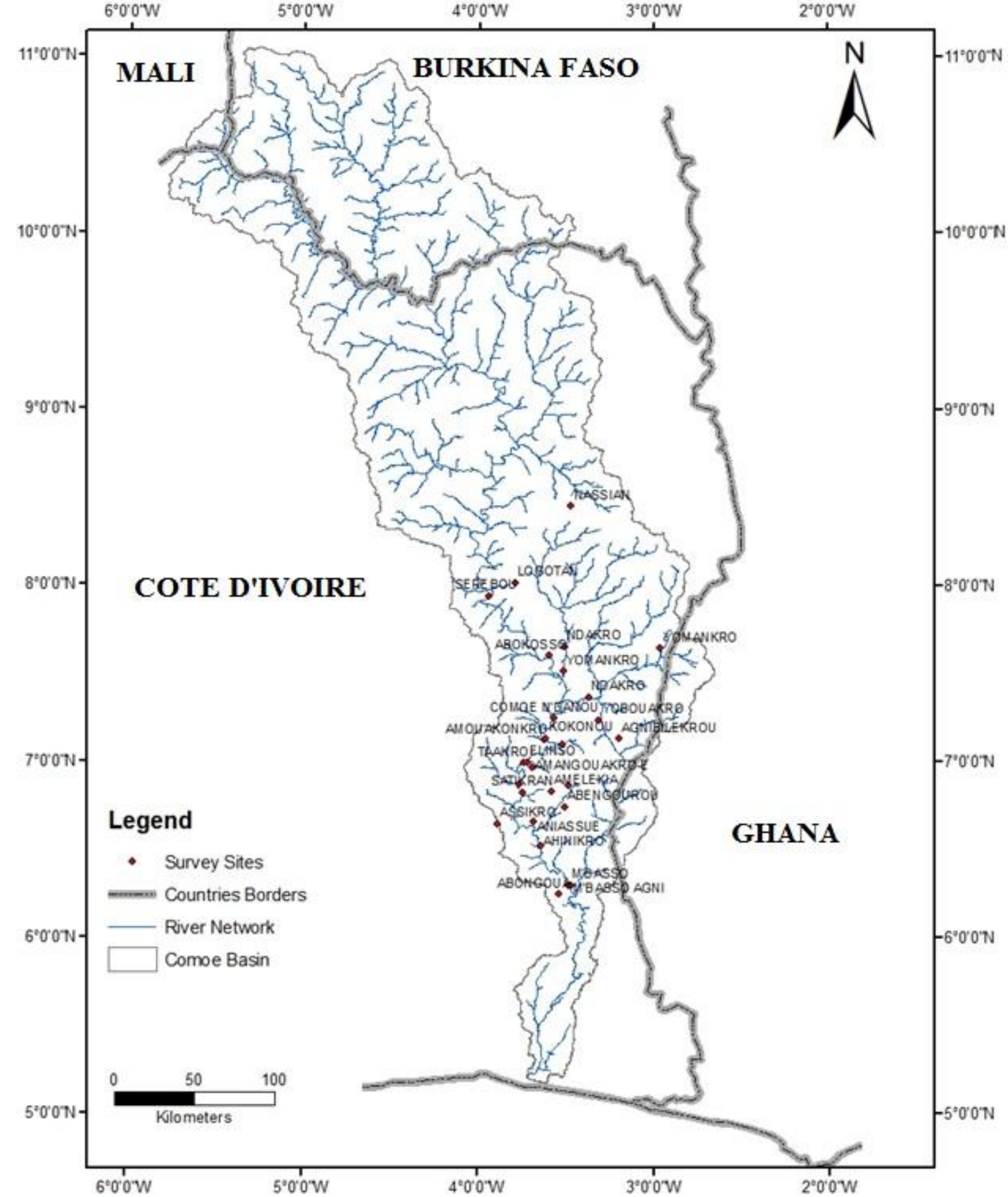


Figure 21: Study sites in the Comoe River Basin (Yéo, Goula, Diekkrüger, & Afouda, 2016)

3.3.4.1. Sample size

The sample size for the survey population was determined using the (Cochran, 1977) equation

$$\boldsymbol{n} = \frac{\boldsymbol{Z^2 P(1-P)}}{\boldsymbol{C^2}} \qquad \textbf{Equation 9}$$

With, n = sample size; Z = confidence level; P = percentage picking a choice, expressed as decimal; c = confidence interval, expressed as decimal.

Data presented in this paper were collected during a period of fieldwork; April to May 2014. The survey was conducted with a team of socioeconomics using a mixture of participatory methods including Focus Group Discussions (FGDs), questionnaire surveys and key informant interviews. This research only considered interviews with water users and stakeholders involved in water use and management.

3.3.4.2. Questionnaire

Two structured questionnaires were designed to collect information on perception on climate change, concerns for changes in climate and potential adaptation measures and strategies Annexes (1&2). The questionnaires were designed in French but the interviews were conducted in the local language, *Agni, Baoule, Andoh.* The following headings composed the different sections of the questionnaire:

a) **Site and respondent**: this section was used to obtain information on the survey site and the water users group.

b) **Social and cultural information**: this section was used to obtain information on the survey site communities, their representativeness, and social organization, everyday diseases of children, men and women.

c) **Climate context**: this section was used to obtain data about communities’ awareness of climate change, relative risks to climate change, observed impacts and local strategies to adapt to climate change, vulnerable population and economic sectors to climate change.

d) **Livelihood**: this section was used to obtain information on communities' source of income, source of domestic energy, available resources to fight against natural disasters, infrastructures for water management.

e) **Extreme events:** this section was used to obtain information on extreme events frequency, the understanding of these extreme events, the loss of production and reduction of income.

Data from the questionnaires were analysed using Sphinx software. Rainfall and temperature data were obtained from the Burkina Faso and Cote d'Ivoire Meteorological Agencies covering the period between 1941 and 2010. These data gave an overview of the trends of rainfall and temperature and vulnerability of the CRB to droughts and floods.

CHAPTER 4: CLIMATE VARIABILITY

4.1. Rainfall and temperature

Crop management needs good knowledge on the timing of the onset and end of the rainy season. Also, it is very important to know the period of the year with high rainfall variability (Miyan, 2014); (ASSAR, 2015). Farming and many sectors are very sensitive to rainfall variability. The survey sites lie within the equatorial climate zone (Girard et al., 1971). Figure 22 presents historical climate monthly averages for the closest synoptic stations (BoboDioulasso, Bondoukou, Dimbokro and Adiake) and shows a bimodal rainfall pattern with two rainy seasons in the central and southern parts of the basin since the forties to 2010: one is long (from March to July) and another is short (from September to October). The driest period is from November to February. August corresponds to an intermediary season with low rainfall. Figure 22 also shows a monomodal rainfall pattern in the northern part of the basin with one rainy season (from May to September) and one dry season (from October to April).

August is the wettest month for BoboDioulasso in the northern part of the Comoe River Basin. The wettest month in the central part of the basin is September at Bondoukou station. June is the wettest month for Dimbokro and Adiake in the south. The wettest monthly average is respectively around 500 mm, 270 mm, 180 mm, 180 mm for Adiake, BoboDioulasso, Bondoukou and Dimbokro.

January is the driest month with an average of 0.2 mm, 9.3 mm, 13.6 mm and 28.8 mm of total monthly rainfall respectively for BoboDioulasso, Bondoukou, Dimbokro and Adiake.

The minimum average temperature recorded from the forties to 2010 is 18.8°C, 20°C, 20.9°C in January respectively for BoboDioulasso, Bondoukou, Dimbokro and 21.8°C in August.

The maximum average temperature is 32.3°C, 35.1°C and 35.7°C in February respectively for Adiake, Bondoukou, Dimbokro and 37.2°C in March for BoboDioulasso.

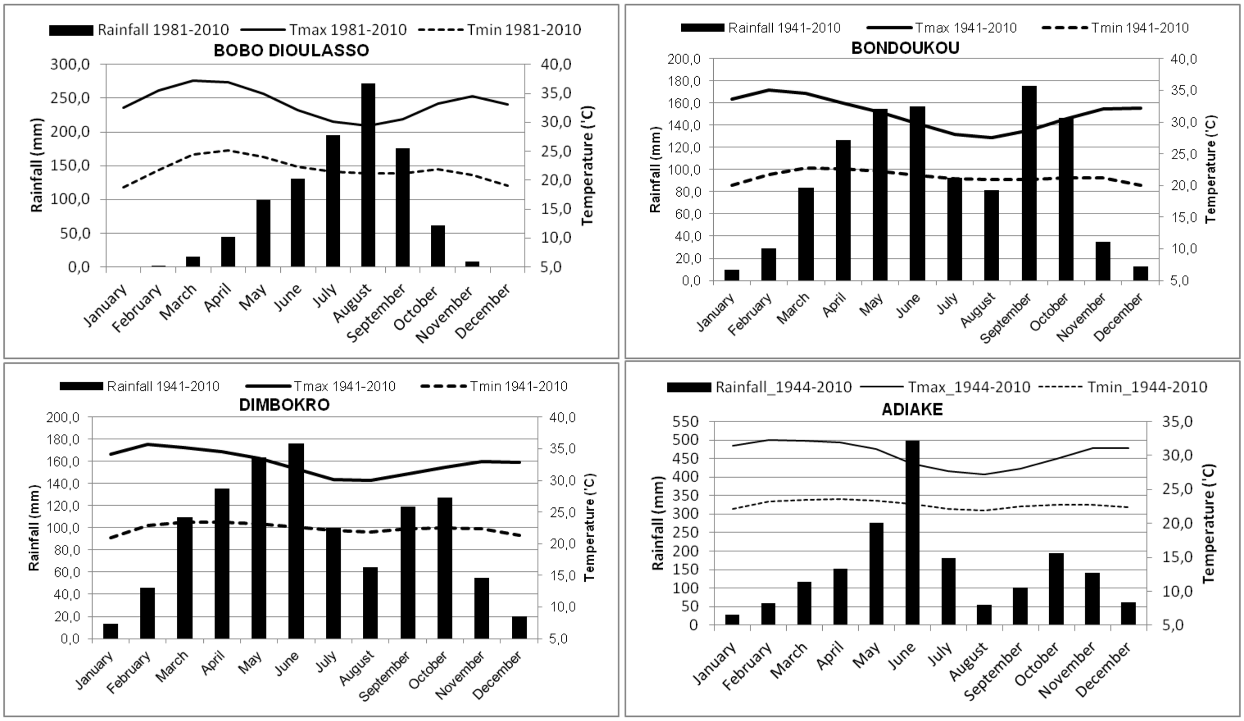


Figure 22: Historical climate monthly averages, BoboDioulasso, Bondoukou, Dimbokro and Adiake stations (Yéo et al., 2016)

A 55-years record of data from 6 rain gauges of the survey area examined for temporal distribution show a succession of humid and drought periods with an extreme dry period beginning in 1969 (Figure 23). The humid period took place before 1969 and after it is the drought period. Table 10 shows a delay and a shortage of rainy seasons at Abidjan, Adiake and Dimbokro stations.

These findings were in accordance with others in West Africa and especially in Cote d'Ivoire. Many authors have assessed precipitations changes over West Africa (S. E. Nicholson et al., 2000); (Lebel & Ali, 2009); (Ackerley et al., 2011); (Ben Mohamed, 2011); (M. Biasutti, 2013). They found that precipitations have decreased the last century and they noticed a recovery toward the last 20 years of the century due to natural variability (Mohino et al., 2011) or a forced response to increased greenhouse gases (Haarsma et al., 2005; Biasutti, 2013) or reduced aerosols (Ackerley et al., 2011). (Michela Biasutti & Giannini, 2006); (Mahé et al., 2009); (Ruti et al., 2011) have noticed the occurrence of drought periods since the seventies. The clear occurrence of drought periods in Cote d'Ivoire since the seventies was also noticed by (Bigot et al., 2005), (Saley et al., 2005), (Dao et al., 2010), (Kouakou Koffi Eugène, 2007), (Soro et al., 2011).

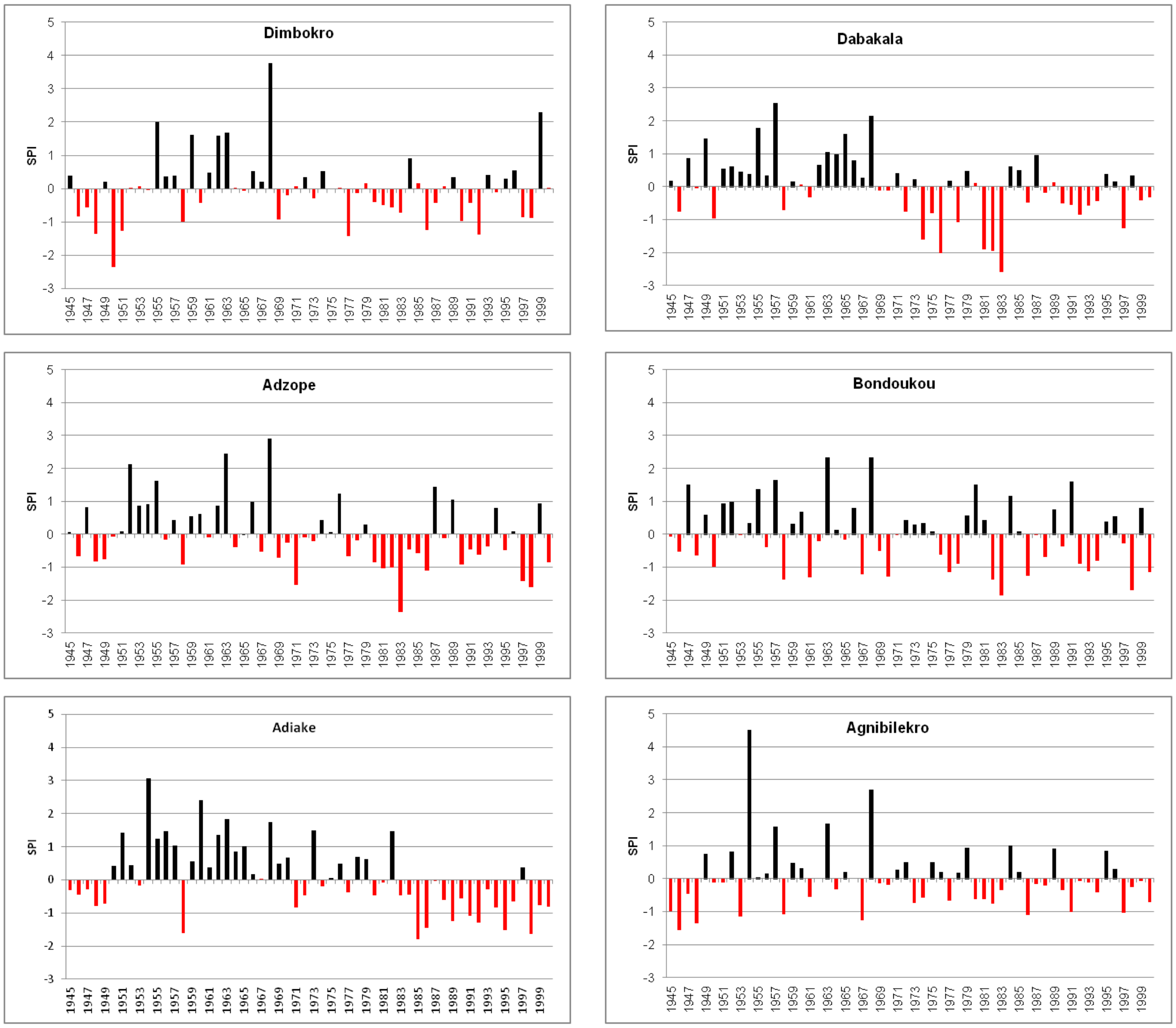
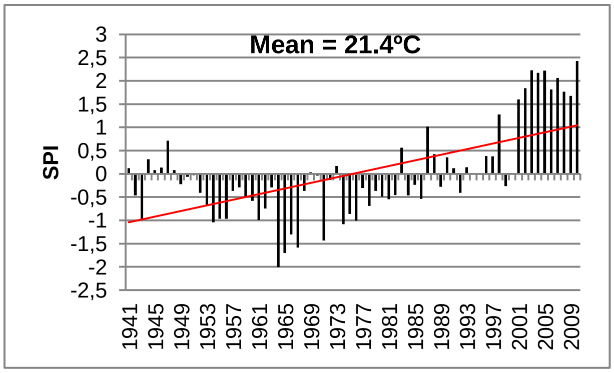


Figure 23: Interannual variability of rainfall in the study sites, 1945-2000

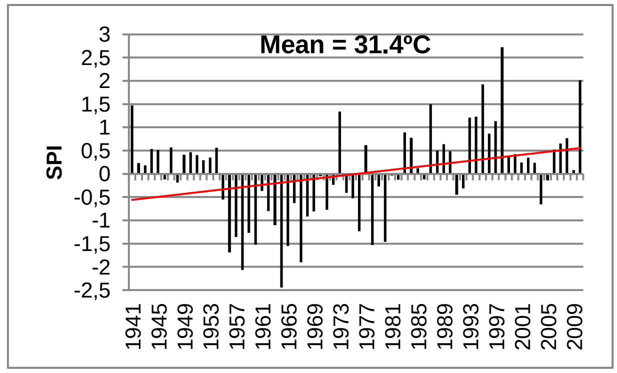
Table 10: Delay in rainy seasons

		First rainy season			Second rainy season		
Station	Period	Start	End	Length (days)	Start	End	Length (days)
Abidjan	1951-1980	Mar-27	Aug-22	149	Oct-11	Dec-31	82
	1971-2000	Apr-03	Aug-17	137	Oct-17	Dec-31	76
	Delay (days)	-7	-5	-12	-6	0	-6
Adiake	1951-1980	Mar-21	Sep-23	187	Sep-28	Dec-30	93
	1971-2000	Apr-08	Sep-14	160	Sep-30	Dec-24	85
	Delay (days)	-18	-9	-27	-2	-6	-8
Dimbokro	1951-1980	Apr-03	Jul-29	117	Sep-11	Nov-03	53
	1971-2000	Apr-04	Jul-11	98	Sep-06	Nov-08	63
	Delay (days)	-1	-18	-19	5	5	10

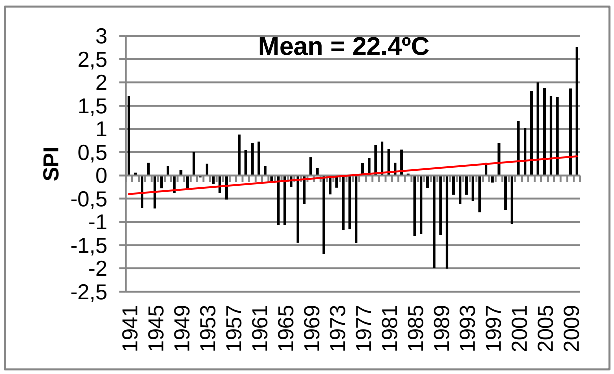
The interannual variability of temperature from the forties to 2010 at Bondoukou, Dimbokro and Adiake synoptic stations shows a continuous increase of temperature (Figure 24). This increase is more pronounced at the minima with about 2°C and 3°C than maxima level with about 1°C and 1.5°C respectively at Bondoukou and Adiake. The average minima temperatures are 21.4°C, 22.4°C and 22.7°C while the average maxima temperatures are 31.4°C, 32.8°C and 30.2°C respectively at Bondoukou, Dimbokro and Adiake. Around 1975, the observed interannual values exceeded the 1945-2010 interannual mean.



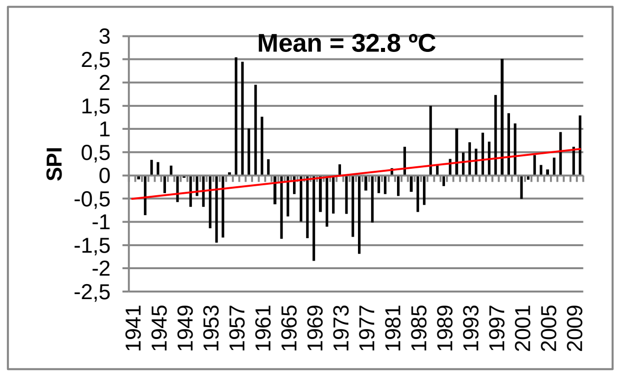
a) Minima temperature at Bondoukou



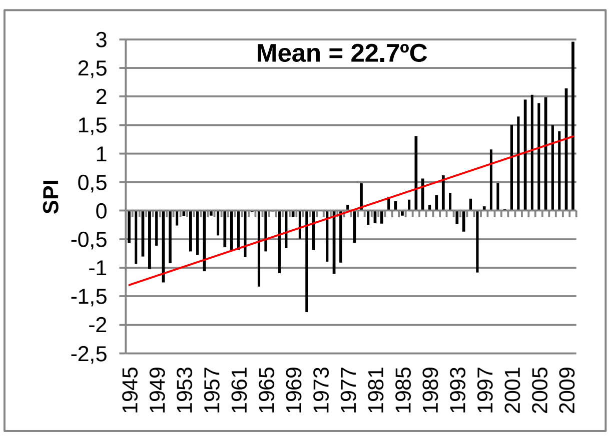
b) Maxima temperature at Bondoukou



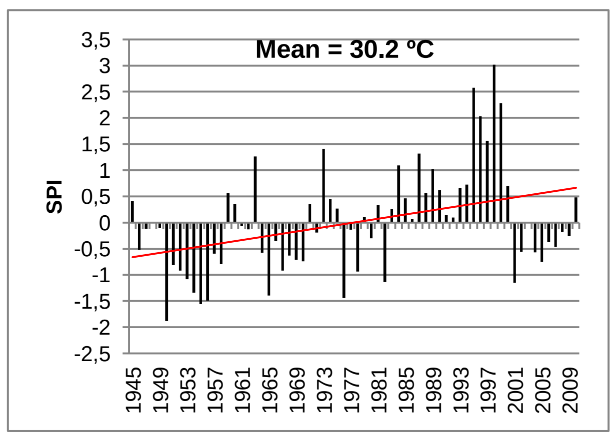
c) Minima temperature at Dimbokro



d) Maxima temperature at Dimbokro



e) Minima temperature at Adiake



f) Maxima temperature at Adiake

Figure 24: Interannual variability of temperature at Bondoukou, Dimbokro and Adiake

These results are in accordance with others in Africa and especially in West Africa. Many authors have shown that temperatures over most part of Africa, have increased by 0.5°C or more during the last 50 to 100 years (Hulme, Doherty, Ngara, New, & Lister, 2001), (Jones & Moberg, 2003); (Stern et al., 2011), (Sharon E. Nicholson, 2013). They noticed that this increase was more pronounced for the minima temperatures.

Temperatures trends over West Africa were assessed by (New et al., 2006). They found an increase of temperature from 1961 to 2000 with a decrease of cold days and cold nights whereas warm days and warm nights have increased. Results from the study of (Collins, 2011) show an increase of temperatures (0.5°C to 0.8°C) for 1970-2010 period over West Africa.

4.2. River discharge

In the Comoe River Basin, annual precipitation ranges from 1,100 mm in the northern part of the basin to 1,600 mm in the south. During the rainy season, precipitation is the main contributor to runoff. Groundwater is the main contributor to runoff in the dry season.

Long records of river discharge at Folonzo, Yendere, Serebou, Akacomoekro, Aniassue and M'Basso gauging stations show a decline of discharge of about 20 $m^3.s^{-1}$ in the northern part and 100 $m^3.s^{-1}$ in the southern part of the Comoe River Basin (Figure 25).

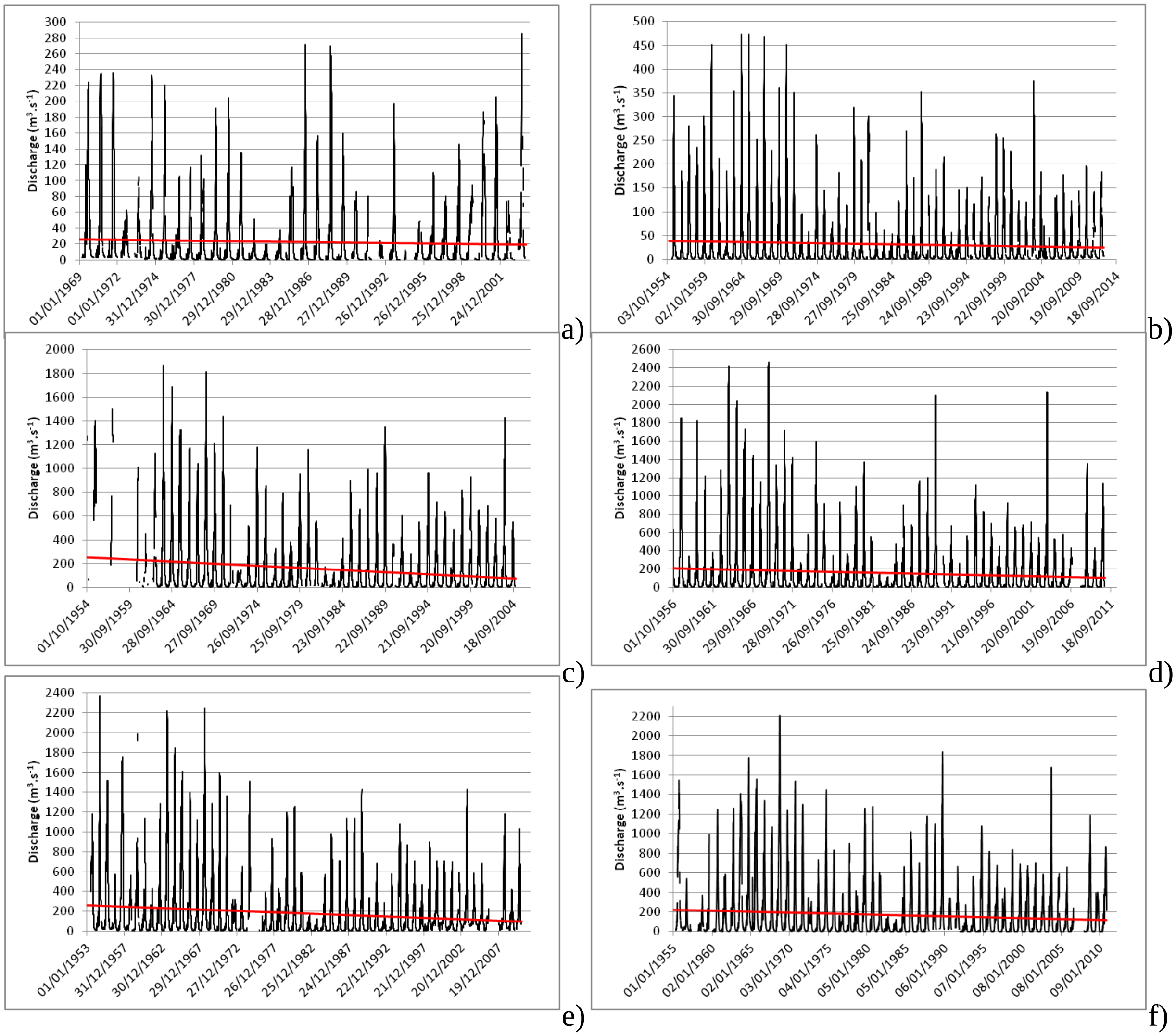


Figure 25: Discharge trend in the Comoe River at Folonzo (1969-2003), Yendere (1954-2012), Serebou (1954-2004), Akacomoekro (1956-2010), Aniassue (1953-2010) and M'Basso (1955-2010) gauging stations

CHAPTER 5: ROBUSTNESS OF THE GR4J MODEL

5.1. Thiessen

The Thiessen polygons were generated using the spatial analyst tool of ArcGIS and manually overlapped with the delineated subwatershed (Figure 26).

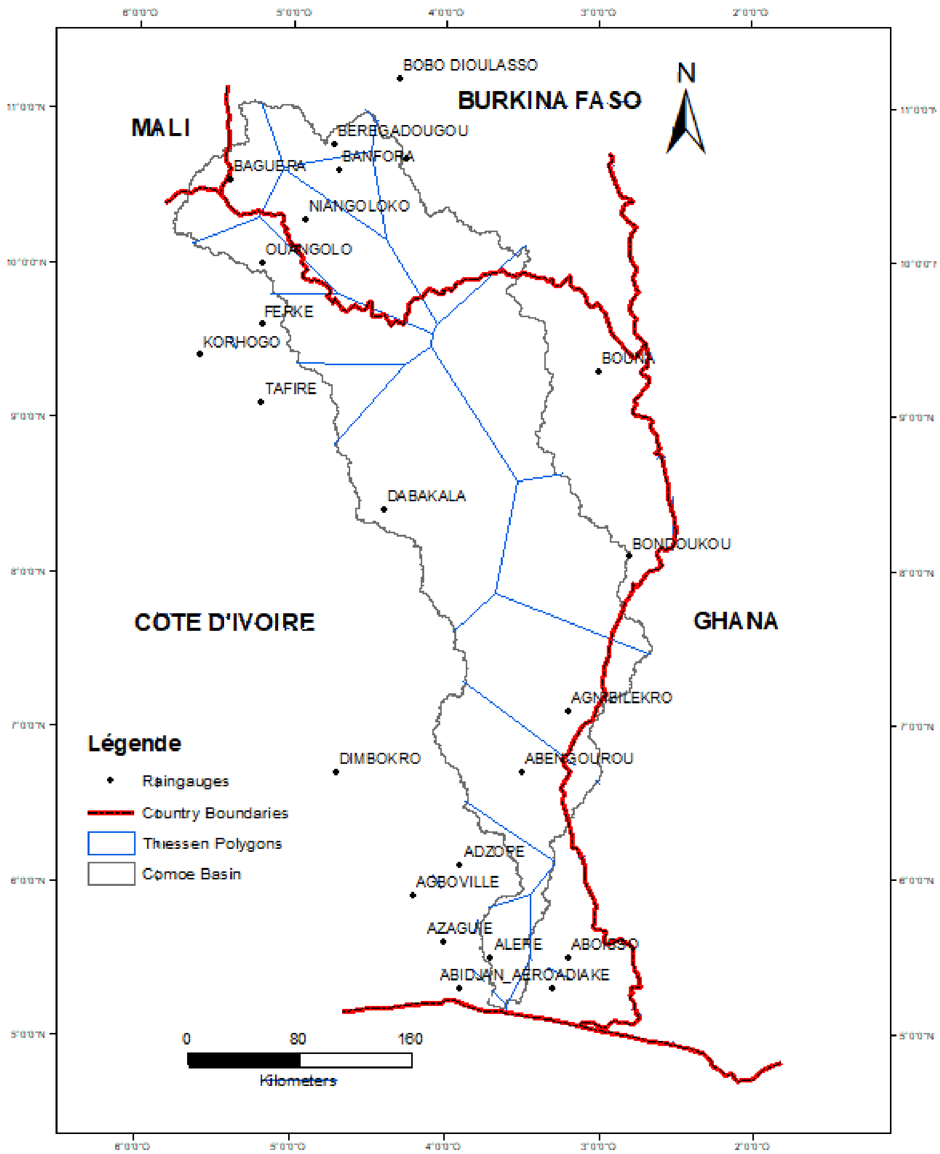


Figure 26: Thiessen polygons for areal rainfall

5.2. GR4J model Calibration and validation

For calibration, the range of data covering the period from 01/01/1979 to 31/12/1992 was used, with six years (1979-1984) used to settle the values of S and R and not taken into account for the efficiency computation (six years model warm-up). The 4 parameters X1, X2, X3 and X4 were calibrated so as to maximize the NSE criterion calculated on flow values (NSE (ln(Q)) calibration). The model calibration on the period 1979-1992 gave the parameters values presented in the Table 11.

The observed and simulated flow values at Yendere, Serebou, Akacomokro and M'Basso are shown on Figure 27. A summary of the model calibration and validation is given in Table 12.

Table 11: Model parameters values

Parameter	Yendere	Serebou	Akacomoekro	Aniassue	MBasso
x1: Capacity of production store (mm)	549.86	400.61	399.55	467.16	414.85
x2: Water exchange coefficient (mm)	0.04	0.05	0.02	-0.03	-0.13
x3: Capacity of routing store (mm)	0.36	1.33	2.56	4.45	4.93
x4: UH time base (days)	4.58	9.99	10.00	10.00	9.90

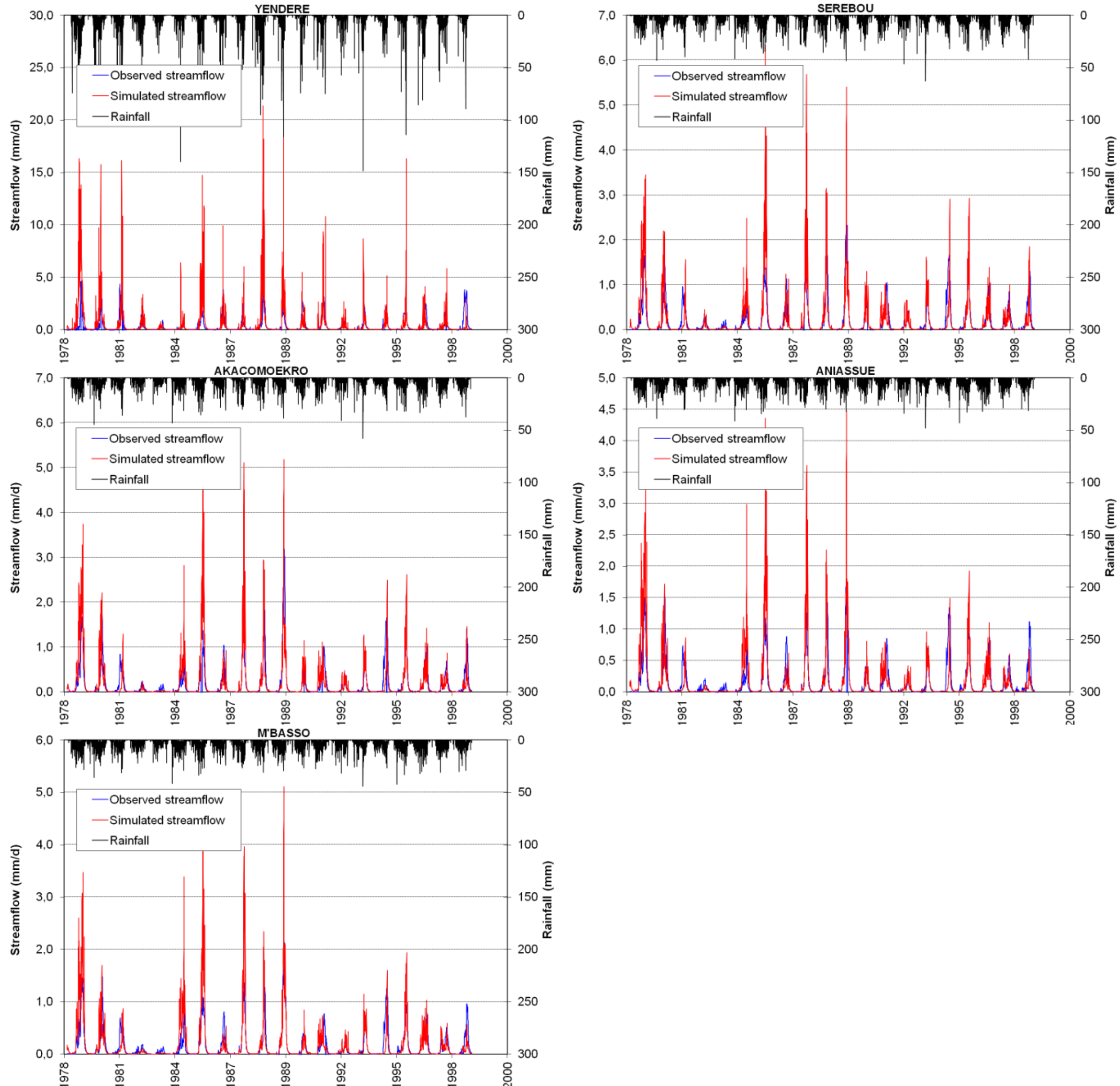


Figure 27: Observed and simulated streamflow at Yendere, Serebou, Akacomokro and M’Basso

Table 12: Summary of the GR4J model calibration and validation

Coordinates	Area (Km^{2})	Warm-up period	Calibration period	Validation period	NSE Calibration	NSE Validation
Yendere	5,930	01/01/1979-31/12/1984	01/01/1985-31/12/1992	01/01/1993-31/12/1998	70.4	55.6
Serebou	49,000	01/01/1979-31/12/1984	01/01/1985-31/12/1992	01/01/1993-31/12/1998	88.6	75.2
Akacomoekro	57,000	01/01/1979-31/12/1984	01/01/1985-31/12/1992	01/01/1993-31/12/1998	88.2	76.1
Aniassue	66,500	01/01/1979-31/12/1984	01/01/1985-31/12/1992	01/01/1993-31/12/1998	87.6	74.4
M’Basso	70,500	01/01/1979-31/12/1984	01/01/1985-31/12/1992	01/01/1993-31/12/1998	86.3	80.7

5.3. GR4J Model performance

The model shows a good NSE for all the gauging stations both for calibration and validation. The performance of the model when passing from calibration to validation is good at M’Basso gauging station (5.6%) while the bad performance is at Yendere (14.8%) as shown in Figure 28.

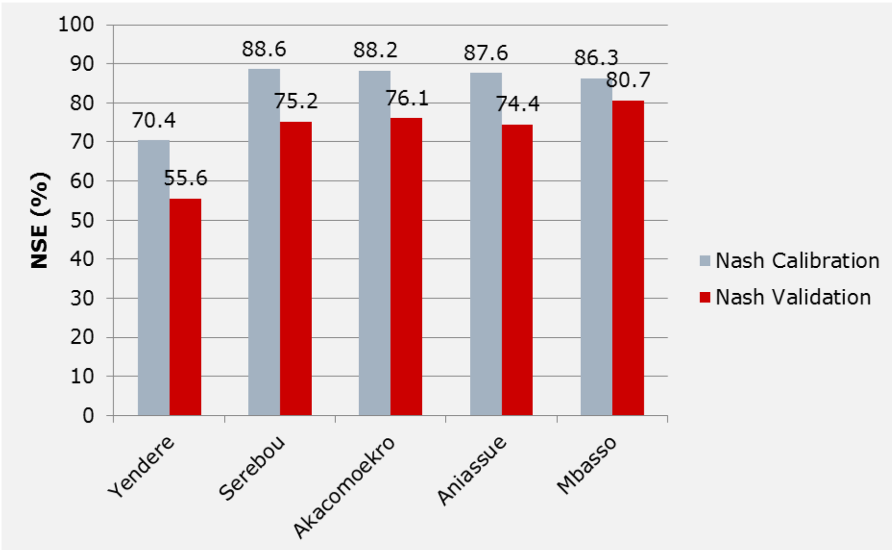


Figure 28: The GR4J model performance in the Comoe Basin, 1979-1998

CHAPTER 6: POTENTIAL EFFECTS OF CLIMATE CHANGE UNDER THE RCP 4.5 AND 8.5 SCENARIOS

6.1. Precipitation

6.1.1. Observed and simulated rainfall patterns

Figure 29 compares observed and simulated rainfall patterns at M'Basso for the three RCM. CLMcom-CCLM4-8-17 shows a ship towards the right of the simulation in comparison to the observed rainfall.

KNMI-RACMO22T shows gaps between the maximum of observed and simulated rainfall.

SMHI-RCA4 reproduces the observed rainfall patterns. But the gap between the observed and simulated maximum is around 100 mm.

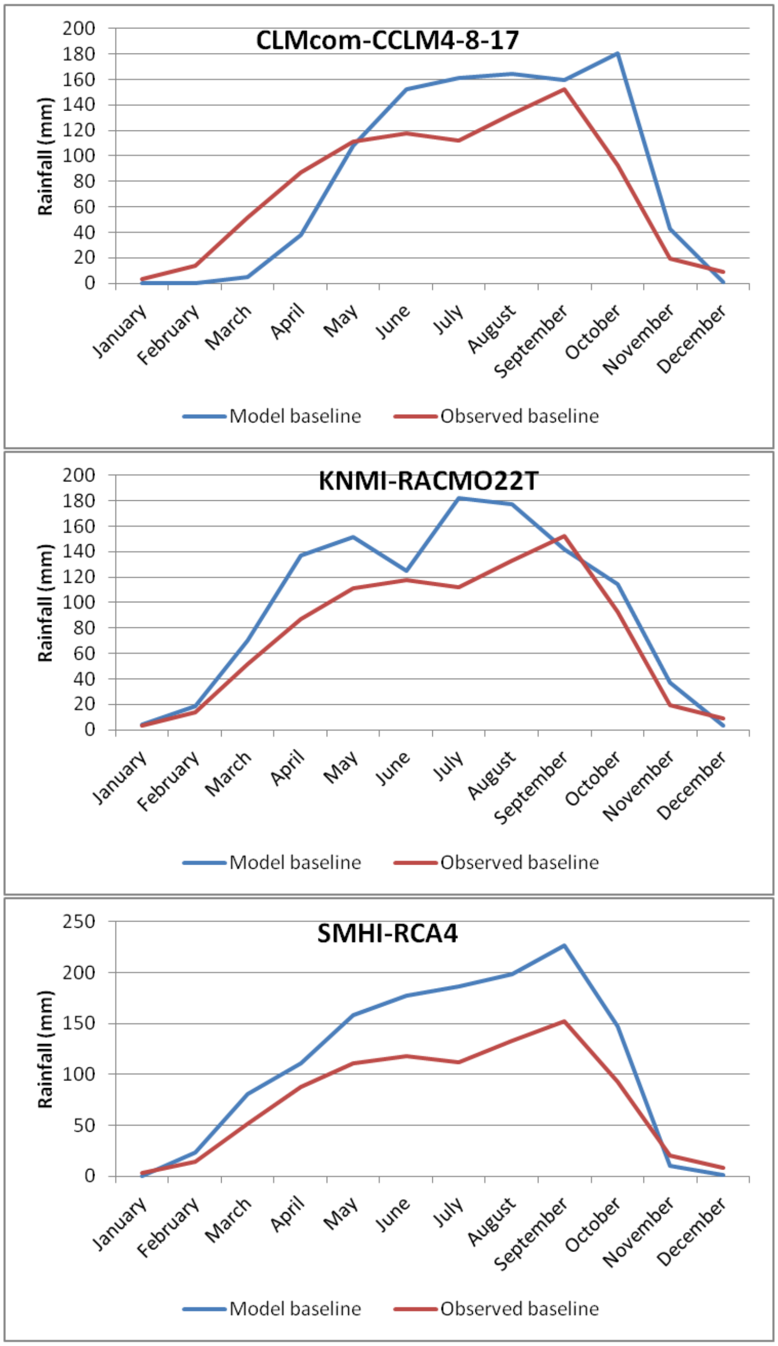


Figure 29: Comparison of observed and simulated rainfall patterns

6.1.2. Observed, simulated and corrected precipitation comparison

Figure 30, Figure 31 and Figure 32 compare simulated, observed and corrected precipitation at the Comoe River Basin outlet (M'Basso) for 2041-2060, 2081-2100 periods and for the three RCM: CLMcom-CCLM4-8-17, KNMI-RACMO22T and SMHI-RCA4.

Future scenarios have the same variability as observations and future precipitations are lower than baseline ones. The three RCM are found to underestimating precipitation. The gaps between observed and model baseline precipitations on the one hand and the simulated and the corrected precipitation on the other hand are not important for CLMcom-CCLM4-8-17. However, these gaps are relatively important for SMHI-RCA4.

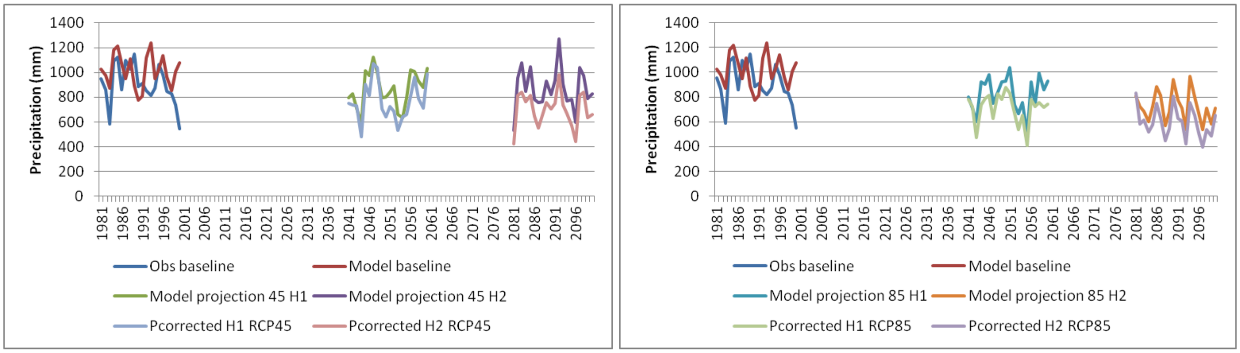


Figure 30: Simulated, observed and corrected precipitation comparison for CLMcom-CCLM4-8-17

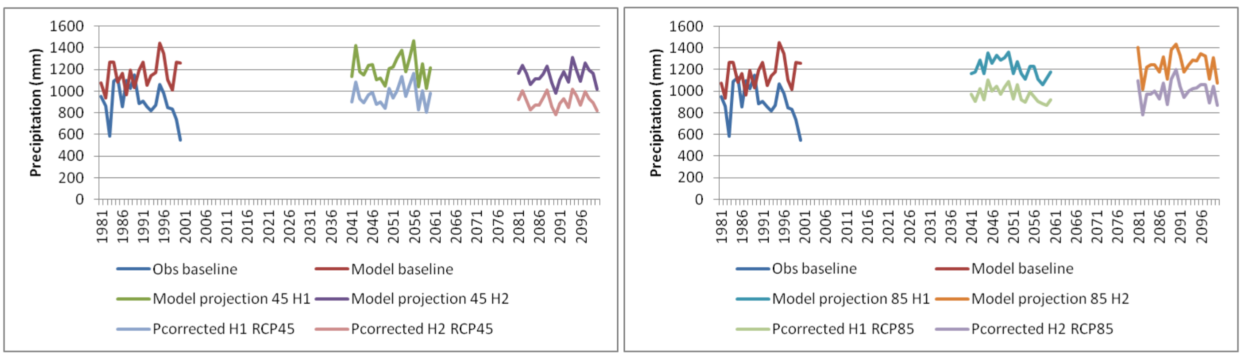


Figure 31: Simulated, observed and corrected precipitation comparison for KNMI-RACMO22T

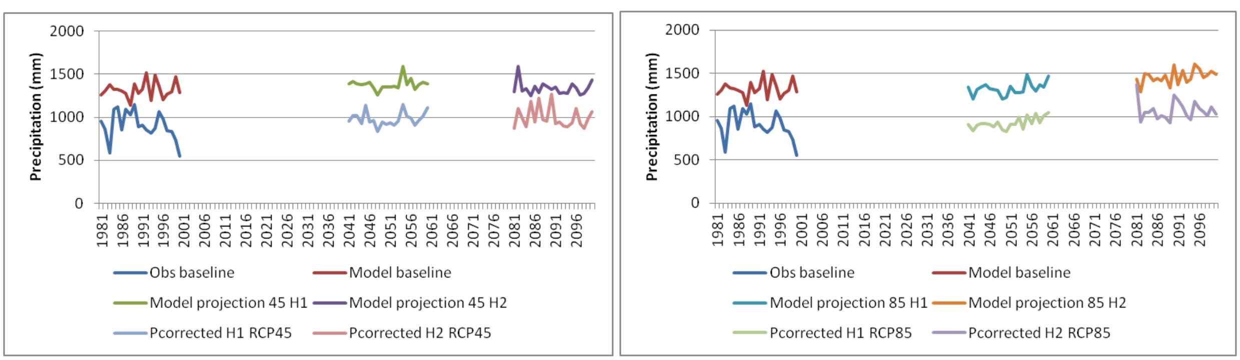


Figure 32: Simulated, observed and corrected precipitation comparison for SMHI-RCA4

6.1.3. Average monthly precipitation changes

Comparison between average monthly precipitations simulated by RCM for 2041-2060, 2081-2100 periods and observed precipitation for baseline period 1981-2000. Table 13 shows changes for the RCP4.5 and RCP8.5 scenarios and for the three RCM. CLMcom-CCLM4-8-17 is underestimating mean annual rainfall, 0.4 to 0.6 for RCP4.5 and 0.5 to 0.8 for RCP8.5 for 2041-2060 and 2081-2100 periods. Whereas, SMHI-RCA4 and KNMI-RACMO22T are overestimating mean annual rainfall, 0.2 to 0.3 for RCP4.5 and 0.1 to 0.5 for RCP8.5.

Table 13: Average monthly precipitation changes for RCP 4.5 and 8.5

	Rainfall change for SMHI-RCA4 (%)				**Rainfall change for KNMI-RACMO22T (%)**				**Rainfall change for CLMcom-CCLM4-8-17 (%)**			
	2041-2060		**2081-2100**		**2041-2060**		**2081-2100**		**2041-2060**		**2081-2100**	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
January	480.7	354.9	1502.8	636.8	12.5	55.7	54.2	134.9	-54.8	-31.5	-83.6	-54.4
February	-19.9	-35.6	-14.4	-48.8	11.2	28.1	5.5	25.1	-71.2	-72.5	-75.9	-37.6
March	-2.1	-23.4	-11.9	-4.0	0.1	6.3	-1.8	4.7	-43.0	-38.5	-65.1	-45.8
April	24.6	14.9	19.8	22.4	-8.9	2.4	-9.1	7.4	3.6	-31.8	-65.4	-81.5
May	3.4	2.5	-2.1	1.9	3.2	-4.8	-3.6	0.7	-17.0	-26.8	-14.7	-56.7
June	3.1	-0.7	-2.1	3.6	15.7	-3.8	6.2	0.2	-19.1	-30.8	-17.5	-41.8
July	3.5	2.4	-5.8	15.5	-11.2	-7.3	-19.4	-10.4	-11.7	-11.2	-12.3	-4.4
August	4.8	5.9	6.0	19.0	9.6	3.8	3.8	15.0	-15.1	-9.9	-19.4	-17.0
September	-0.4	0.5	1.7	11.8	9.2	9.3	3.9	20.0	-2.5	-12.4	-6.5	-18.1
October	2.1	-10.2	-3.8	5.3	9.0	18.8	-1.8	7.6	-21.9	-19.8	-6.1	-29.2
November	112.8	59.6	76.2	153.8	19.1	28.9	26.2	23.5	-22.5	-18.7	6.4	-36.9
December	11.7	-13.9	249.1	368.1	189.7	347.6	157.8	309.9	-6.4	-4.0	-70.8	-39.3
Annual	**0.2**	**0.1**	**0.3**	**0.5**	**0.2**	**0.2**	**0.0**	**0.3**	**-0.4**	**-0.5**	**-0.6**	**-0.8**

6.1.4. Linear correlations for observed and corrected precipitations

Figure 33, Figure 34 and Figure 35 show good linear correlations between monthly observed and corrected precipitation at M'Basso for CLMcom-CCLM4-8-17, KNMI-RACMO22T and SMHI-RCA4. The linear correlation is good both for the two horizons (2041-2060 and 2081-2100) and for the two scenarios RCP 4.5 and 8.5. R^2 values are generally above 0.9.

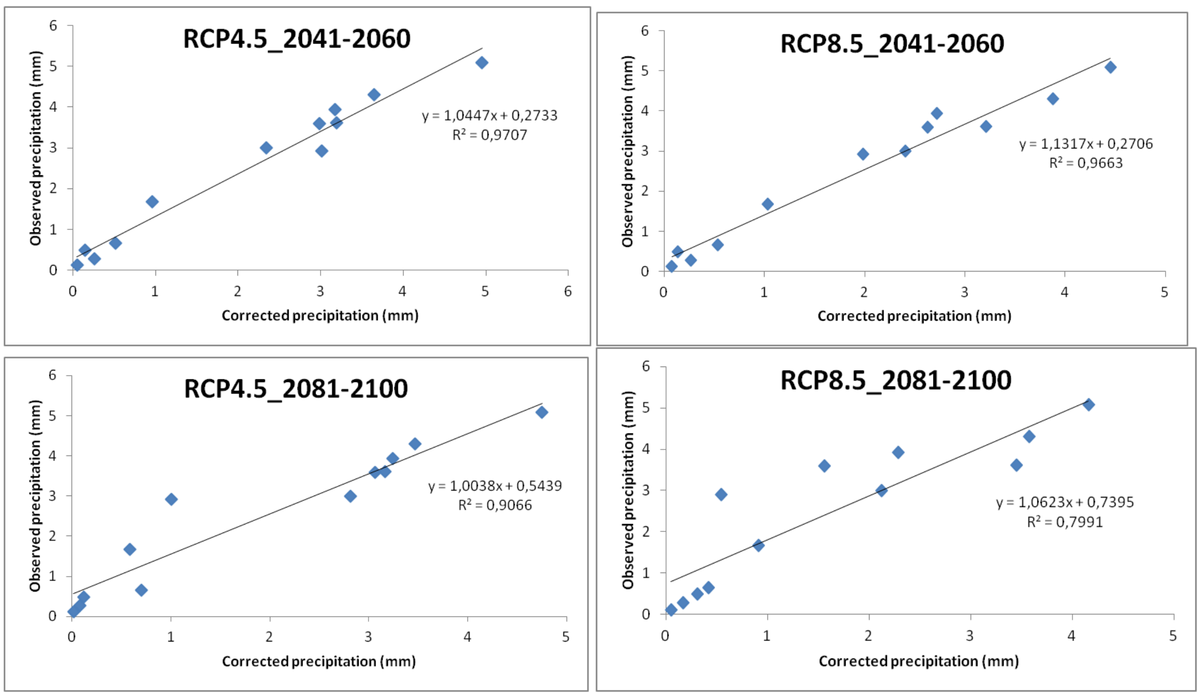


Figure 33: Linear correlation between monthly observed and corrected precipitation at M'Basso for CLMcom-CCLM4-8-17

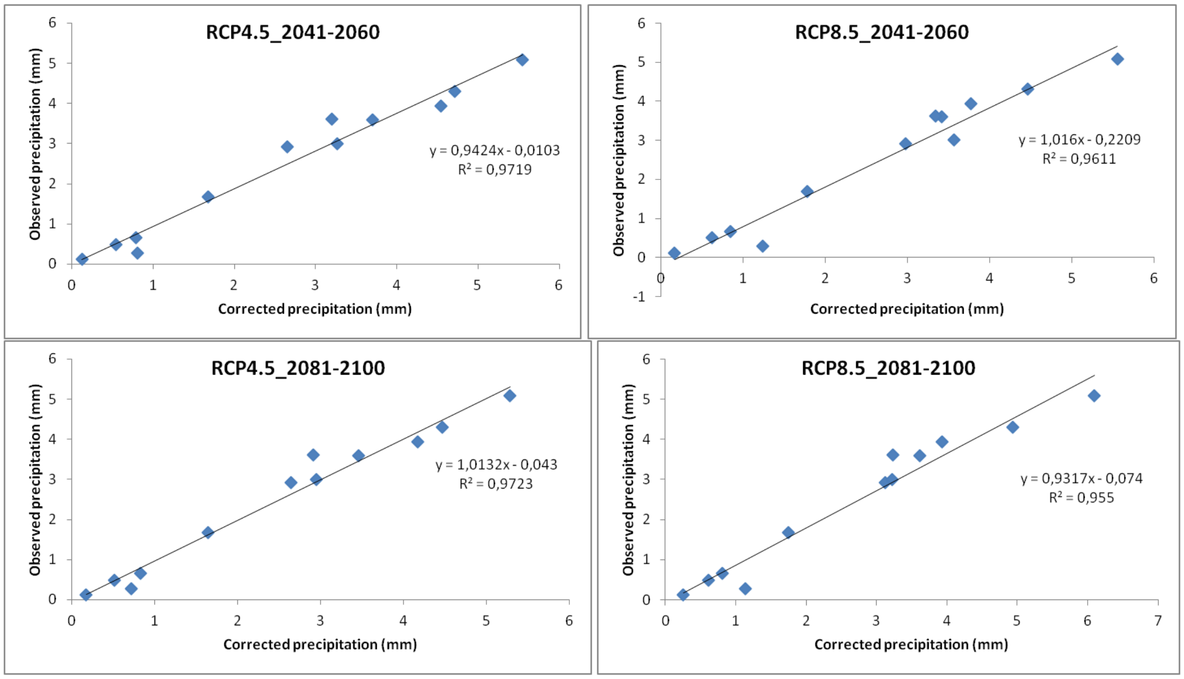


Figure 34: Linear correlation between monthly observed and corrected precipitation at M'Basso for KNMI-RACMO22T

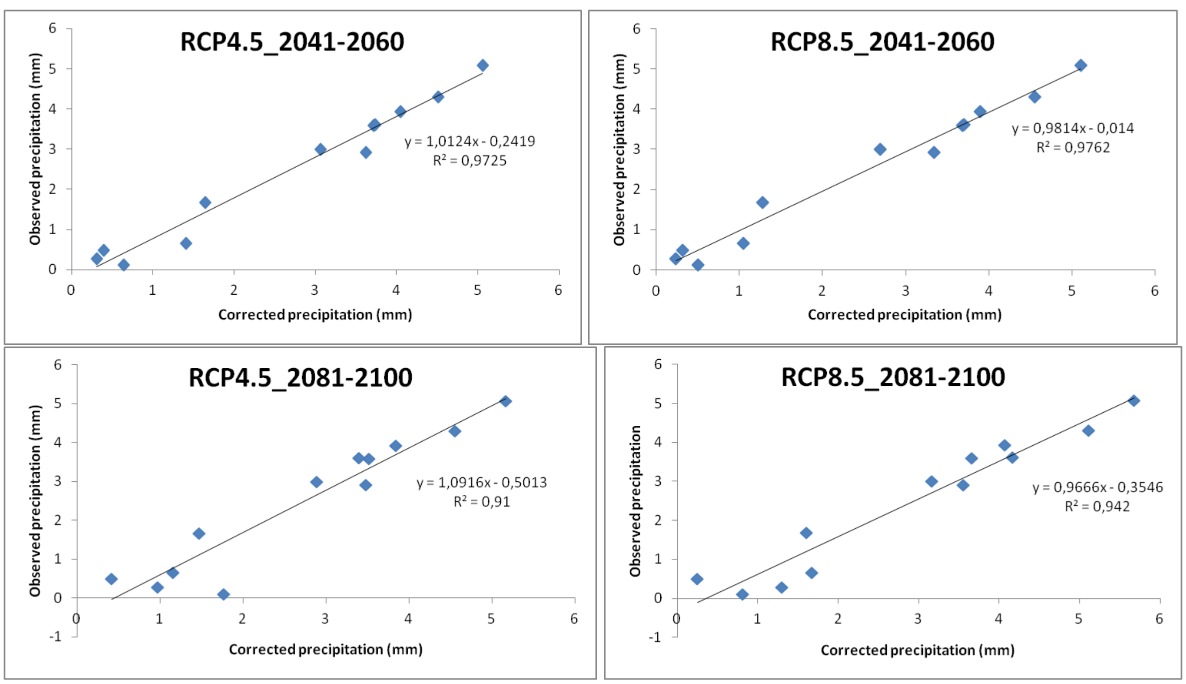


Figure 35: Linear correlation between monthly observed and corrected precipitation at M'Basso for SMHI-RCA4

These results are in accordance with others in West Africa. Many authors have assessed the projected changes in precipitations. Findings from the study of WGI AR5 Section 14.8.7 and (M. Biasutti, 2013) reveal a delay to rainy season by the end of the 21^{st} century. Because of convective rainfall in this region, precipitation projections are showing inter-model variation in both the amplitude and direction of change (Michela Biasutti & Giannini, 2006); (Janicot et al., 2011), (Roehrig et al., 2013). For the Comoe River Basin, precipitations projections for this century (2031-2040 and 209-2100), Regional Climate Model version 3 is indicating a decrease in average total monthly rainfall by 10 percent and 20 percent for the whole basin (KOUAKOU, 2011).

6.2. Temperature

6.2.1. Observed and simulated temperature patterns

Figure 36 compares Observed and simulated baseline temperature patterns for CLMcom-CCLM4-8-17 model at Abidjan, Adiake, Dimbokro, Bondoukou and Bobo Dioulasso for the three RCM. CLMcom-CCLM4-8-17, KNMI-RACMO22T and SMHI-RCA4 reproduce accurately the observed temperature patterns. Observed temperatures are generally above the simulated ones for the three RCM.

Figure 36: Observed and simulated baseline temperature patterns for CLMcom-CCLM4-8-17, KNMI-RACMO22T and SMHI-RCA4 model

6.2.2. Bias correct model projection

5.2.2.1. CLMcom-CCLM4-8-17

Figure 37 shows bias temperature between observed and model baseline on the one hand and model projection and temperature correction on the other hand for CLMcom-CCLM4-8-17. Future scenarios have the same variability as observations and future temperatures are higher than baseline ones. CLMcom-CCLM4-8-17 is overestimating temperature.

The observed baseline is above the model baseline for all the stations. The biases identified at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and Bobo Dioulasso are recpectively about 0.8°C, 1.5°C, 1°C, 1.7°C, 0.8°C and 4.2°C.

The corrected temperatures are greater than the model projection for RCP 4.5 and 8.5 for 2041-2060 and 2081-2100 periods. The biases identified at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and Bobo Dioulasso are respectively about 1.7°C, 0.8°C, 1°C, 1.7°C, 0.7°C and 3.7°C.

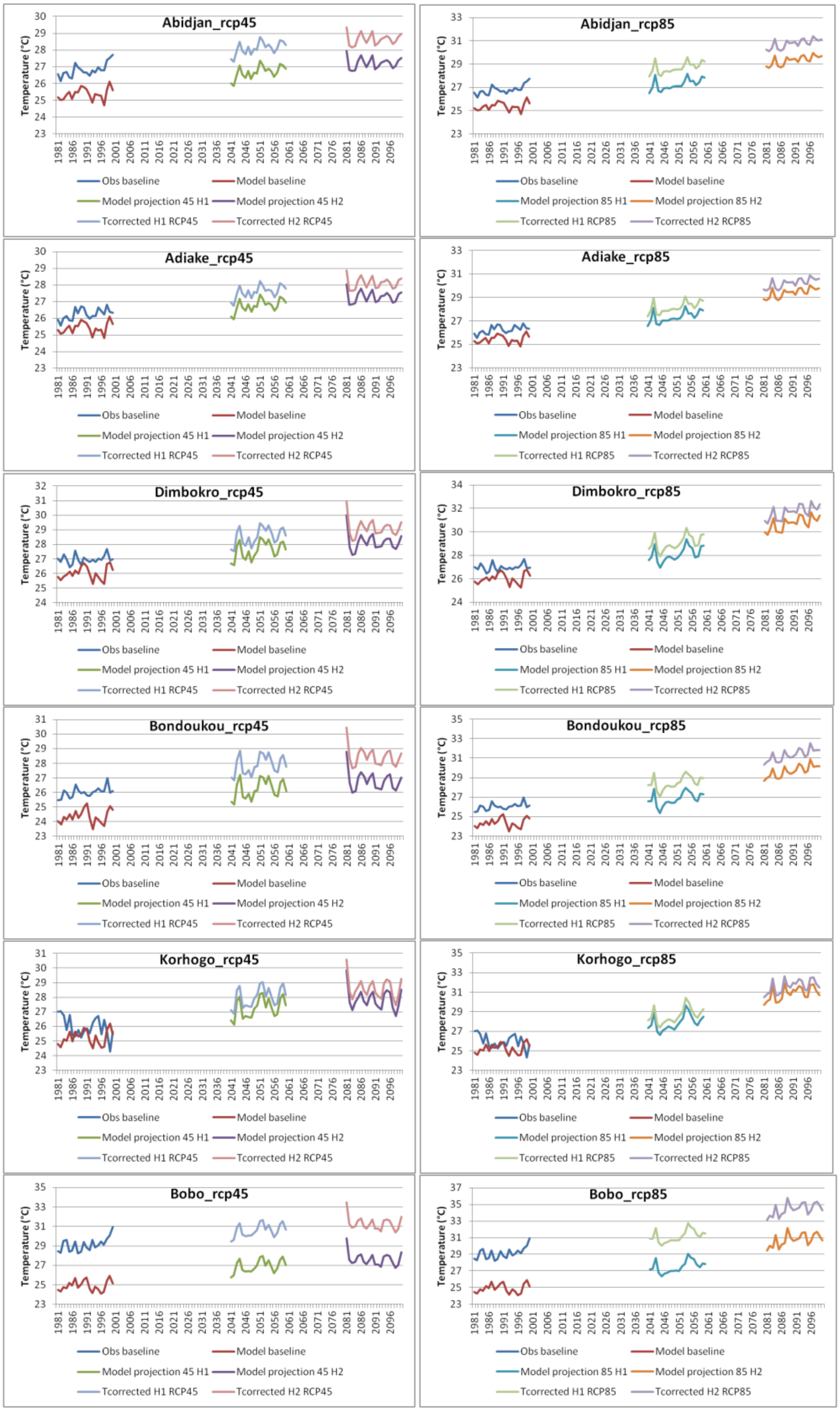


Figure 37: Bias correct model projection at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and Bobo Dioulasso for CLMcom-CCLM4-8-17

5.2.2.2. KNMI-RACMO22T

Figure 38 shows bias temperature between observed and model baseline on the one hand and model projection and temperature correction on the other hand for KNMI-RACMO22T. Future scenarios have the same variability as observations and future temperatures are higher than baseline ones. KNMI-RACMO22T is overestimating temperature.

The observed baseline is above the model baseline for all the stations. The biases identified at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and Bobo Dioulasso are recpectively about 3.2°C, 2.8°C, 4°C, 3.4°C, 3.7°C and 6.6°C.

The corrected temperatures are greater than the model projection for RCP 4.5 and 8.5 for 2041-2060 and 2081-2100 periods. The biases identified at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and Bobo Dioulasso are respectively about 3.2°C, 0.8°C, 3.8°C, 3.4°C, 3.7°C and 6.6°C.

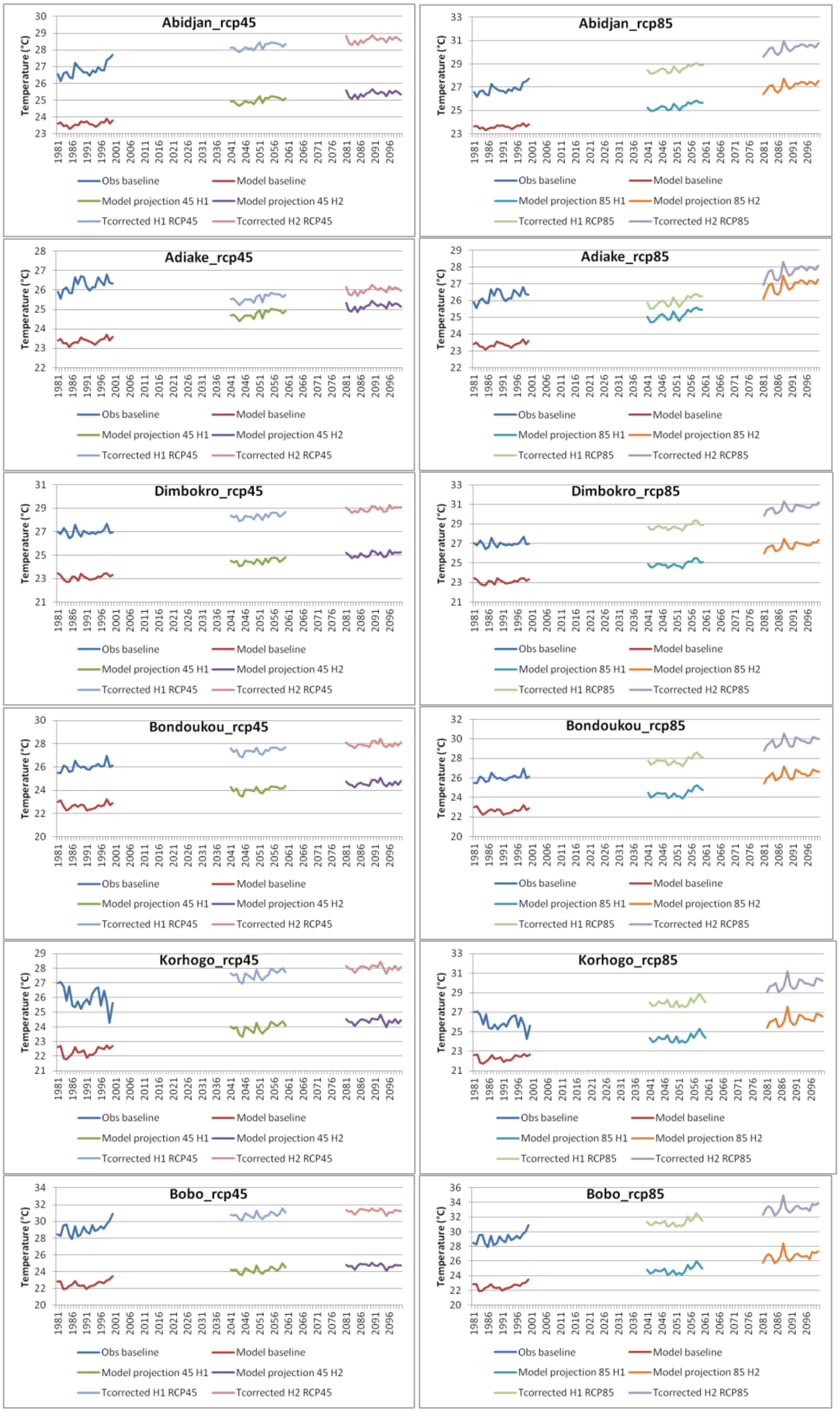


Figure 38: Bias correct model projection at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and Bobo Dioulasso for KNMI-RACMO22T

5.2.2.3. SMHI-RCA4

Figure 39 shows bias temperature between observed and model baseline on the one hand and model projection and temperature correction on the other hand for SMHI-RCA4. Future scenarios have the same variability as observations and future temperatures are higher than baseline ones. SMHI-RCA4 is overestimating temperature.

The observed baseline is generally above the model baseline for all the stations. The biases identified at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and Bobo Dioulasso are recpectively about 0.2°C, 0.2°C, 1.3°C, 1.4°C, 1.5°C and 4.5°C.

The corrected temperatures are greater than the model projection for RCP 4.5 and 8.5 for 2041-2060 and 2081-2100 periods. The biases identified at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and Bobo Dioulasso are respectively about 0.3°C, 0.1°C, 1.3°C, 1.3°C, 1.5°C and 4.4°C.

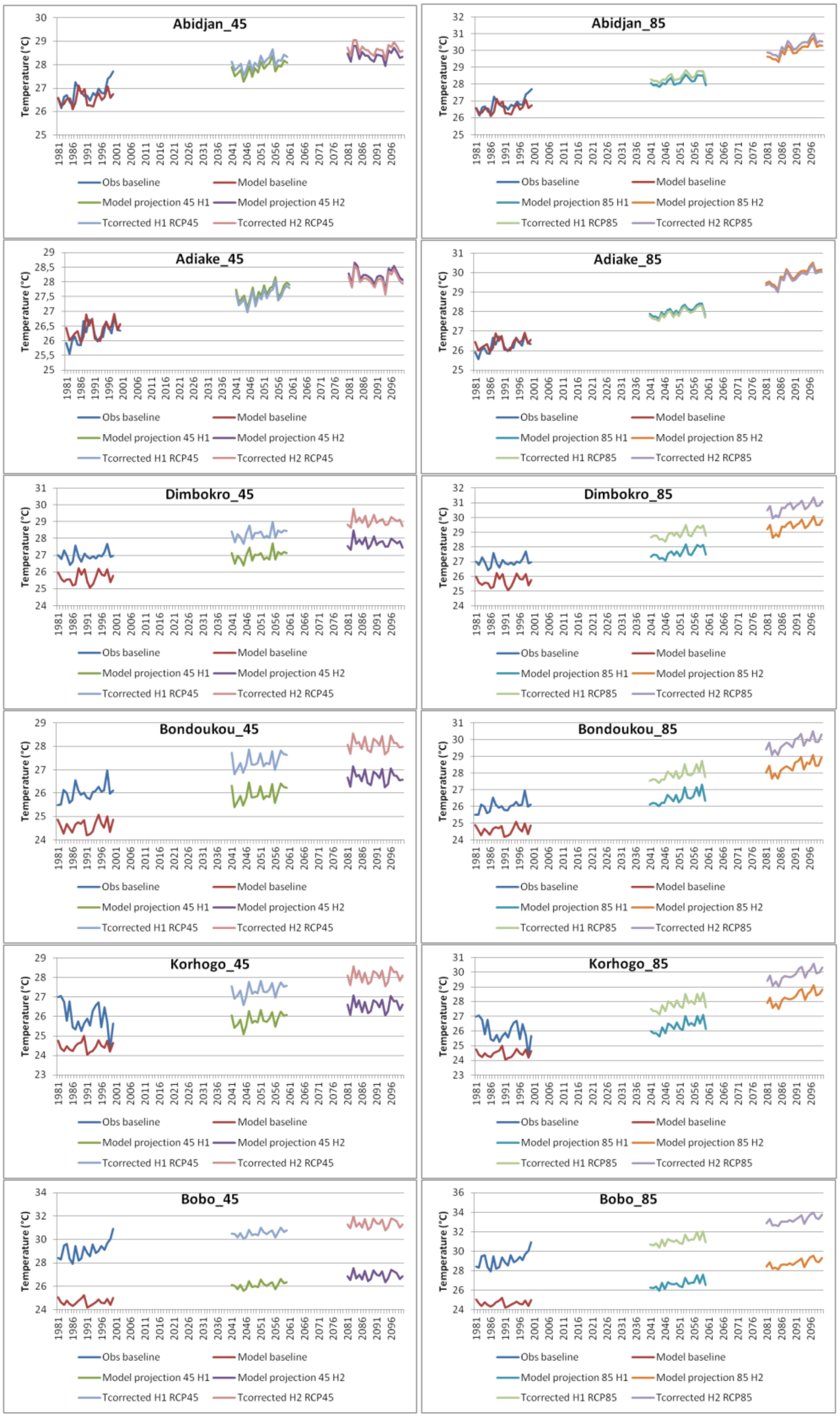


Figure 39: Bias correct model projection at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and Bobo Dioulasso for SMHI-RCA4

6.2.3. Average monthly temperature changes

Comparison between average monthly temperatures simulated by RCM for 2041-2060, 2081-2100 periods and observed temperature for baseline period 1981-2000 was done in this study. Table 14, Table 15, Table 16, Table 17, Table 18 and Table 19 show changes for the RCP4.5 and RCP8.5 scenarios and for the three RCM at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and Bobo Dioulasso. All scenarii and all models reveal an increase of temperature up to 5.6°C for 2041-2060 and 2081-2100 periods. Also, temperatures for 2081-2100 period are more important than the ones of 2041-2060 period. High values are generally observed in January.

Table 14: Average monthly temperature changes for RCP 4.5 and 8.5 at Abidjan

	Temperature change for CLMcom-CCLM4-8-17 (°C)				Temperature change for KNMI-RACMO22T (°C)				Temperature change for SMHI-RCA4 (°C)			
	2041-2060		**2081-2100**		**2041-2060**		**2081-2100**		**2041-2060**		**2081-2100**	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
January	1.5	2.2	2.1	4.8	1.6	2.0	1.8	3.8	1.6	1.9	2.2	4.1
February	1.4	1.9	1.9	4.3	1.4	1.8	1.8	3.5	1.2	1.4	1.8	3.5
March	1.3	1.9	1.8	4.1	1.3	1.8	1.8	3.5	1.1	1.7	2.0	3.5
April	1.4	2.4	2.4	4.6	1.3	1.6	1.7	3.3	1.2	1.6	1.7	3.1
May	1.5	2.0	2.4	4.3	1.3	1.9	1.8	3.6	1.2	1.5	1.8	3.2
June	1.3	1.8	1.7	3.9	1.4	1.8	1.8	3.6	1.3	1.3	1.7	3.2
July	1.3	1.8	1.6	3.6	1.4	1.7	1.9	3.6	1.1	1.5	1.8	3.1
August	1.2	1.6	1.5	3.4	1.4	1.7	1.8	3.5	1.2	1.4	1.5	3.1
September	1.1	1.5	1.4	3.3	1.4	1.8	1.7	3.4	1.2	1.6	1.8	3.2
October	1.1	1.6	1.6	3.4	1.4	1.7	1.8	3.5	1.3	1.8	2.0	3.6
November	1.3	1.8	1.7	3.7	1.4	1.7	1.7	3.6	1.6	1.9	2.2	3.6
December	1.4	2.0	2.1	4.1	1.4	1.8	1.8	3.6	1.3	1.8	1.9	4.2
Annual	**1.3**	**1.9**	**1.8**	**4.0**	**1.4**	**1.8**	**1.8**	**3.5**	**1.3**	**1.6**	**1.9**	**3.5**

Table 15: Average monthly temperature changes for RCP 4.5 and 8.5 at Adiake

	Temperature change for CLMcom-CCLM4-8-17 (°C)				**Temperature change for KNMI-RACMO22T (°C)**				**Temperature change for SMHI-RCA4 (°C)**			
	2041-2060		**2081-2100**		**2041-2060**		**2081-2100**		**2041-2060**		**2081-2100**	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
January	1.6	2.3	2.2	4.9	-0.4	0.1	0.0	1.9	1.6	2.0	2.2	4.2
February	1.6	2.0	1.9	4.4	-1.5	-1.1	-1.1	0.6	1.2	1.5	1.7	3.6
March	1.2	2.0	1.8	4.0	-3.6	-3.2	-3.2	-1.5	1.2	1.8	2.0	3.6
April	1.5	2.5	2.5	4.6	-2.8	-2.5	-2.4	-0.7	1.2	1.7	1.7	3.1
May	1.5	2.0	2.4	4.3	-0.8	-0.3	-0.4	1.4	1.2	1.7	1.8	3.2
June	1.3	1.8	1.7	3.9	0.5	0.8	0.9	2.6	1.3	1.4	1.7	3.2
July	1.3	1.8	1.6	3.6	0.6	0.9	1.1	2.8	1.1	1.5	1.7	3.1
August	1.2	1.6	1.5	3.4	0.5	0.9	1.0	2.6	1.2	1.4	1.5	3.1
September	1.1	1.5	1.4	3.3	0.4	0.8	0.8	2.4	1.2	1.6	1.8	3.2
October	1.1	1.6	1.6	3.4	0.1	0.4	0.5	2.2	1.2	1.8	1.9	3.6
November	1.4	1.8	1.7	3.7	-0.5	-0.2	-0.1	1.7	1.6	2.0	2.3	3.7
December	1.4	2.1	2.1	4.2	-0.6	-0.2	-0.1	1.6	1.4	1.9	2.0	4.3
Annual	**1.3**	**1.9**	**1.9**	**4.0**	**-0.7**	**-0.3**	**-0.3**	**1.5**	**1.3**	**1.7**	**1.9**	**3.5**

Table 16: Average monthly temperature changes for RCP 4.5 and 8.5 at Bobo Dioulasso

	Temperature change for CLMcom-CCLM4-8-17 (°C)				**Temperature change for KNMI-RACMO22T (°C)**				**Temperature change for SMHI-RCA4 (°C)**			
	2041-2060		**2081-2100**		**2041-2060**		**2081-2100**		**2041-2060**		**2081-2100**	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
January	-2.9	-2.3	-2.5	0.4	1.9	2.7	3.1	5.2	1.9	2.7	3.1	5.2
February	-0.9	-0.6	-0.5	2.4	1.3	1.8	2.1	4.0	1.3	1.8	2.1	4.0
March	2.4	2.6	3.5	6.4	1.8	2.6	2.4	4.9	1.8	2.6	2.4	4.9
April	6.1	6.9	7.3	10.6	1.3	2.0	2.1	3.8	1.3	2.0	2.1	3.8
May	6.6	7.4	7.7	11.4	1.2	1.8	2.2	3.8	1.2	1.8	2.2	3.8
June	3.6	4.9	4.8	9.2	1.3	1.6	2.3	3.4	1.3	1.6	2.3	3.4
July	1.5	2.2	2.1	5.3	1.2	1.5	2.0	3.2	1.2	1.5	2.0	3.2
August	0.6	1.1	1.1	3.5	1.2	1.4	1.6	3.0	1.2	1.4	1.6	3.0
September	1.0	1.5	1.3	3.8	1.2	1.5	1.8	3.1	1.2	1.5	1.8	3.1
October	1.7	2.2	2.4	5.2	1.7	2.2	2.4	4.2	1.7	2.2	2.4	4.2
November	1.0	1.3	1.4	5.3	1.9	2.4	2.9	5.2	1.9	2.4	2.9	5.2
December	-2.8	-2.4	-2.2	0.5	1.6	2.3	2.5	5.5	1.6	2.3	2.5	5.5
Annual	**1.5**	**2.1**	**2.2**	**5.3**	**1.5**	**2.0**	**2.3**	**4.1**	**1.5**	**2.0**	**2.3**	**4.1**

Table 17: Average monthly temperature changes for RCP 4.5 and 8.5 at Bondoukou

	Temperature change for CLMcom-CCLM4-8-17 (°C)				Temperature change for KNMI-RACMO22T (°C)				Temperature change for SMHI-RCA4 (°C)			
	2041-2060		**2081-2100**		**2041-2060**		**2081-2100**		**2041-2060**		**2081-2100**	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
January	2.7	3.3	2.9	6.5	1.7	2.5	2.9	4.7	1.7	2.5	2.9	4.7
February	2.1	2.5	2.3	5.7	1.6	1.9	2.1	4.2	1.6	1.9	2.1	4.2
March	1.8	2.4	2.6	5.3	1.7	2.5	2.4	4.3	1.7	2.5	2.4	4.3
April	1.6	2.6	2.8	5.4	1.1	1.6	1.7	3.3	1.1	1.6	1.7	3.3
May	2.2	2.8	3.4	6.2	1.1	1.8	1.9	3.4	1.1	1.8	1.9	3.4
June	1.8	2.8	2.6	5.8	1.2	1.5	1.8	3.3	1.2	1.5	1.8	3.3
July	1.6	2.2	2.0	4.5	1.2	1.5	1.8	3.1	1.2	1.5	1.8	3.1
August	1.3	1.8	1.8	4.0	1.1	1.4	1.6	3.0	1.1	1.4	1.6	3.0
September	1.3	1.7	1.6	4.0	1.2	1.5	1.7	3.1	1.2	1.5	1.7	3.1
October	1.4	2.0	2.0	4.3	1.4	1.8	2.0	3.7	1.4	1.8	2.0	3.7
November	2.3	2.6	2.4	5.9	1.7	2.6	2.7	4.6	1.7	2.6	2.7	4.6
December	2.4	2.9	2.8	6.3	1.2	2.3	2.3	4.6	1.2	2.3	2.3	4.6
Annual	**1.9**	**2.5**	**2.4**	**5.3**	**1.4**	**1.9**	**2.1**	**3.8**	**1.4**	**1.9**	**2.1**	**3.8**

Table 18: Average monthly temperature changes for RCP 4.5 and 8.5 at Dimbokro

	Temperature change for CLMcom-CCLM4-8-17 (°C)				**Temperature change for KNMI-RACMO22T (°C)**				**Temperature change for SMHI-RCA4 (°C)**			
	2041-2060		**2081-2100**		**2041-2060**		**2081-2100**		**2041-2060**		**2081-2100**	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
January	2.3	2.8	2.7	6.1	2.1	3.2	3.2	5.2	2.1	3.2	3.2	5.2
February	1.9	2.3	2.1	5.2	1.4	2.0	1.8	3.9	1.4	2.0	1.8	3.9
March	1.4	2.1	2.2	4.5	1.4	2.4	2.5	4.2	1.4	2.4	2.5	4.2
April	1.5	2.6	2.8	5.3	1.1	1.7	1.7	3.4	1.1	1.7	1.7	3.4
May	1.7	2.1	3.0	5.5	1.1	1.7	1.9	3.3	1.1	1.7	1.9	3.3
June	1.5	2.1	2.0	4.7	1.2	1.5	1.7	3.3	1.2	1.5	1.7	3.3
July	1.3	1.8	1.7	3.7	1.1	1.5	1.8	3.1	1.1	1.5	1.8	3.1
August	1.2	1.5	1.6	3.6	1.1	1.4	1.5	3.0	1.1	1.4	1.5	3.0
September	1.1	1.5	1.4	3.5	1.2	1.6	1.8	3.1	1.2	1.6	1.8	3.1
October	1.2	1.7	1.8	3.8	1.2	1.7	1.9	3.4	1.2	1.7	1.9	3.4
November	1.7	1.9	1.9	4.7	1.5	2.4	2.7	4.1	1.5	2.4	2.7	4.1
December	2.0	2.5	2.6	5.8	1.1	2.3	2.4	5.1	1.1	2.3	2.4	5.1
Annual	**1.6**	**2.1**	**2.1**	**4.7**	**1.3**	**1.9**	**2.1**	**3.8**	**1.3**	**1.9**	**2.1**	**3.8**

Table 19: Average monthly temperature changes for RCP 4.5 and 8.5 at Korhogo

	Temperature change for CLMcom-CCLM4-8-17 (°C)				**Temperature change for KNMI-RACMO22T (°C)**				**Temperature change for SMHI-RCA4 (°C)**			
	2041-2060		**2081-2100**		**2041-2060**		**2081-2100**		**2041-2060**		**2081-2100**	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
January	2.9	3.5	3.2	6.5	1.7	2.5	2.9	4.9	1.7	2.5	2.9	4.9
February	1.9	2.2	2.1	5.1	1.5	2.0	2.0	4.2	1.5	2.0	2.0	4.2
March	1.7	2.0	2.6	5.2	1.6	2.2	2.1	4.3	1.6	2.2	2.1	4.3
April	2.0	2.8	3.2	6.2	1.2	1.5	1.8	3.3	1.2	1.5	1.8	3.3
May	2.7	3.5	3.8	7.4	0.9	1.6	1.9	3.5	0.9	1.6	1.9	3.5
June	2.0	3.1	2.7	6.7	1.2	1.5	2.0	3.3	1.2	1.5	2.0	3.3
July	1.7	2.4	2.1	4.7	1.1	1.5	1.8	3.0	1.1	1.5	1.8	3.0
August	1.4	1.8	1.8	4.0	1.1	1.3	1.5	2.9	1.1	1.3	1.5	2.9
September	1.3	1.9	1.8	4.1	1.2	1.5	1.7	3.1	1.2	1.5	1.7	3.1
October	1.6	2.1	2.2	4.6	1.4	1.9	2.1	3.8	1.4	1.9	2.1	3.8
November	2.6	3.0	2.9	6.6	1.8	2.4	2.9	4.9	1.8	2.4	2.9	4.9
December	2.7	3.2	3.2	6.4	1.5	2.3	2.4	4.9	1.5	2.3	2.4	4.9
Annual	**2.1**	**2.6**	**2.6**	**5.6**	**1.4**	**1.9**	**2.1**	**3.8**	**1.4**	**1.9**	**2.1**	**3.8**

6.2.4. Linear correlations for temperatures

5.2.4.1. CLMcom-CCLM4-8-17 model

Figure 40, Figure 41, Figure 42, Figure 43, Figure 44 and Figure 45 show the linear correlations between monthly observed (1981-2000) and corrected temperature (2041-2060 and 2081-2100) at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and BoboDioulasso for CLMcom-CCLM4-8-17. The linear correlation is good both for the two horizons (2041-2060 and 2081-2100) and for the two scenarii. For all the stations, R^2 values are around 0.9 excepted for Korhogo where are below 0.5.

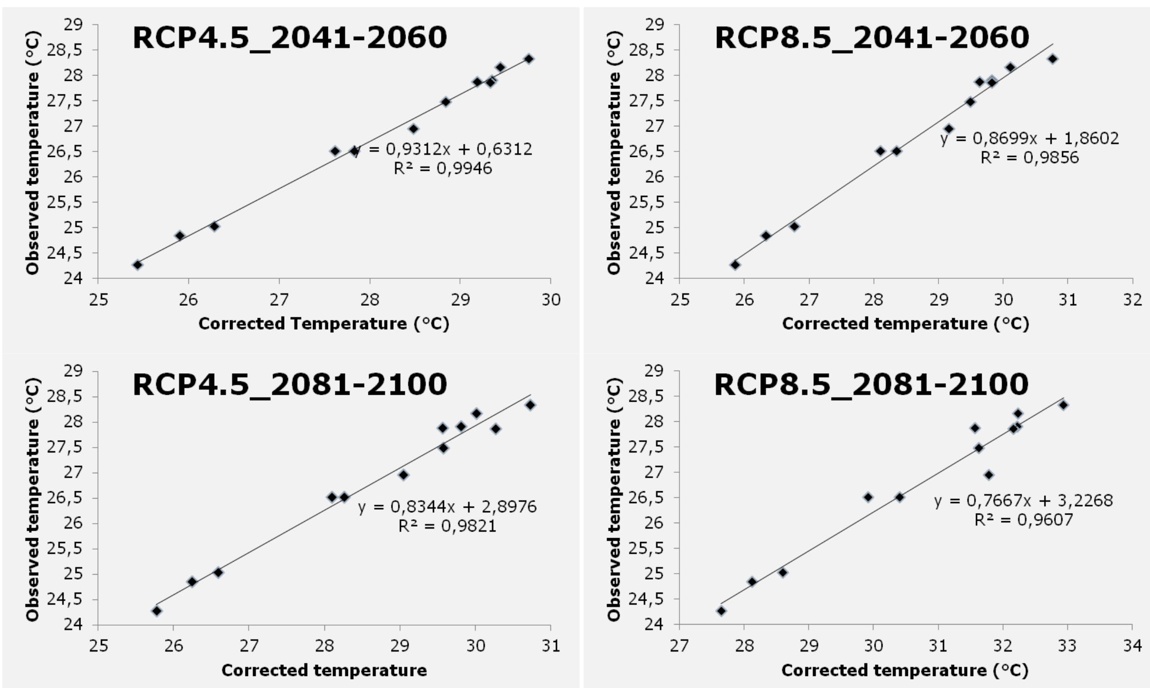


Figure 40: Linear correlation between monthly observed and corrected temperature at **Abidjan** for CLMcom-CCLM4-8-17

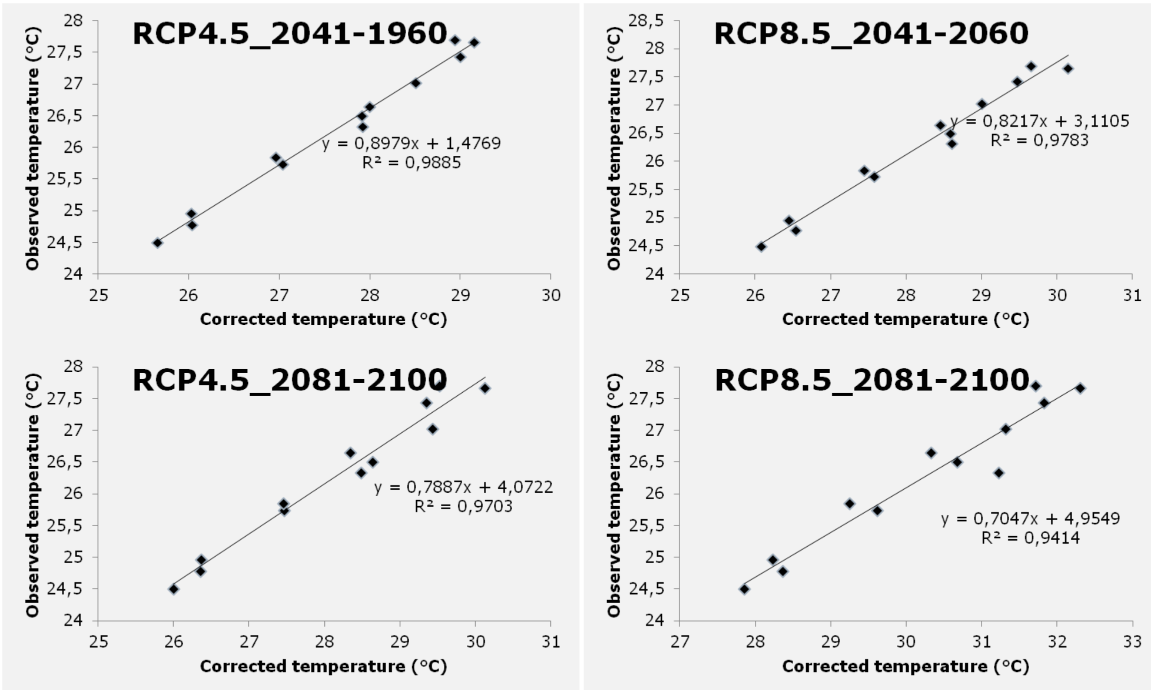


Figure 41: Linear correlation between monthly observed and corrected temperature at **Adiake** for CLMcom-CCLM4-8-17

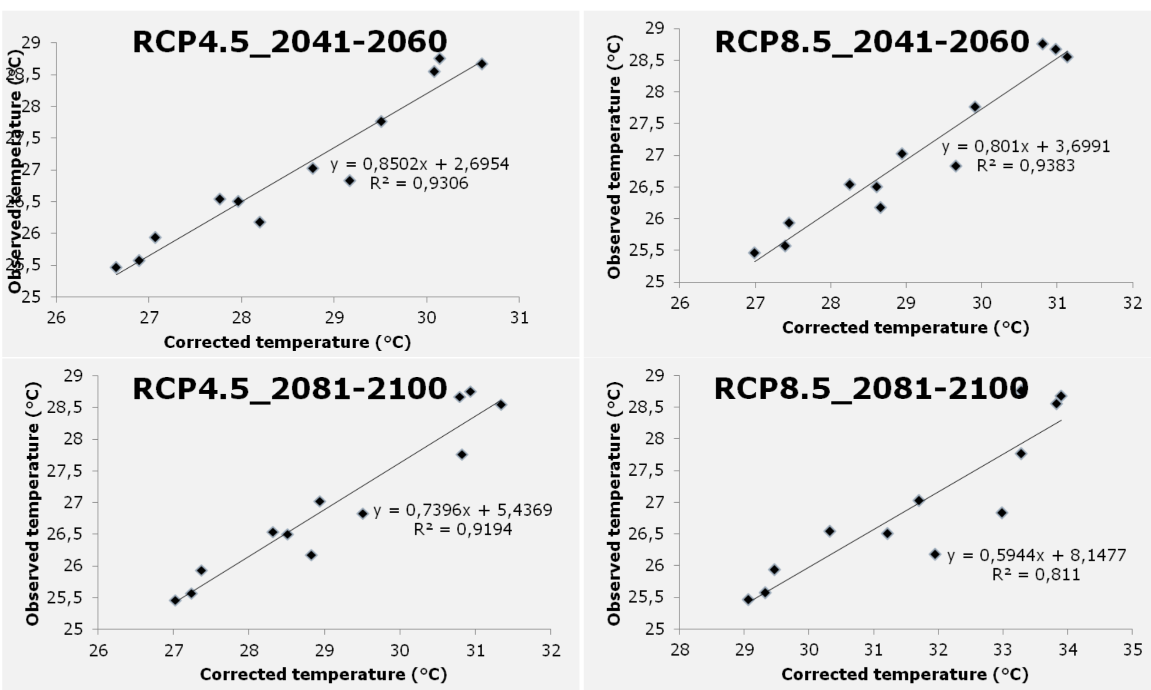


Figure 42: Linear correlation between monthly observed and corrected temperature at **Dimbokro** for CLMcom-CCLM4-8-17

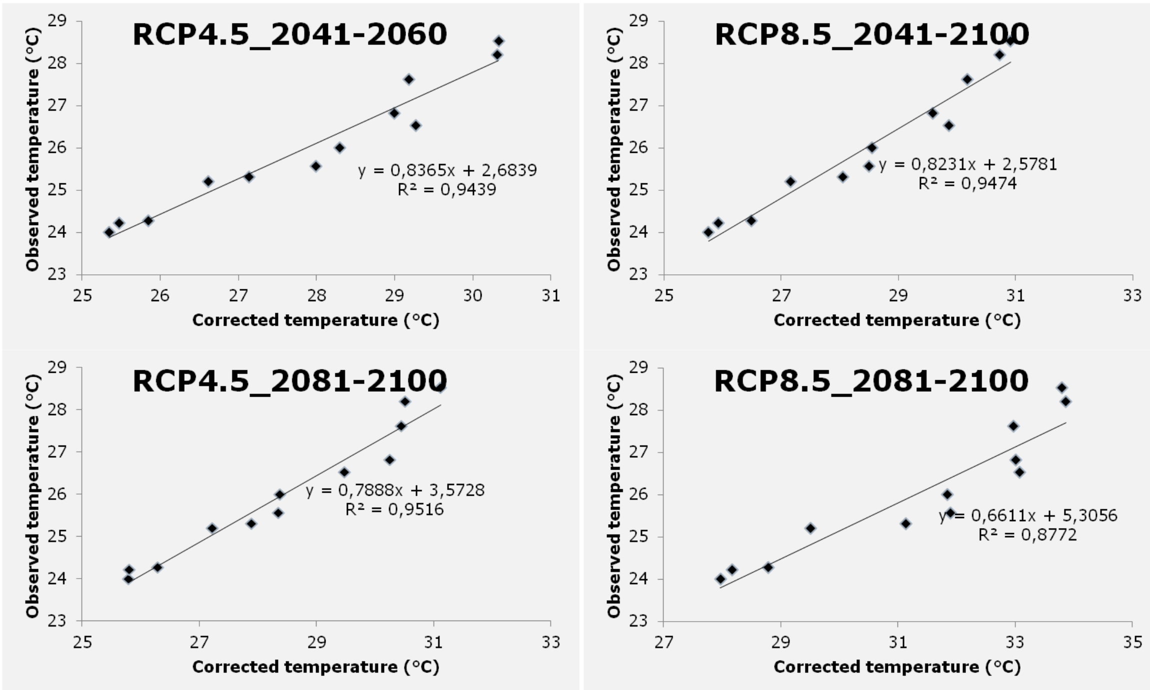


Figure 43: Linear correlation between monthly observed and corrected temperature at **Bondoukou** for CLMcom-CCLM4-8-17

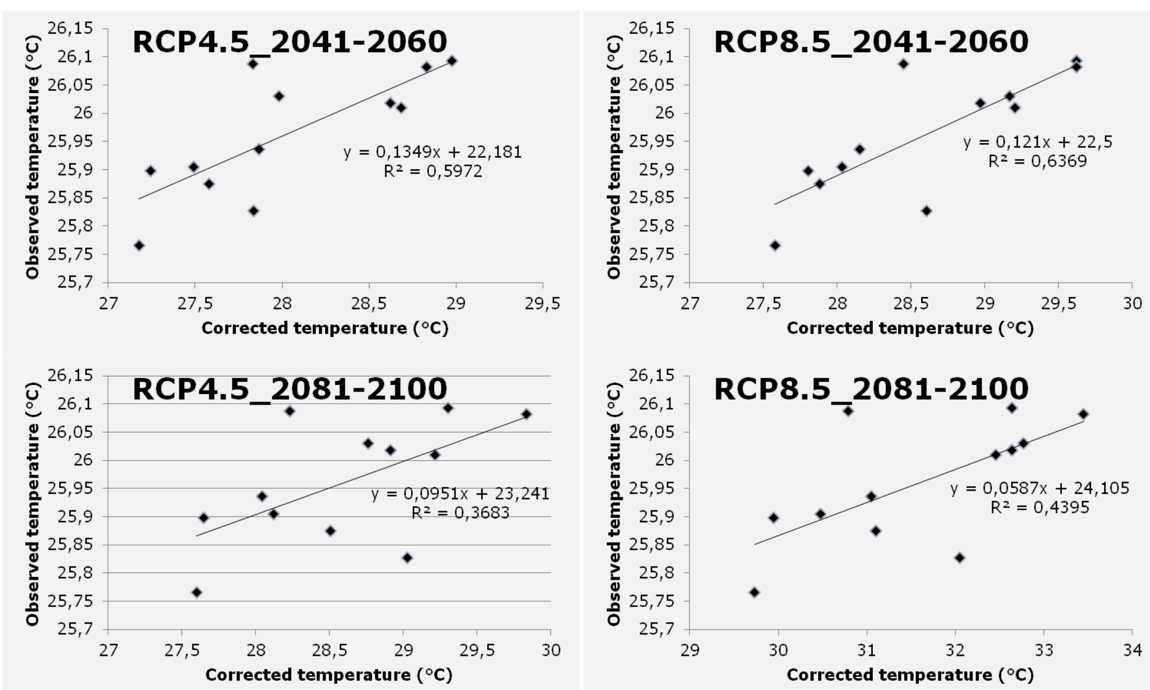


Figure 44: Linear correlation between monthly observed and corrected temperature at **Korhogo** for CLMcom-CCLM4-8-17

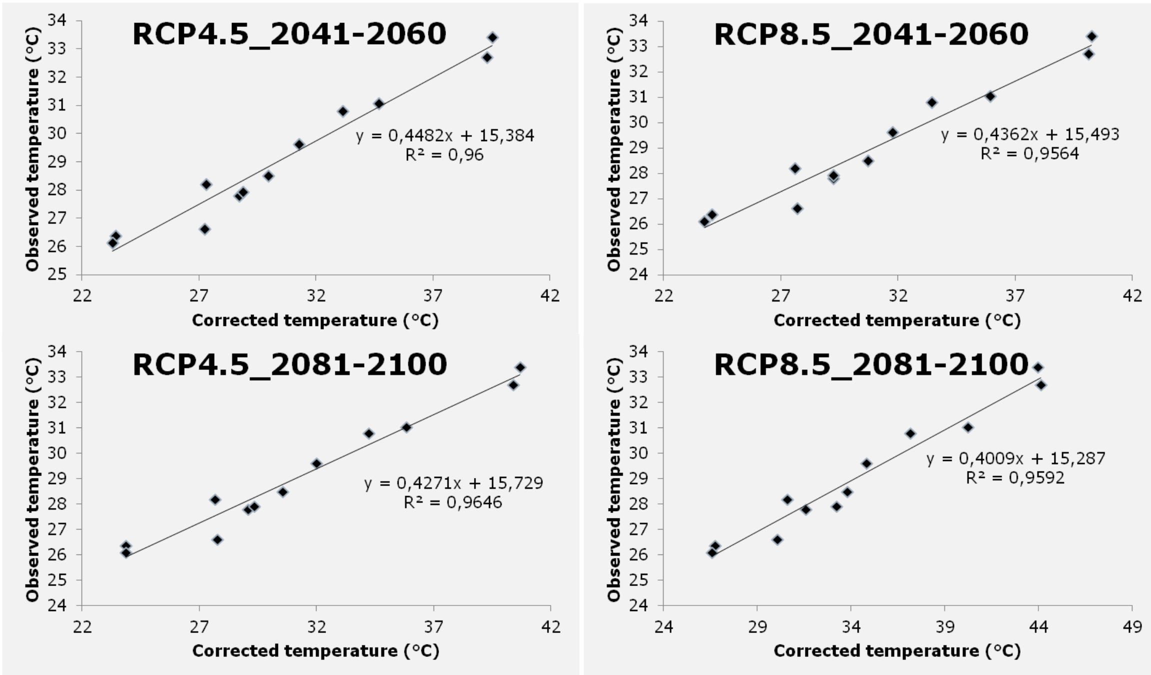


Figure 45: Linear correlation between monthly observed and corrected temperature at **Bobo Dioulasso** for CLMcom-CCLM4-8-17

5.2.4.2. KNMI-RACMO22T model

Figure 46, Figure 47, Figure 48 and Figure 49 show the linear correlations between monthly observed and corrected temperature at Abidjan, Dimbokro, Bondoukou and BoboDioulasso for KNMI-RACMO22T model. The linear correlation is good both for the two horizons (2041-2060 and 2081-2100) and for the two scenarios. For all the stations, R^2 values are around 0.8.

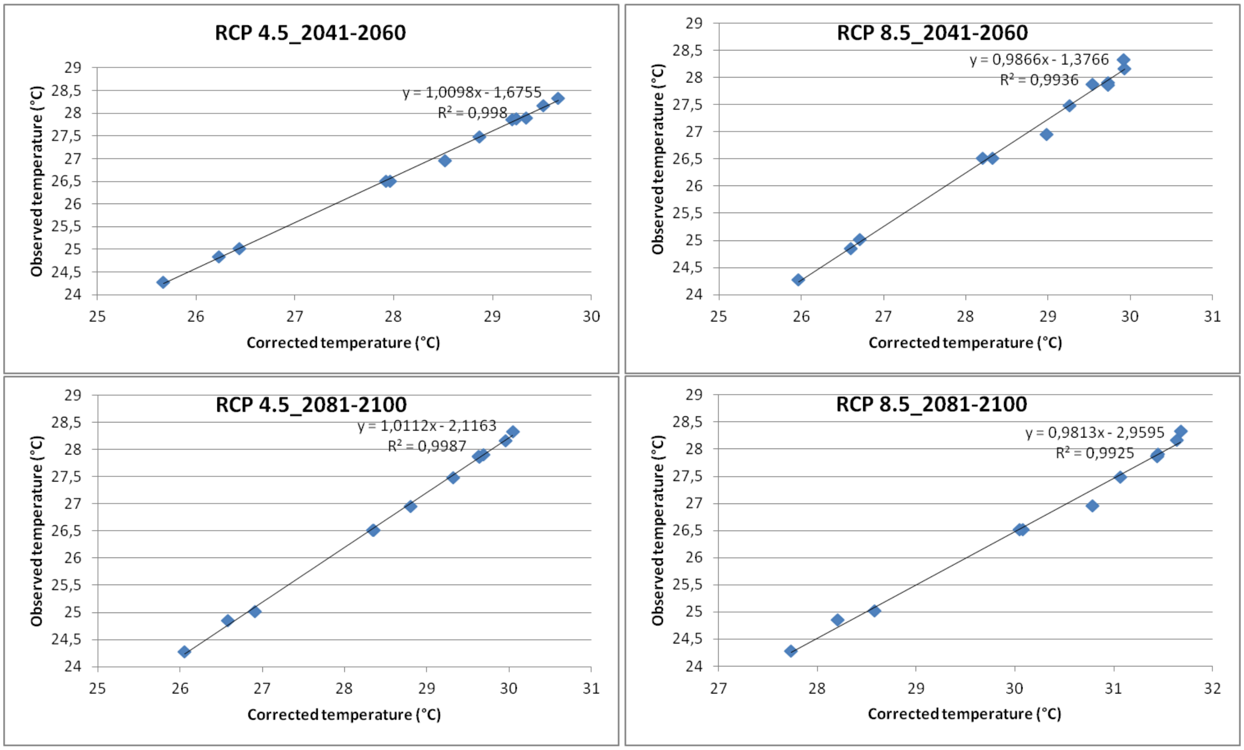


Figure 46: Linear correlation between monthly observed and corrected temperature at **Abidjan** for KNMI-RACMO22T

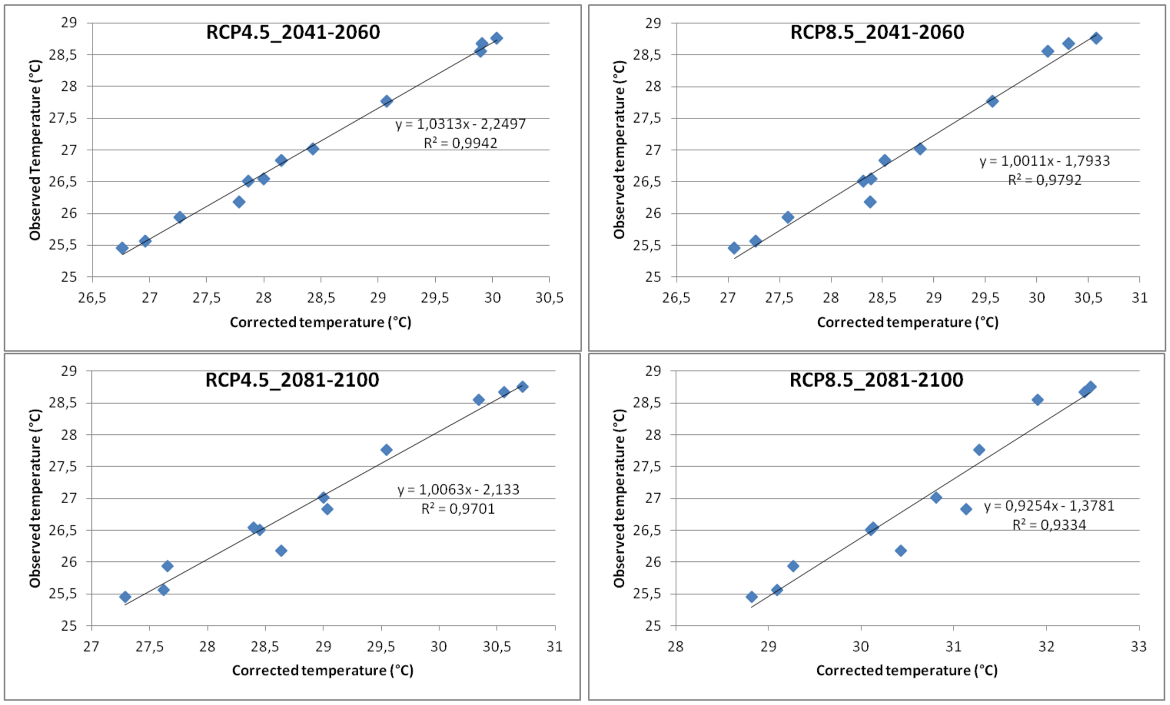


Figure 47: Linear correlation between monthly observed and corrected temperature at **Dimbokro** for KNMI-RACMO22T

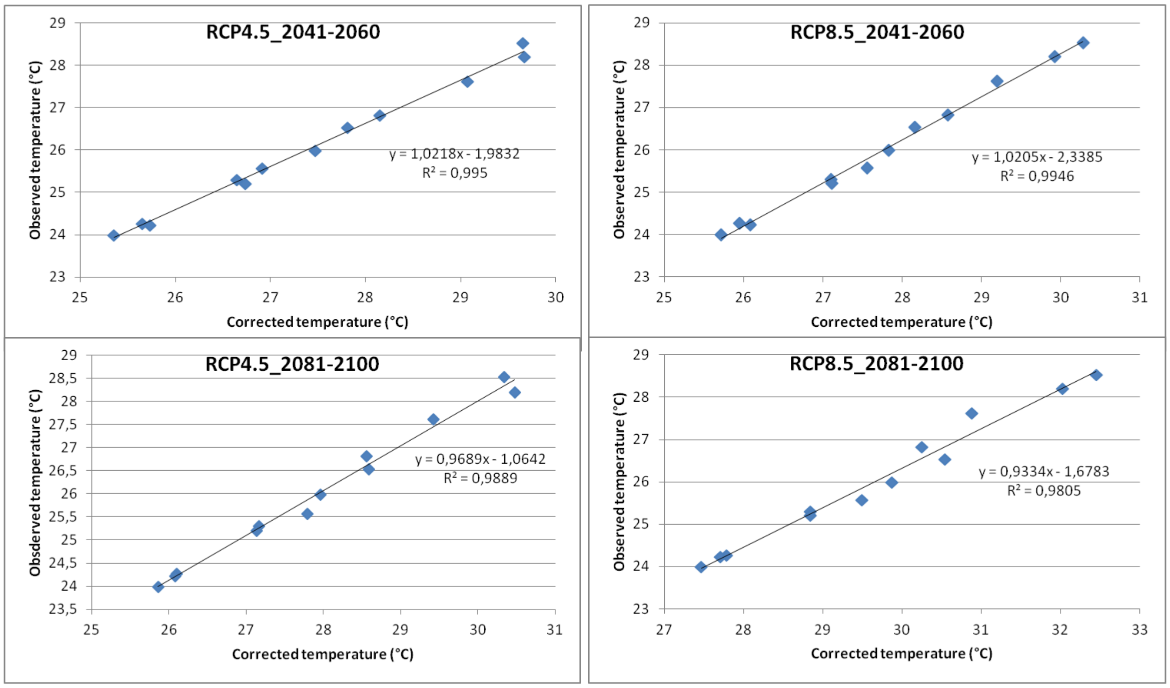


Figure 48: Linear correlation between monthly observed and corrected temperature at **Bondoukou** for KNMI-RACMO22T

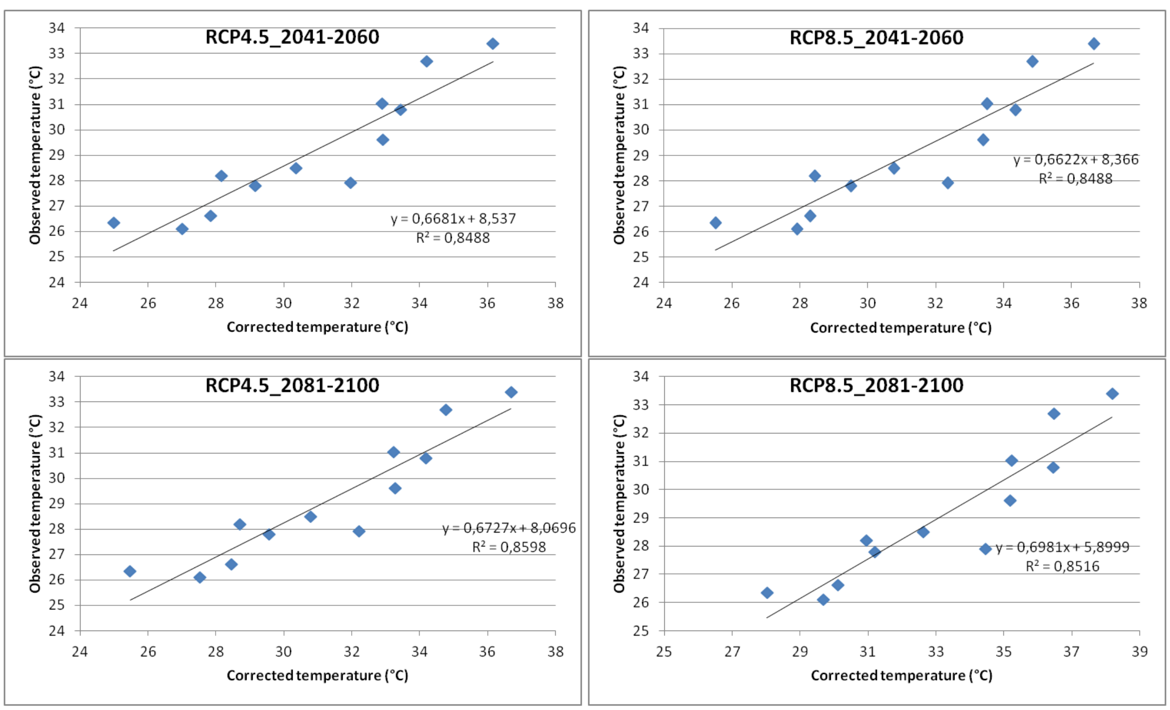


Figure 49: Linear correlation between monthly observed and corrected temperature at **Bobo Dioulasso** for KNMI-RACMO22T

5.2.4.3. SMHI-RCA4 model

Figure 50, Figure 51, Figure 52, Figure 53 and Figure 54 show the linear correlations between monthly observed and corrected temperature at Abidjan, Adiake, Dimbokro, Bondoukou, Korhogo and BoboDioulasso for SMHI-RCA4 model. The linear correlation is good both for the two horizons (2041-2060 and 2081-2100) and for the two scenarios. For all the stations, R^2 values are around 0.9 excepted for Korhogo where are below 0.5.

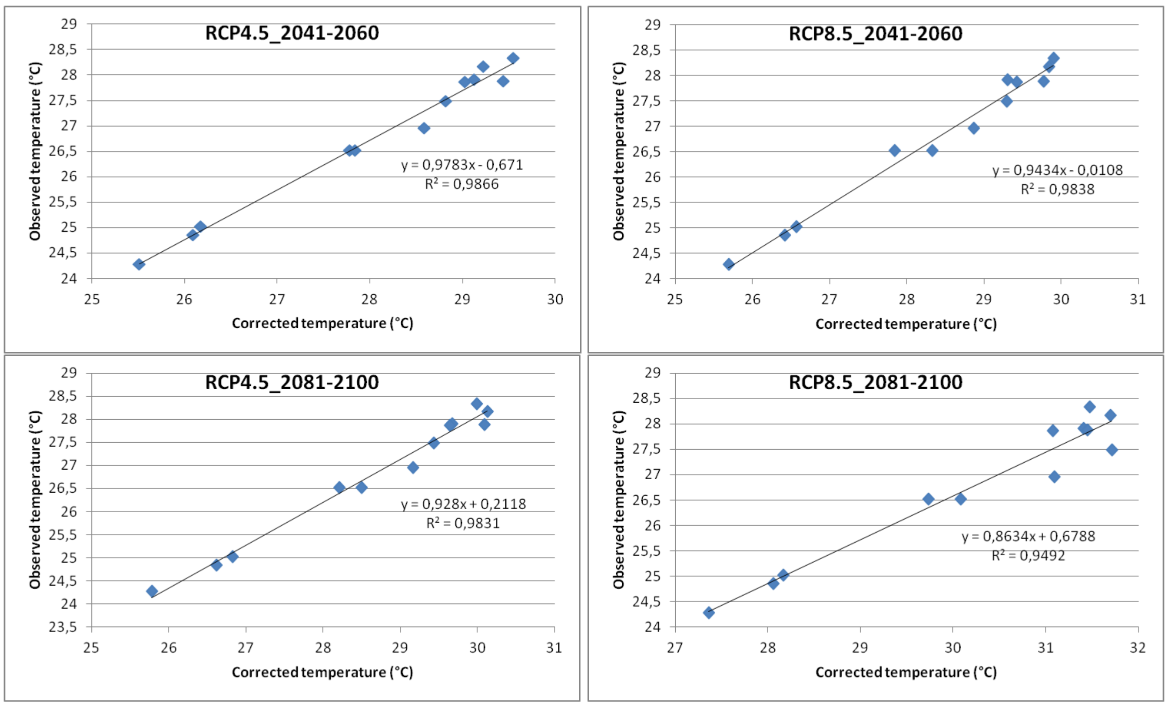


Figure 50: Linear correlation between monthly observed and corrected temperature at **Abidjan** for SMHI-RCA4

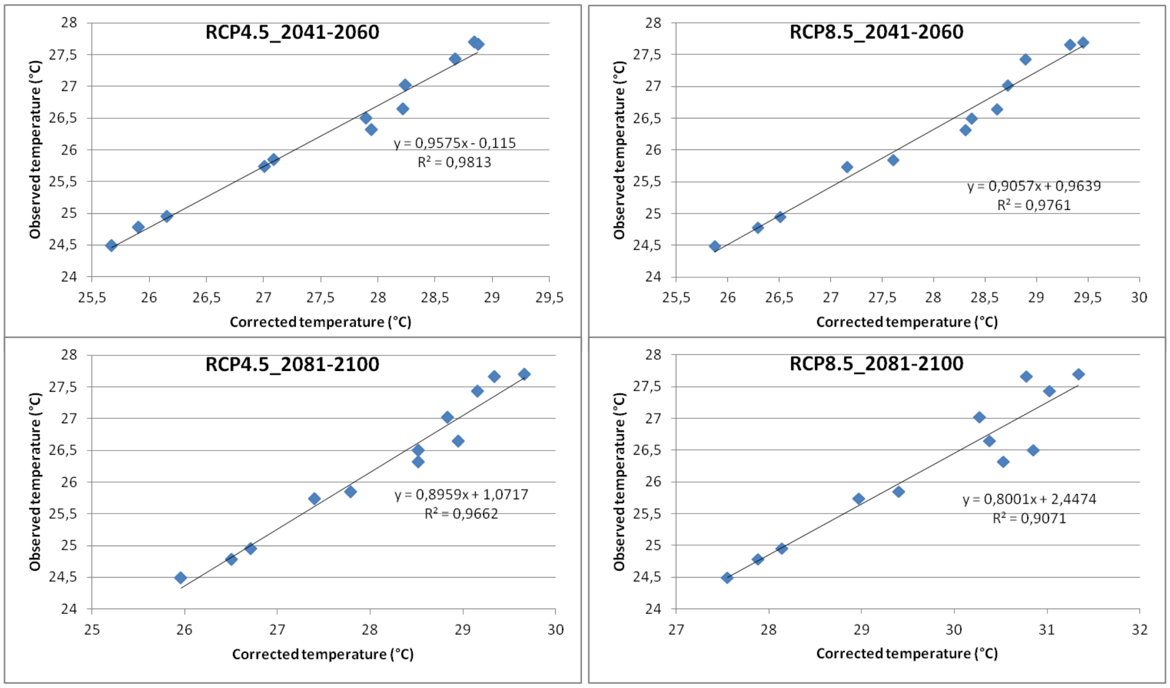


Figure 51: Linear correlation between monthly observed and corrected temperature at **Adiake** for SMHI-RCA4

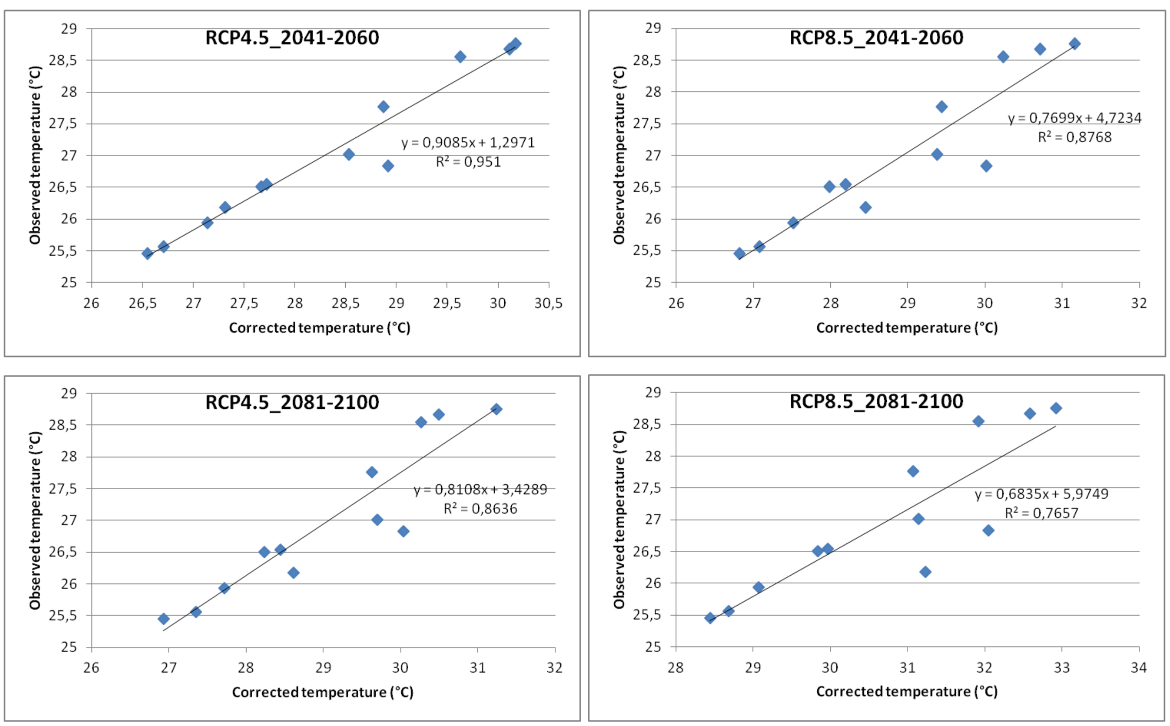


Figure 52: Linear correlation between monthly observed and corrected temperature at **Dimbokro** for SMHI-RCA4

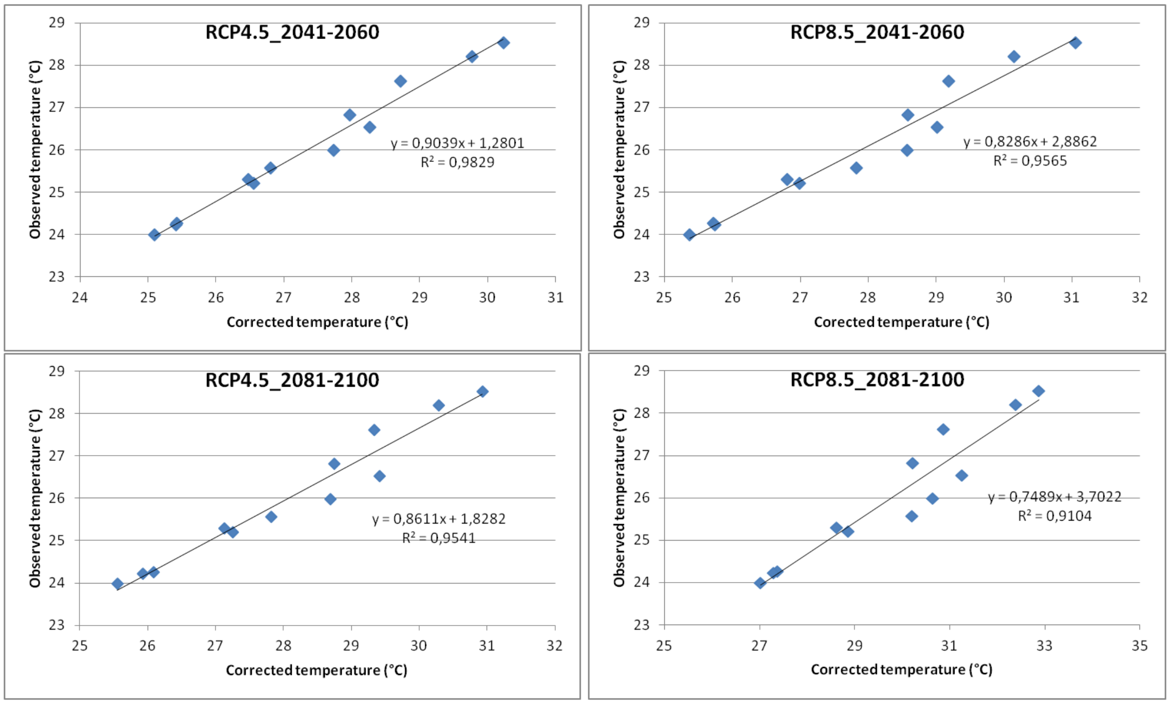


Figure 53: Linear correlation between monthly observed and corrected temperature at **Bondoukou** for SMHI-RCA4

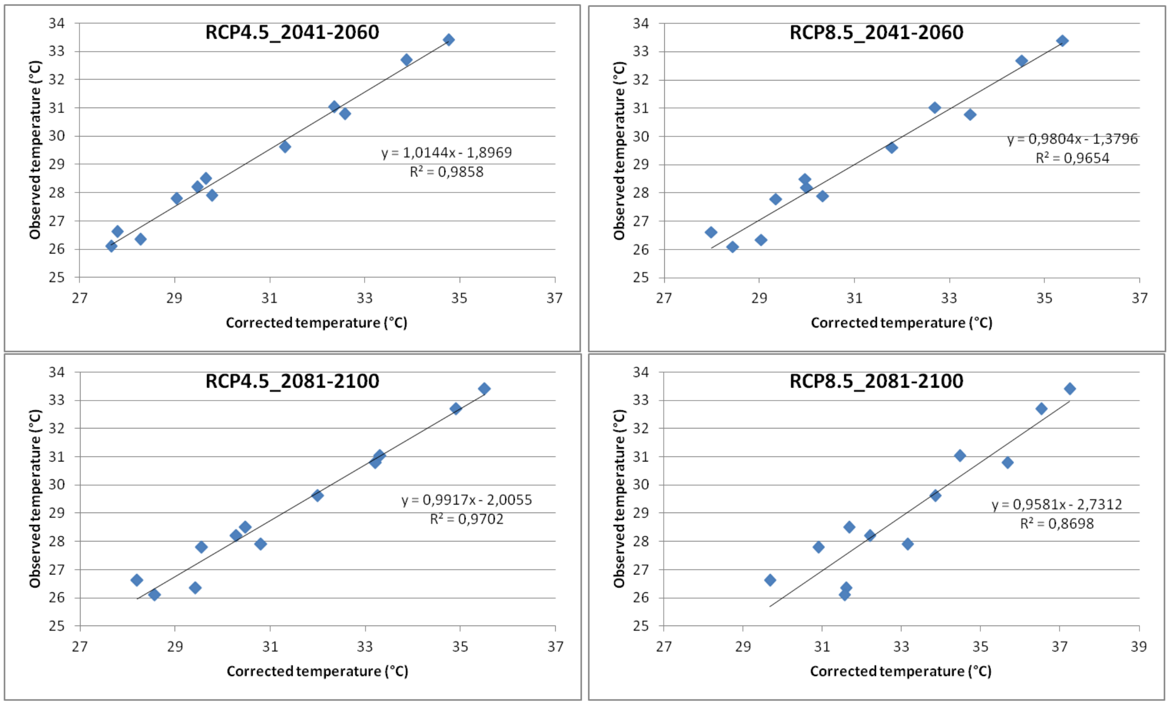


Figure 54: Linear correlation between monthly observed and corrected temperature at **Bobo Dioulasso** for SMHI-RCA4

These results are in accordance with others in Africa and especially in West Africa. Many authors have projected Africa temperatures to rise faster during this century (Beniston et al., 2007), (Sanderson, Hemming, & Betts, 2011).

According to (Meehl et al., 2012); (Diallo, Sylla, Giorgi, Gaye, & Camara, 2012); (Fontaine, Roucou, & Monerie, 2011), the projections of temperature over West Africa using CMIP5 GCMs for RCP4.5 and RCP8.5 and regional downscaling (Wisser et al., 2010), (Roudier, Sultan, Quirion, & Berg, 2011), (Paeth et al., 2011) are indicating an increase from 3°C to 6°C by the end of this century.

In Cote d'Ivoire, medium changes in temperatures and rainfall will entail changes in various types of climate events and their probability of occurrence is known to a greater or lesser extent. Climate scenarios for Cote d'Ivoire have been generated using the Coupled Model Intercomparison Project Phase 5 (CMIP5) climate model. The various scenarios validated by the IPCC's Fifth Assessment Report (AR5), available on the Digital Atlas of Climate Change managed by Royal Netherlands Meteorological Institute (KNMI) show a temperature increase of 3°C by 2100 in most part of the country, from North to South. The RCP4.5 scenario shows a decline in rainfall about 8% during the April to July season.

For the Comoe River Basin, temperature projections for this century (2031-2040 and 2094-2100), Regional Climate Model version 3 is indicating a clear increase in monthly average temperature, about 0.62°C to 0.74°C for the period 2031-2040 and 3°C to 4.1°C for the period 2094-2100 (KOUAKOU, 2011).

6.3. Average monthly discharge evolution

Figure 55 shows average monthly discharge for 2041-2060 and 2081-2100 periods in comparison with the one of 1981-2000 period at M'Basso. Hydrologic patterns are conserved by only KNMI-RACMO22T model. Also, the three models result on low discharge values for 2041-2060 and 2081-2100 periods. High flow and low flow periods are quit the same for the three RCM.

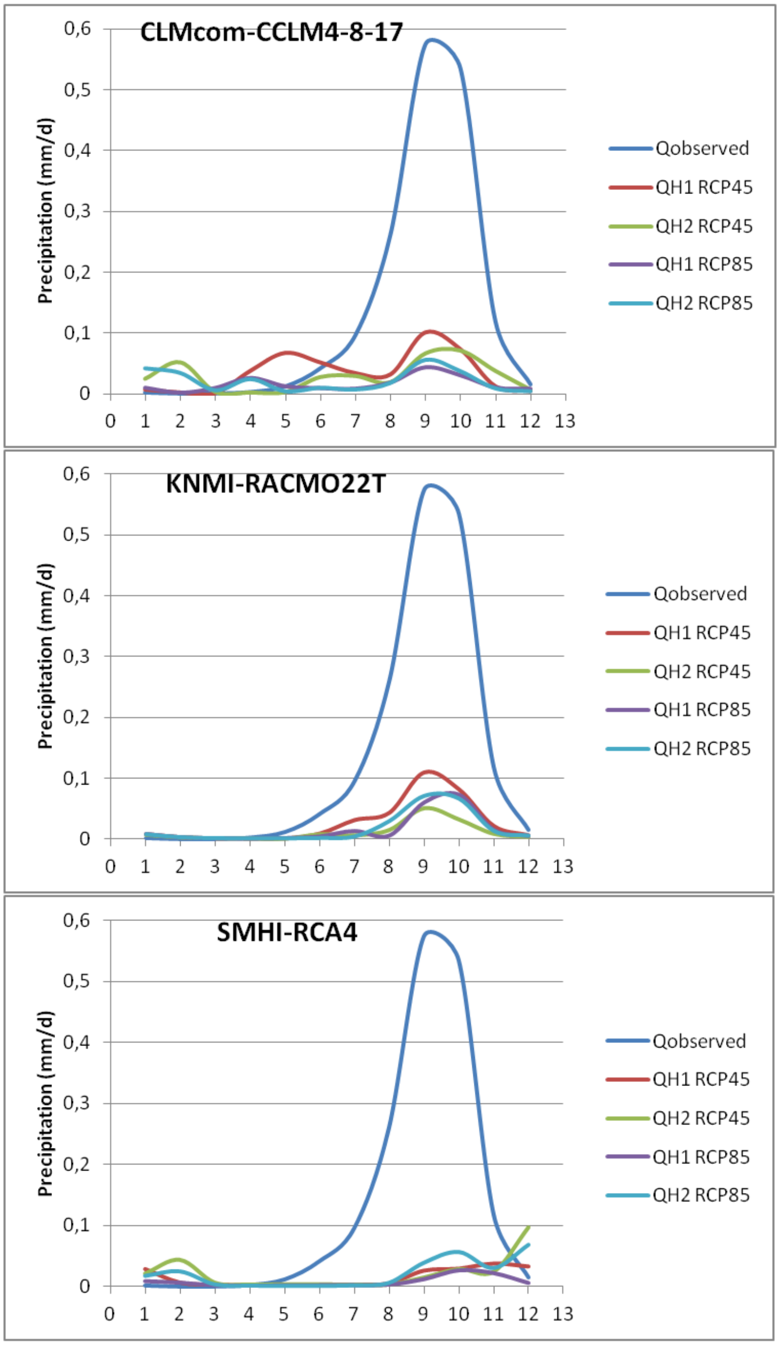


Figure 55: Monthly discharge change for 1981-2000, 2041-2060 and 2081-2100 periods at M'Basso

Figure 56 shows good linear correlations between monthly observed and simulated discharge at M'Basso for KNMI-RACMO22T model. R^2 values are above 0.87.

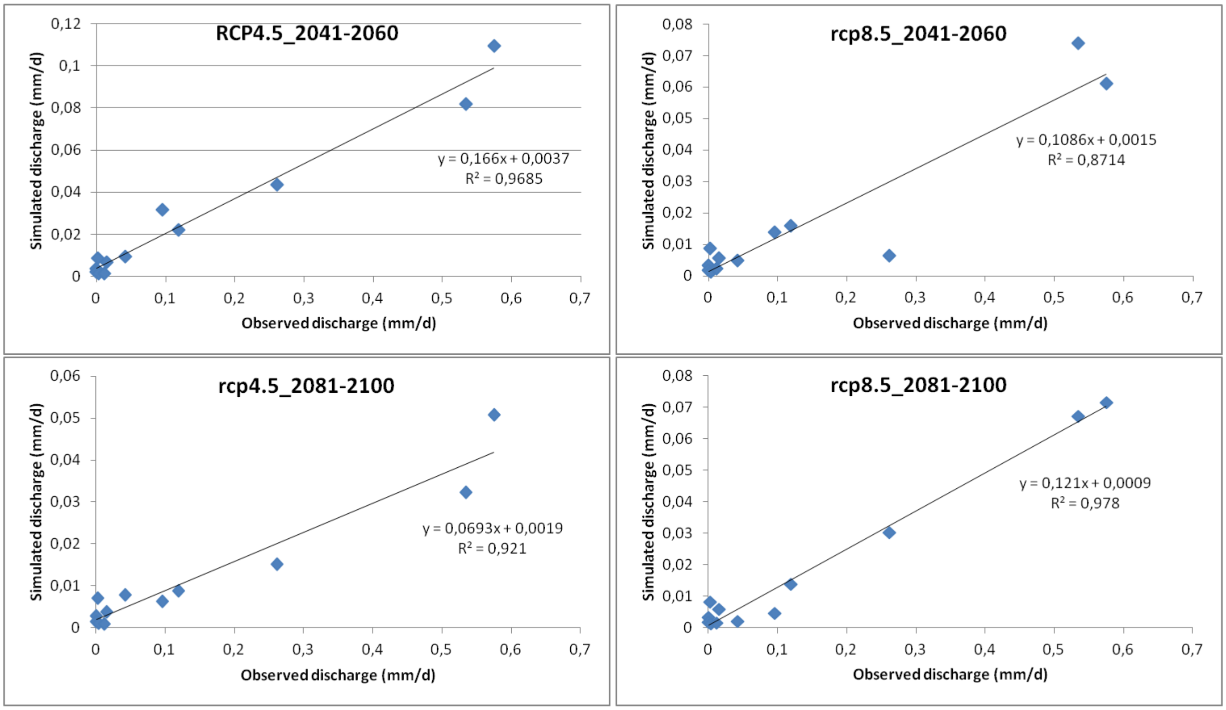


Figure 56: Linear correlation between monthly observed and simulated discharge at M'Basso for KNMI-RACMO22T

6.4. Average yearly discharge evolution

Mean yearly discharge for 2041-2060 and 2081-2100 periods was compared to 1981-2000 periods at M'Basso to determine deficit in flows. Table 20 reveals that flows will decrease respectively for 2041-2060 and 2081-2100 periods about 41% and 45% according to the scenario RCP 4.5 KNMI-RACMO22T model. The decrease of flows following RCP 8.5 for the same periods is about 46% and 44%.

Table 20: Mean yearly discharge change for 2041-2060 and 2081-2100 periods in comparison to 1981-2000 periods at M'Basso

RCM		**1981-2000**	**2041-2060**		**2081-2100**	
			Rcp 4.5	Rcp 8.5	Rcp 4.5	Rcp 8.5
CLMcom-CCLM4-8-17	Discharge(mm/d)	0.14	0.04	0.03	0.01	0.04
	Flow (mm)	50.8	13.2	10.3	4.9	14.4
	Deficit (mm)		**-37.6**	**-40.5**	**-45.9**	**-36.4**
KNMI-RACMO22T	Discharge(mm/d)	0.14	0.03	0.01	0.02	0.02
	Flow (mm)	50.8	9.8	4.2	6.1	6.5
	Deficit (mm)		**-41.0**	**-46.5**	**-44.7**	**-44.3**
SMHI-RCA4	Discharge(mm/d)	0.14	0.01	0.03	0.01	0.04
	Flow (mm)	50.8	5.4	10.5	2.9	15.8
	Deficit (mm)		**-45.4**	**-40.3**	**-47.8**	**-34.9**

Interannual variability of yearly discharge for 2041-2060 and 2081-2100 periods was compared to 1981-2000 periods at M'Basso. Figure 57 reveals clear decrease of flows for 2041-2060 and 2081-2100 with the three RCM.

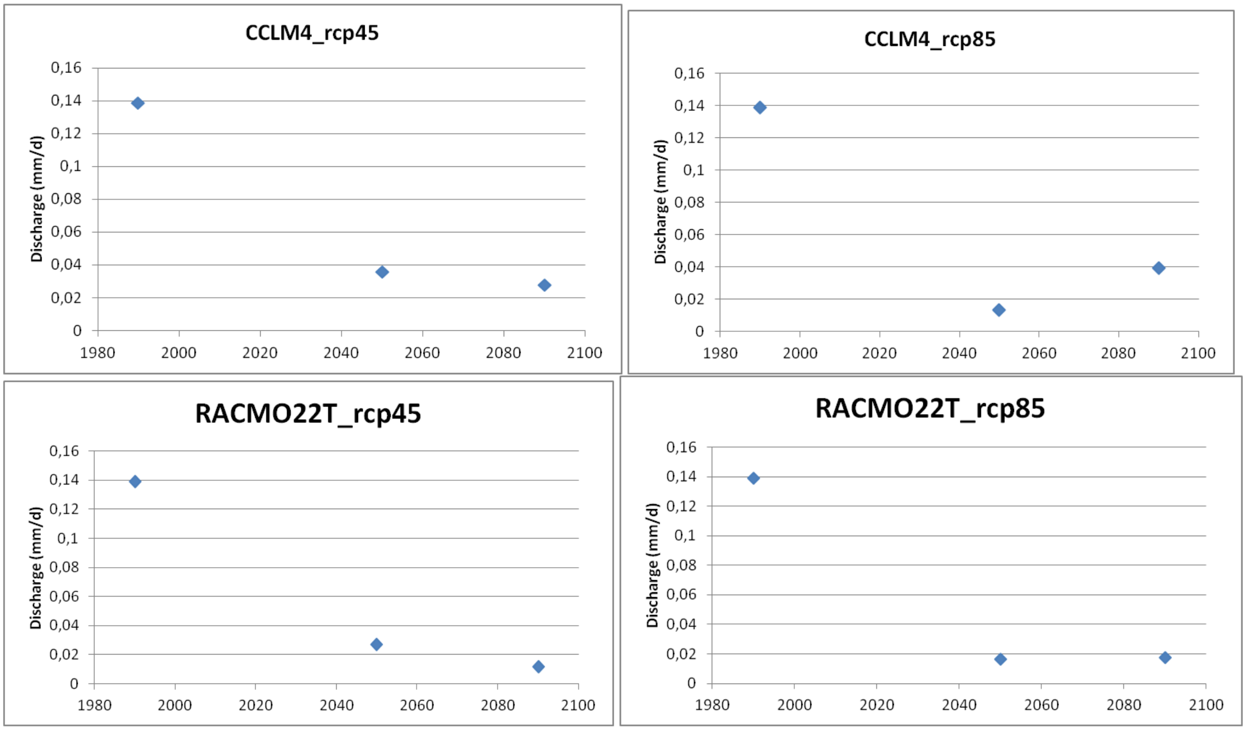


Figure 57: Interannual variability of yearly discharge for 2041-2060 and 2081-2100 periods was compared to 1981-2000 periods at M'Basso

6.5. Hydrologic and climatic parameters changes

Hydrologic and climatic parameters for 1981-2000, 2041-2060 and 2081-2100 periods were compared at M'Basso. Figure 58 reveals an increase of potential evopotranspiration for the two horizons and for the three RCM. Also, precipitations and potential evopotranspiration are important than discharge which is very low.

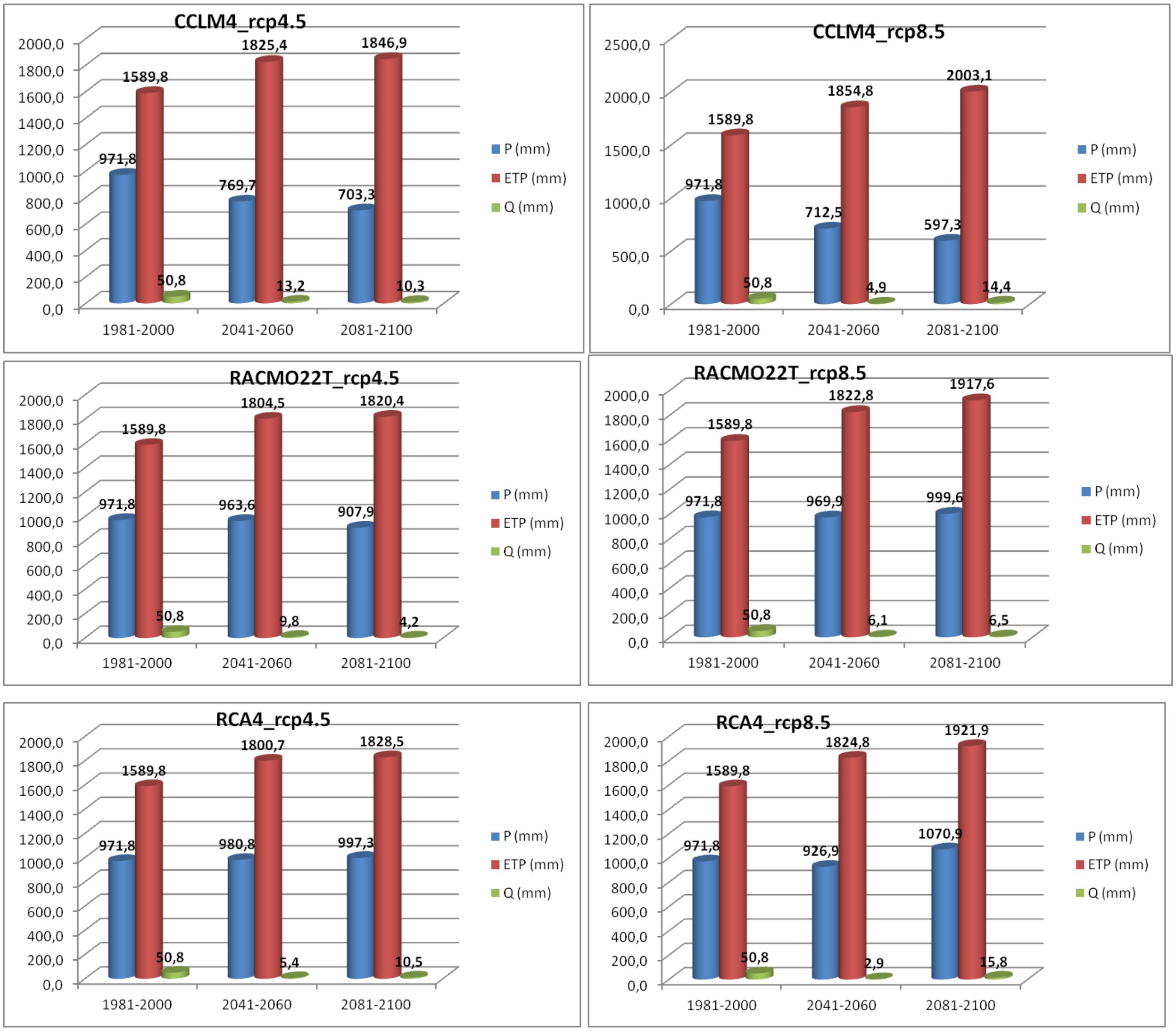


Figure 58: Hydrologic and climatic parameters changes for 1981-2000, 2041-2060 and 2081-2100 periods at M'Basso

Findings from (Kasei, 2009), (Paeth et al., 2011) come to the conclusion that drought occurring is accentuated by land-cover changes in tropical and subtropical Africa. The decline of rainfall and the rise of temperature by the middle and end of the century were found to conform to others climate projections (Sarr, 2012).

CHAPTER 7: VULNERABILITY TO CLIMATE CHANGE

This chapter is taken from the publication (Yéo et al., 2016).

7.1. Survey sites

Population of the survey areas are multi-ethnic. On the one hand, Attié, Agni, Koulango, Abron, Baoulé and Andoh make up the natives. On the other hand, non-natives are composed of people from Economic Community Of West African States (ECOWAS). Table 21 shows how some key characteristics of the survey area.

Table 21: Key demographic and socioeconomic characteristics of the survey area

Characteristics	**Study area**
Mean annual rainfall (mm)	1,100
Rainfall patterns	Bimodal
Temperature (ºC)	28
Main livelihood	Agriculture
Major crops grown	Coffee, Cocoa, Hevea, Cashew, Plantain, Yam, Pepper, Tomato, Gumbo and Aubergine
Types of association (%)	11% of men, 31% of women, 28% of young, 28% of mutual, 2% of no association
Population in agriculture (%)	83
Ethnic composition	*Attié, Agni, Koulango, Abron, Baoule* and *Andoh*

7.2. Water users' awareness of climate change in the study communities

The questionnaire survey was used to know if water users have heard of climate change before or if they have never heard of this concept. 95 % of the interviewee in the study communities had heard of it and are aware that climate change is occurring. They had perceived climate change in terms of various changes (Figure 59). Among them, 86 % have observed late rain. Another 82 % of the opinion was that rainfall has decreased and therefore increased the frequent occurrence of droughts (27 %). Majority of the water users (95 and 86 %) interviewed believe that temperature and winds are becoming warmer and stronger respectively. Going by the opinion of 91 % of water users, the crop diseases and pests have increased. Only 5 % of them were observing torrential rain. There was almost unanimous agreement across the water users that there is a delay in the onset of the rainfall compared with their childhoods.

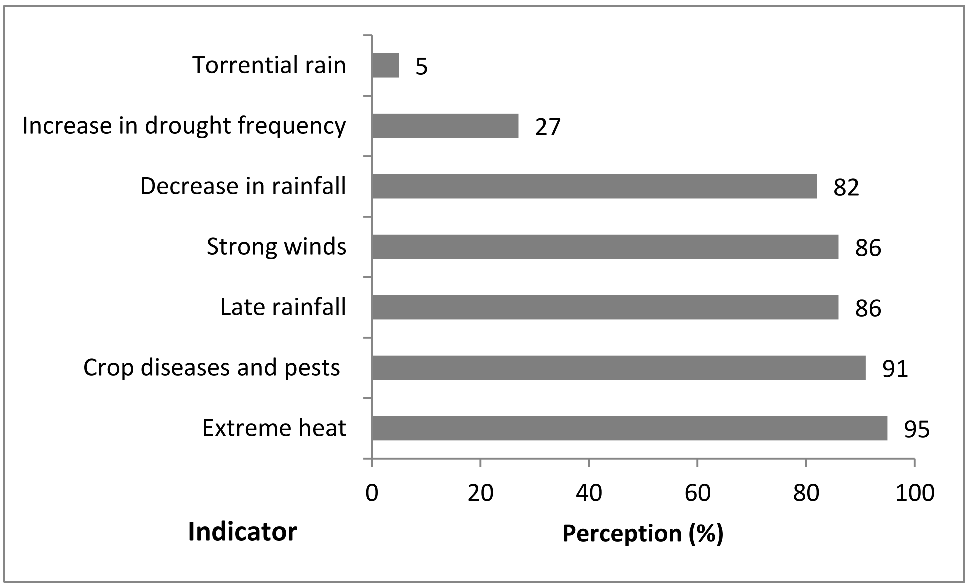


Figure 59: Water users' perceptions about climate change in the survey area

The answer of the origin of climate change varies from literate to illiterate people. Literate interviewed water users define climate change as a change in, for example, rainfall and temperature from the past to now. For the illiterate, climate change is a divine sanction against human who have broken social values. They were of the opinion that rainfall is not coming as more as in the past because of deforestation.

Water users in the CRB have heard of climate change and their understanding of it is closed to scientist definition: climate change is a change in, for example, rainfall and temperature from the past to now. Most water users have noticed that temperatures are getting warmer and there is a decline in rainfall over the last three decades. These perceptions were found to conform to the perceptions of water users in Cote d'Ivoire the last forty years (Bigot et al., 2005); (Y. T. Brou, 2009) and in many African countries (Mertz et al., 2010); (Mertz et al., 2011). Findings from (Sharon E. Nicholson, 2013) and (Hope, Sr, Sr, & Ronald, 2009) have showed that temperatures vary from day to night and throughout the year in tropical areas. Water users were also of the opinion that deforestation for cropping contribute to changes in climate.

7.3. Socioeconomics impacts of climate change in the study area

Agriculture is the largest economic sector in the CRB and most communities reported that they have been experiencing changes in climate (Figure 60). According to 95 % of the interviewed people, crop yield is decreasing over years because of climate change, ultimately leading to drop in income and food insecurity. About 91 % of water users noticed new pests and diseases like *Swollen-Shoot* in cocoa and malaria for human. While 86 % of interviewed people reported a delay in cropping season, 82 % noticed crop failure. One-third of them have perceived declining water level in rivers. According to 14 % of the water users, there is a change in cropping pattern. About 5 % of the interviewed people reported a change in economic activity. It was the case of the fishermen community of M'Basso called 'Bozos' who became farmers.

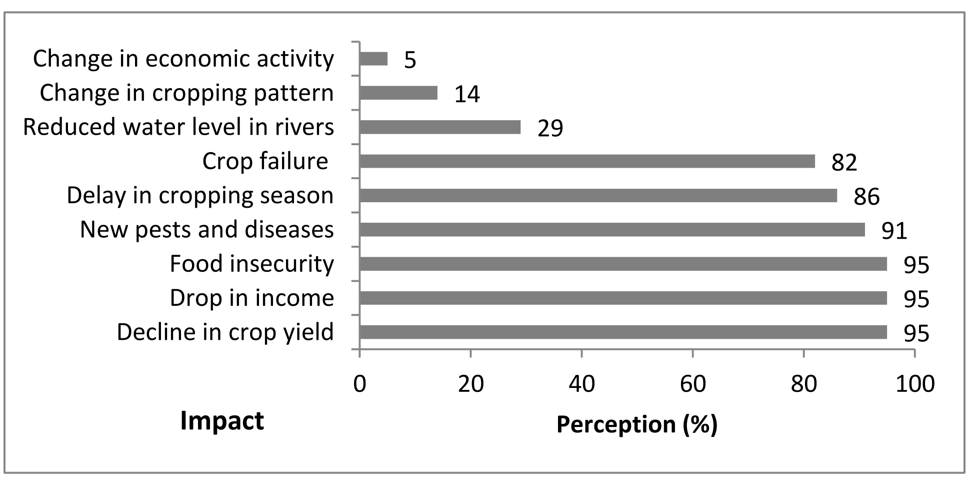


Figure 60: Perceived impacts of climate change in the survey area, n=384

Climate change is affecting several sectors in Cote d'Ivoire. Agriculture is affected through shorter average vegetative growth periods (the cultivation season begins earlier), low biomass growth and a decrease in the productive potential of ecosystems (less arable land due to its degradation, increased water stress for plants and shrinking surface water in most regions). Rainfall disruptions have a significant impact on cocoa production and yields may fall by more than 20% during El Nino episodes in comparison to previous campaigns (Kouassi et al., 2010). One of the key perceived effects of changes in climate was declining in crop yield. Most of cash crops need good rainfall and their development is done to the detriment of forest areas. According to (Bigot et al., 2005) and (Y. T. Brou, 2009), the rate of deforestation is one of the most important rates in the world (90 %). It is the case of cocoa which need annual rainfall between 1,200 and 1,500 mm (T. Brou, 2010). Any change in such condition lead to declining in crop yield (Dao et al., 2010), (Dao et al., 2010). One net impact of climate change reported by respondents was pest and diseases. The recommendations for the described Cocoa swollen-shoot virus are to cut down alternative hosts. This results in a decrease of cocoa yield (Francisco, 2009), (Wisser et al., 2010). The presence of mosquitoes is mainly a question of temperatures and humidity. Increased temperatures will increase occurrence of malaria. Crops destruction is increasing the cost of food because it is leading to low yields, food shortage and communities' incomes declining (Cooper et al., 2008). Food insecurity due to climate change is reality in the CRB as well as in various geographic areas of Cote d'Ivoire (Asante, Boakye, Egyir, & Jatoe, 2012).

Water resources is also affected by climate change through a decrease in available surface water for the Bandama and Sassandra Rivers, dropping respectively from -21 to -22% and from -5.1 to -8.35%, a significant decrease in groundwater recharge with a drop from 7.44% to 13.73% by 2031-2040 and from 49.34% to 70% by 2091-2100 (KOUAKOU, 2011).

Another sector affected by climate change in Cote d'Ivoire is human health. A positive correlation between rainfall and temperature variations, and the incidence of malaria, respiratory and diarrheal diseases in several places of the country has been observed (Caminade et al., 2011). Also, the meningitis belt moves from north to south of the country with the Harmattan during the dry season.

7.4. Local adaptation measures to climate change

To manage the changes perceived by communities in the CRB, various adaptation strategies have been employed. Figure 61 summarizes these and shows three broad strategies, namely, on-farm, financial and preventive adaptation strategies are undertaken by interviewed people in response to the effects of climate change.

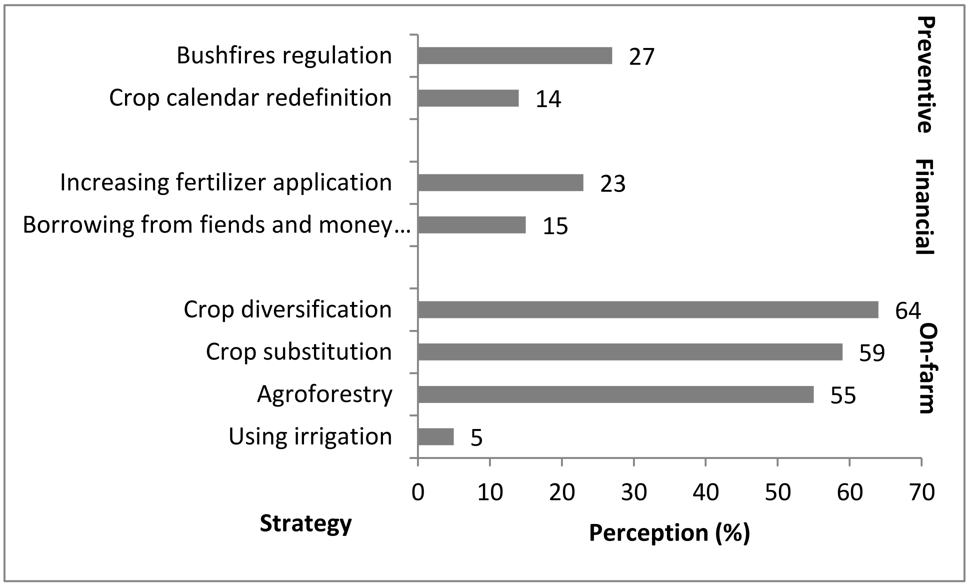


Figure 61: Adaptation strategies practiced by study communities

Firstly, on-farm adaptation measures refer to agricultural management practices undertaken in the study communities and include crop diversification (64 %), crop substitution (59 %), agroforestry (55 %) and irrigation (5 %). Secondly, financial adaptation strategies refer to income management strategies to sustain livelihood during climate adversities. These strategies include increasing fertilizer application (23 %) to improve crop productivity and borrowing from friends and money lenders (15 %). Thirdly, preventive adaptation strategies that were reported include bushfires regulation (27 %) and crop calendar redefinition (14 %).

Various adaptation measures are employed by water users to respond to climate change. The foremost adaptation strategy adopted by the study communities is crop diversification. The advantage of crop diversification is in the compensation of one crop failure by the yield of another crop. Many crops are grown at the same time on the same field. Association used for cash food are cocoa + plantain; Cocoa + cashew nut; Cocoa + cashew nut + teak. For food crops concern mainly yam, groundnut, taro, tomatoes, pepper and aubergine. The second important strategy is crop substitution. Water users are now using drought-tolerant crops to secure their occupation and income from the adversities caused by climate change. Thus, they have been replacing cocoa and coffee by hevea, cashew nut and teak. Also, long duration crops and varieties are getting replaced by short duration ones. For example, the variety of cocoa called 'French cocoa' has been replaced by 'Mercedes cocoa' promoted by '*Centre National de Recherche Agronomique (CNRA)*'. This adaptation strategy has a negative consequence the region is nomore called '*boucle du cacao*' and people are immigrating to the South East of the country. Another adaptation strategy used by the study communities is agroforestry. It concerns the use of fast-growing-species of trees in the farm. The frequent tree species are teak (*Verbenaceae*), framire (*Terminalia ivorensis*) and frake (*Terminalia superba*). A respondent states for example 'when there is forest, there is rain and wind speed is reduced'. Bushfires and crop calendars redefinition are preventive adaptation strategies used by water users. Respondents reported that bushfires are now well regulated with the actions of local comities and non-governmental organizations (NGO) like « *SIN NAN SOPKA MIN* » (e.g. fire made me poor). Also, crop calendars are redefined to facilitate adaptation by way of planning when to plant their crops. Time of rainfall has changed over the years, what the respondents termed as 'untimely rainfall' that poses much difficulty in the cultivation of crops. They usually manipulate the sowing date in accordance with the arrival of rain. Some water users rely on past rainfall patterns including the start and ending of the rainy season to form expectations and predict the rainfall patterns for the coming season. This redefinition of seasonal calendars is done most of the time in collaboration with some national agencies like ANADER (*Agence National d'Appui au Développement Rural*), FIRCA (*Fonds Interprofessionnel pour la Recherche et le Conseil Agricoles*) and SAPH (*Société Africaine de Plantations d'Hévéa*). Increasing fertilizer application and borrowing from friends and money lenders are financial adaptation strategies used by water users in the CRB. They resorted to these strategies to keep the household food secure and sometimes after they have run out of provisions from their own production. Getting money enables farmers to look for fertilizer and seeds of improved varieties.

CHAPTER 8: GENERAL CONCLUSION AND PERSPECTIVES

8.1. Conclusion

Climate variability and change in West Africa has led to decrease in rainfall since the late 70s. This resulted in a reduction of streamflow and wetlands leading to severe droughts. The responses of local communities to the impacts of climate change have mostly been reactive instead of proactive due to unpreparedness.

The 55-years records of rainfall from 5 stations of the Comoe River Basin examined for temporal distribution show a succession of humid and drought periods and a climate breakdown around 1969. The humid period took place before 1969 and after it is the drought period up to now. The interannual variability of temperature shows a continuous increase of temperature. This increase is more pronounced at the minima than maxima level. Both the decrease in rainfall and the clear increase in temperature by the middle and end of the century were found to conform to others climate projections. Climate projections for respectively the middle and the end of the century, is indicating a decrease in average total monthly rainfall. Also, the temperature projections show a clear increase in monthly average temperature.

For the evaluation of climate change impacts on water resources in the Comoe Basin, the robustness of a lumped hydrological model in modelling streamflow the Comoe River Basin was assessed. The GR4J model was successfully calibrated and validated at Yendere, Serebou, Akacomokro and M'Basso gauging stations. According to the NSE values, the model fitted actual time series for all the gauging stations. The calibration and validation NSE at M'Basso (our outlet) was respectively 86.3 and 80.7. The performance of the model when passing from calibration to validation is good at M'Basso gauging station (5.6%).

The potential effects of climate change under the RCP 4.5 and 8.5 scenarios on streamflow in the Comoe River Basin were examined using three RCM. CLMcom-CCLM4-8-17, KNMI-RACMO22T and SMHI-RCA4. These models were found reproducing accurately the observed rainfall patterns. The comparison of simulated, observed and corrected precipitation at the Comoe River Basin outlet (M'Basso) for 2041-2060, 2081-2100 periods revealed that future scenarios have the same variability as observations and future precipitations are lower than baseline ones.

The gaps between observed and model baseline precipitations on the one hand and the simulated and the corrected precipitation on the other hand are not important for CLMcom-CCLM4-8-17. However, these gaps are relatively important for SMHI-RCA4. CLMcom-CCLM4-8-17 is underestimating mean annual rainfall, 0.4 to 0.6 for RCP4.5 and 0.5 to 0.8 for RCP8.5 for 2041-2060 and 2081-2100 periods. Whereas, SMHI-RCA4 and KNMI-RACMO22T are overestimating mean annual rainfall, 0.2 to 0.3 for RCP4.5 and 0.1 to 0.5 for RCP8.5.

CLMcom-CCLM4-8-17, KNMI-RACMO22T and SMHI-RCA4 reproduce accurately the observed temperature patterns at Abidjan, Adiake, Dimbokro, Bondoukou and Bobo Dioulasso stations. Observed temperatures are generally above the simulated ones for the three RCM. Future scenarios have the same variability as observations and future temperatures are higher than baseline ones for the three RCM. CLMcom-CCLM4-8-17, KNMI-RACMO22T and SMHI-RCA4 are overestimating temperature. The observed baseline is generally above the model baseline for all the stations. All scenarios and all models reveal an increase of temperature up to 5.6°C for 2041-2060 and 2081-2100 periods. Also, temperatures for 2081-2100 period are more important than the ones of 2041-2060 period. High values are generally observed in January.

The comparison of mean yearly discharge for 2041-2060 and 2081-2100 periods to 1981-2000 periods at M'Basso revealed that flows will decrease respectively for 2041-2060 and 2081-2100 periods about 41% and 45% according to the scenario RCP 4.5 KNMI-RACMO22T model. The decrease of flows following RCP 8.5 for the same periods is about 46% and 44%. High flow and low flow periods are quit the same for the three RCM.

Hydrologic and climatic parameters comparison at M'Basso for 1981-2000, 2041-2060 and 2081-2100 periods revealed an increase of potential evopotranspiration for the two horizons and for the three RCM. Also, precipitations and potential evopotranspiration are important than discharge which is very low.

This study presented water users' perception on changing climate in the study site based on interviews and questionnaires. Findings have revealed that 95 % of the sample in the study communities had heard of climate change and are aware that it is happening. This study also, found that agriculture is the largest economic sector in the CRB. Communities have experienced changing climate as changes in economic activity and cropping pattern, reduced water level in rivers, crop failure, delay in cropping season, new pests and diseases, food insecurity, drop in income and decline in crop yield. Others results revealed that communities have employed various adaptation strategies such as crops diversification, substitution and calendar redefinition, agroforestry, borrowing from friends and money lenders, increasing fertilizer application, bushfires regulation and irrigation.

8.2. Perspectives

This study helps understand changes in streamflow due to future climate change. However, to achieve sustainable water resource planning and management in the Comoe River Basin, we recommend to assess the robustness of a distributed hydrological model in modelling streamflow considering consistent land use/land cover (LULC). In addition, the impact of future climate and LULC changes on streamflow under the RCP 4.5 and 8.5 scenarios should be examine. Researchers, planners and policy makers must work together o implement Integrate Water Resource Management in the Comoe River Basin.

REFERENCES

Ackerley, D., Booth, B. B. B., Knight, S. H. E., Highwood, E. J., Frame, D. J., Allen, M. R., Rowell, D. P. (2011). Sensitivity of Twentieth-Century Sahel Rainfall to Sulfate Aerosol and CO_2 Forcing. *Journal of Climate*, *24*(19), 4999–5014. https://doi.org/10.1175/JCLI-D-11-00019.1

Asante, F. a., Boakye, a. a., Egyir, I. S., & Jatoe, J. B. D. (2012). Climate change and farmers' adaptive capacity to strategic innovations: The case of northern Ghana. *International Journal of Development and Sustainability*, *1*(3), 766–784. Retrieved from http://isdsnet.com/ijds-v1n3-11.pdf

ASSAR. (2015). Use and Communication of Climate Information to Support Uptake of Adaptation Action in the Semi-Arid Regions of Africa and Asia, 1–59.

Ben Mohamed, A. (2011). Climate change risks in Sahelian Africa. *Regional Environmental Change*, *11*(S1), 109–117. https://doi.org/10.1007/s10113-010-0172-y

Beniston, M., Stephenson, D. B., Christensen, O. B., Ferro, C. A. T., Frei, C., Goyette, S., Woth, K. (2007). Future extreme events in European climate: an exploration of regional climate model projections. *Climatic Change*, *81*(S1), 71–95. https://doi.org/10.1007/s10584-006-9226-z

Biasutti, M. (2013). Forced Sahel rainfall trends in the CMIP5 archive. *Journal of Geophysical Research: Atmospheres*, *118*(4), 1613–1623. https://doi.org/10.1002/jgrd.50206

Biasutti, M., & Giannini, A. (2006). Robust Sahel drying in response to late 20th century forcings. *Geophys. Res. Lett*, *33*. https://doi.org/10.1029/2006GL026067

Bigot, S., Brou, T. Y., Oszwald, J., & Diedhiou, A. (2005). Facteurs de la variabilité pluviométrique en Côte d'Ivoire et relations avec certaines modifications environnementales. *Sécheresse*, *16*(1), 5–13.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Yanda, P. (2008). Africa ,Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on*

Climate Change. https://doi.org/10.2134/jeq2008.0015br

Brou, T. (2010). Variabilité climatique, déforestation et dynamique agrodémographique en Côte d'Ivoire. *Secheresse*, *21*(1), 1–6. https://doi.org/10.1684/sec.2010.0277

Brou, Y. T. (2009). Impacts des modifications bioclimatiques et des l'amenuisement des terres forestières dans les paysanneries ivoiriennes: quelles solutions pour une agriculture durable en côte d'ivoire. *Cuadernos Geograficos*, *45*(45), 13–29. https://doi.org/0210-5462

Cai, Y. P., Huang, G. H., Tan, Q., & Yang, Z. F. (2011). An integrated approach for climate-change impact analysis and adaptation planning under multi-level uncertainties. Part I: Methodology. *Renewable and Sustainable Energy Reviews*, *15*(6), 2779–2790. https://doi.org/10.1016/j.rser.2011.03.013

Caminade, C., Ndione, J. a., Kebe, C. M. F., Jones, a. E., Danuor, S., Tay, S., Morse, a. P. (2011). Mapping Rift Valley fever and malaria risk over West Africa using climatic indicators. *Atmospheric Science Letters*, *12*(1), 96–103. https://doi.org/10.1002/asl.296

Cochran, W. G. (William G. (1977). *Sampling techniques (third edition)*. JOHN WILEY & SONS.

Cohen, S.J., Miller, K., Hamlet, A.F., Avis, W. (2000). Climate change and resource management in the Columbia River Basin. *Water International*, *25*(2), 253–272. Retrieved from https://cig.uw.edu/publications/climate-change-and-resource-management-in-the-columbia-river-basin/

Collins, J. M. (2011). Temperature Variability over Africa. *Journal of Climate*, *24*(14), 3649–3666. https://doi.org/10.1175/2011JCLI3753.1

Conway, D., Persechino, A., Ardoin-Bardin, S., Hamandawana, H., Dieulin, C., & Mahé, G. (2009). Rainfall and Water Resources Variability in Sub-Saharan Africa during the Twentieth Century. *Journal of Hydrometeorology*, *10*(1), 41–59. https://doi.org/10.1175/2008JHM1004.1

Cooper, P. J. M., Dimes, J., Rao, K. P. C., Shapiro, B., Shiferaw, B., & Twomlow, S. (2008). Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems and Environment*, *126*(1–2), 24–35. https://doi.org/10.1016/j.agee.2008.01.007

Dao, A., Kamagate, B., Mariko, A., Goula Bi, T. A., Seguis, L., Maiga, H. B., & Savane, I. (2010). Variabilité Climatique et Réponse Hydrologique du Bassin Versant Transfrontalier de Kolondièba au Sud du Mali. *European Journal of Scientific Research*, *43*(4), 435–444.

Devineau, J.-L. (1984). Structure et dynamique de quelques forêts trophophiles de l'Ouest africain (Côte-d'Ivoire). *Traveaux Des Chercheurs de La Station de Lamto*, 1–294. Retrieved from https://www.mendeley.com/research-papers/structure-et-dynamique-quelques-forêts-trophophiles-louest-africain-côtedivoire/?utm_source=desktop&utm_medium=1.17.11&utm_campaign=open_catalog&userDocumentId=%7Be52d8464-bcc2-3f4e-89b4-1e08c76f6feb%7D

Dezetter, A., Servat, E., & Mahe, G. (2005). Évaluation des impacts du changement climatique sur les ressources en eau d'Afrique de l'Ouest et Centrale. *Regional Hydrological Impacts of Climatic Change—Hydroclimatic Variability*, (April), 194–202.

Diallo, I., Sylla, M. B., Giorgi, F., Gaye, a. T., & Camara, M. (2012). Multimodel GCM-RCM Ensemble-Based Projections of Temperature and Precipitation over West Africa for the Early 21st Century. *International Journal of Geophysics*, *2012*, 1–19. https://doi.org/10.1155/2012/972896

Fiseha, B. M., Setegn, S. G., Melesse, A. M., Volpi, E., & Fiori, A. (2014). Impact of Climate Change on the Hydrology of Upper Tiber River Basin Using Bias Corrected Regional Climate Model. *Water Resources Management*, *28*(5), 1327–1343. https://doi.org/10.1007/s11269-014-0546-x

Fontaine, B., Roucou, P., & Monerie, P.-A. (2011). Changes in the African monsoon region at medium-term time horizon using 12 AR4 coupled models under the A1b emissions scenario. *Atmospheric Science Letters*, *12*(1), 83–88. https://doi.org/10.1002/asl.321

Francisco, S. (2009). Managing Risk in Côte d'Ivoire's Cocoa Sector.

Girard, G., Sircoulon, J., Touchebeuf, P. (1971). APERÇU SUR LES RÉGIMES HYDROLOGIQUES. Le milieu naturel de la Côte d'Ivoire. Mém. ORSTOM, 50, Paris, pp 109-155

Gosling, S., Taylor, R. G., Arnell, N., & Todd, M. C. (2011). A comparative analysis of projected impacts of climate change on river runoff from global and catchment-scale hydrological models. *Hydrology and Earth System Sciences*, *15*(1), 279–294. Retrieved from http://hydrol-earth-system-sci.net/15/279/2011

Goula, B. T. A., Savane, I., Konan, B., Fadika, V., & Kouadio, G. B. (2006). Impact de la variabilité climatique sur les ressources hydriques des bassins de N'Zo et N'Zi en Côte d'Ivoire (Afrique tropicale humide). *VertigO*, *7*(Volume 7 Numéro 1), 1–12. https://doi.org/10.4000/vertigo.2038

Hamed, K. H. (2008). Trend detection in hydrologic data: The Mann-Kendall trend test under the scaling hypothesis. *Journal of Hydrology*, *349*(3–4), 350–363. https://doi.org/10.1016/j.jhydrol.2007.11.009

Hope, Sr, K. R. (2009). Climate change and urban development in Africa. *International Journal of Environmental Studies*, *66*(5), 643–658. https://doi.org/10.1080/00207230903367955

Hope, Sr, K. R., Sr, & Ronald, K. (2009). Climate change and urban development in Africa. *International Journal of Environmental Studies*, *66*(5), 643–658. https://doi.org/10.1080/00207230903367955

Hulme, M., Doherty, R., Ngara, T., New, M., & Lister, D. (2001). African climate change: 1900-2100. *Climate Research*, *17*(2 SPECIAL 8), 145–168. https://doi.org/10.3354/cr017145

Huo, Z., Feng, S., Kang, S., Li, W., & Chen, S. (2008). Effect of climate changes and water-related human activities on annual stream flows of the Shiyang river basin in arid north-west China, *3167*(October 2007), 3155–3167. https://doi.org/10.1002/hyp

J.M. Avenard, M. Eldin, G. Girard, J. Sircoulon, P. Touchebeuf, A. P. (1971). Le milieu naturel de Côte d'Ivoire.

Janicot, S., Caniaux, G., Chauvin, F., de Coëtlogon, G., Fontaine, B., Hall, N., Taylor, C. M. (2011). Intraseasonal variability of the West African monsoon. *Atmospheric Science Letters*, *12*(1), 58–66. https://doi.org/10.1002/asl.280

Jones, P. D., & Moberg, A. (2003). Hemispheric and Large-Scale Surface Air Temperature Variations: An Extensive Revision and an Update to 2001. *Journal of Climate*, *16*(2), 206–223. https://doi.org/10.1175/1520-0442(2003)016<0206:HALSSA>2.0.CO;2

Kasei, R. A. (2009). Modelling impacts of climate change on water resources in the Volta Basin , West Africa.

KOUAKOU, K. E. (2011). Impacts de la variabilité climatique et du changement climatique sur les ressources en : KOUAKOU : Koffi Eugène Environnement.

Kouakou Koffi Eugène, G. B. T. A. and S. I. (2007). Impacts De La Variabilité Climatique Sur Les Ressources En Eau De Surface En Zone Tropicale Humide: Cas Du Bassin Versant Transfrontalier De La Comoé (Côte D'Ivoire - Burkina Faso). *European Journal of Scientific Research*, *16*(N°1), 31–43. Retrieved from https://www.researchgate.net/profile/Solomon_Osofero/publication/287825591_Length_-_Weight_relationship_of_tilapia_Oreochromis_Niloticus_Linnaeus_1757_under_different_stocking_densities_in_Bamboo_net_cages_in_a_freshwater_reservoir/links/577d378308aeaee3b

Kouassi, A. M., Kouamé, K. F., Koffi, Y. B., Dje, K. B., Paturel, J. E., & Oulare, S. (2010). Analyse de la variabilité climatique et de ses influences sur les régimes pluviométriques saisonniers en Afrique de l'ouest: Cas du bassin versant du N'zi (Bandama) en Côte d'Ivoire. *CyberGeo*. https://doi.org/10.4000/cybergeo.23388

Lebel, T., & Ali, A. (2009). Recent trends in the Central and Western Sahel rainfall regime (1990-2007). *Journal of Hydrology*, *375*(1–2), 52–64. https://doi.org/10.1016/j.jhydrol.2008.11.030

Li, K. Y., Coe, M. T., Ramankutty, N., & Jong, R. De. (2007). Modeling the hydrological impact of land-use change in West Africa. *Journal of Hydrology*, *337*(3–4), 258–268. https://doi.org/10.1016/j.jhydrol.2007.01.038

Mahé, G., Diello, P., Paturel, J., Barbier, B., Dezetter, A., Dieulin, C., Sighomnou, D. (2009). Scale effects in Hortonian surface runoff on agricultural slopes in West Africa: Field data and models. *Journal of Hydrology*, *375*(1–2), 95–101. https://doi.org/10.1016/j.agee.2010.06.006

Meehl, G. A., Washington, W. M., Arblaster, J. M., Hu, A., Teng, H., Tebaldi, C., White, J. B. (2012). Climate system response to external forcings and climate change projections in CCSM4. *Journal of Climate*, *25*(11), 3661–3683. https://doi.org/10.1175/JCLI-D-11-00240.1

Mertz, O., Mbow, C., Nielsen, J. Ø., Maiga, A., Diallo, D., Reenberg, A., Dabi, D. (2010). Climate factors play a limited role for past adaptation strategies in West Africa. *Ecology and Society*, *15*(4). https://doi.org/25

Mertz, O., Mbow, C., Reenberg, A., Genesio, L., Lambin, E. F., D'haen, S., Sandholt, I. (2011). Adaptation strategies and climate vulnerability in the Sudano-Sahelian region of West Africa. *Atmospheric Science Letters*, *12*(1), 104–108. https://doi.org/10.1002/asl.314

Mishra, A. K., & Singh, V. P. (2011). Drought modeling - A review. *Journal of Hydrology*, *403*(1–2), 157–175. https://doi.org/10.1016/j.jhydrol.2011.03.049

Miyan, M. A. (2014). Droughts in Asian least developed countries : Vulnerability and sustainability. *Weather and Climate Extremes*, 1–16. https://doi.org/10.1016/j.wace.2014.06.003

Mohino, E., Rodríguez-Fonseca, B., Mechoso, C. R., Gervois, S., Ruti, P., Chauvin, F., Chauvin, F. (2011). Impacts of the Tropical Pacific/Indian Oceans on the Seasonal Cycle of the West African Monsoon. *Journal of Climate*, *24*(15), 3878–3891. https://doi.org/10.1175/2011JCLI3988.1

Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part I - A discussion of principles. *Journal of Hydrology*, *10*(3), 282–290. https://doi.org/10.1016/0022-1694(70)90255-6

New, M., Hewitson, B., Stephenson, D. B., Tsiga, A., Kruger, A., Manhique, A., Lajoie, R. (2006). Evidence of trends in daily climate extremes over southern and west Africa. *Journal of Geophysical Research*, *111*(D14), D14102. https://doi.org/10.1029/2005JD006289

Niasse, M. (2004). Prévenir les conflits et promouvoir la coopération dans la gestion des fleuves transfrontaliers en Afrique de l'Ouest. *VertigO*, *5*(1). https://doi.org/10.4000/vertigo.3979

Nicholson, S. E. (2013). The West African Sahel: A Review of Recent Studies on the Rainfall Regime and Its Interannual Variability. *ISRN Meteorology*, *2013*, 1–32. https://doi.org/10.1155/2013/453521

Nicholson, S. E., Some, B., Kone, B., Nicholson, S. E., Some, B., & Kone, B. (2000). An Analysis of Recent Rainfall Conditions in West Africa, Including the Rainy Seasons of the 1997 El Niño and the 1998 La Niña Years. *Journal of Climate*, *13*(14), 2628–2640.

https://doi.org/10.1175/1520-0442(2000)013<2628:AAORRC>2.0.CO;2

Nyanga, P. H., Johnsen, F. H., Aune, J. B., & Kalinda, T. H. (2011). Smallholder Farmers' Perceptions of Climate Change and Conservation Agriculture: Evidence from Zambia. *Journal of Sustainable Development*, *4*(4), 73. https://doi.org/10.5539/jsd.v4n4p73

Oecd-. (2016). Agriculture in Sub-Saharan Africa: Prospects and challenges for the next decade. Retrieved from http://www.fao.org/3/a-BO092E.pdf

Paeth, H., Hall, N. M. J., Gaertner, M. A., Alonso, M. D., Moumouni, S., Polcher, J., Rummukainen, M. (2011). Progress in regional downscaling of west African precipitation. *Atmospheric Science Letters*, *12*(1), 75–82. https://doi.org/10.1002/asl.306

Péné, C. B., & Assa, D. A. (2003). *Sécheresse. Science et changements planétaires / Sécheresse* (Vol. 14). John Libbey Eurotext Ltd. Retrieved from http://www.jle.com/fr/revues/sec/e-docs/variations_interannuelles_de_la_pluviometrie_et_de_lalimentation_hydrique_de_la_canne_a_sucre_en_cote_divoire__262863/article.phtml?tab=texte

Perrin, C., Michel, C., & Andre, V. (2001). Does a large number of parameters enhance model performance ? Comparative assessment of common catchment model structures on 429 catchments, *242*.

Perrin, C., Michel, C., & Andréassian, V. (2003). Improvement of a parsimonious model for streamflow simulation. *Journal of Hydrology*, *279*(1–4), 275–289. https://doi.org/10.1016/S0022-1694(03)00225-7

Pierre, V. (1971). Le milieu naturel de la Côte d'Ivoire. 1971 (Mémoire N° 50). *Cahiers D'outre-Mer*, *26*(104), 440–440. Retrieved from http://www.persee.fr/doc/caoum_0373-5834_1973_num_26_104_4499_t1_0440_0000_1

Roehrig, R., Bouniol, D., Guichard, F., Hourdin, F., Redelsperger, J.-L., Roehrig, R., Redelsperger, J.-L. (2013). The Present and Future of the West African Monsoon: A Process-Oriented Assessment of CMIP5 Simulations along the AMMA Transect. *Journal of Climate*, *26*(17), 6471–6505. https://doi.org/10.1175/JCLI-D-12-00505.1

Roudier, P., Sultan, B., Quirion, P., & Berg, A. (2011). The impact of future climate change on West African crop yields: What does the recent literature say? *Global Environmental Change*, *21*(3), 1073–1083. https://doi.org/10.1016/j.gloenvcha.2011.04.007

Ruti, P. M., Williams, J. E., Hourdin, F., Guichard, F., Boone, A., Van Velthoven, P., Traore, A. K. (2011). The West African climate system: a review of the AMMA model inter-comparison initiatives. *Atmospheric Science Letters*, *12*(1), 116–122. https://doi.org/10.1002/asl.305

Saley, M. B., Tanoh, R., Kouamé, K. F., Oga, M. S., Kouadio, B. H., Djagoua, E. V., Savane, I. (2005). Variabilité spatio-temporelle de la pluviométrie et son impact sur les ressources en eaux souterraines : cas du district d ' Abidjan (sud de la Côte d'Ivoire).

Sanderson, M. G., Hemming, D. L., & Betts, R. A. (2011). Regional temperature and precipitation changes under high-end (≥4°C) global warming. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences*, *369*(1934), 85–98. https://doi.org/10.1098/rsta.2010.0283

Sarr, B. (2012). Present and future climate change in the semi-arid region of West Africa: A crucial input for practical adaptation in agriculture. *Atmospheric Science Letters*, *13*(2), 108–112. https://doi.org/10.1002/asl.368

Soro, T. D., Soro, N., Oga, Y. M.-S., Lasm, T., Soro, G., Ahoussi, K. E., & Biémi, J. (2011). La variabilité climatique et son impact sur les ressources en eau dans le degré carré de Grand-Lahou (Sud-Ouest de la Côte d'Ivoire). *Physio-Géo*, (Volume 5), 55–73. https://doi.org/10.4000/physio-geo.1581

Stern, D. I., Gething, P. W., Kabaria, C. W., Temperley, W. H., Noor, A. M., Okiro, E. A., Hay, S. I. (2011). Temperature and Malaria Trends in Highland East Africa. *PLoS ONE*, *6*(9), e24524. https://doi.org/10.1371/journal.pone.0024524

Tastet, J. P., & Guiral, D. (1994). Géologie et sédimentologie. In: Durand, J.-R., Dufour, P., Guiral, D. and Soko, G.F.Z., Eds., Environnement et ressources aquatiques de Côte d'Ivoire; Tome II: Les milieux lagunaires, édition ORSTOM, 35-57.

Thirel, G., Andréassian, V., Perrin, C., Audouy, J.-N., Berthet, L., Edwards, P., Vaze, J. (2016). Hydrology under change: an evaluation protocol to investigate how hydrological models deal with changing catchments. *Hydrological Sciences Journal – Journal Des Sciences Hydrologiques*, *60*(February 2016), 7–8. https://doi.org/10.1080/02626667.2014.967248

Tiani, A. M., Besa, M. C., Devisscher, T., Pavageau, C., Butterfield, R., Mekou, S. B., & Bele,

Y. (2015). *Assessing current social vulnerability to climate change A participatory methodology* (CIFOR Working Paper no. 169). *Center for International Forestry Research (CIFOR)* . Bogor, Indonesia. https://doi.org/http://www.cifor.org/publications/pdf_files/WPapers/WP169Tiani.pdf

Wang, J., Ishidaira, H., & Xu, Z. X. (2012). Effects of climate change and human activities on inflow into the Hoabinh Reservoir in the Red River basin. *Procedia Environmental Sciences*, *13*(2011), 1688–1698. https://doi.org/10.1016/j.proenv.2012.01.162

Wisser, D., Frolking, S., Douglas, E. M., Fekete, B. M., Schumann, A. H., Vörösmarty, C. J., Togunde, K. A. (2010). Future productivity of fallow systems in Sub-Saharan Africa: Is the effect of demographic pressure and fallow reduction more significant than climate change? *Journal of Hydrology*, *384*(3–4), 1120–1130. https://doi.org/10.1016/j.agrformet.2011.03.015

Yang, X., Michel, C., Westerberg, I. K., Guerrero, J.-L., Younger, P. M., Beven, K. J., Niel, H. (2011). The impact of future climate change on seasonal discharge, hydrological processes and extreme flows in the Upper Wye experimental catchment, Mid-Wales. *Journal of Hydrology*, *15*(1–2), n/a-n/a. https://doi.org/10.1016/j.advwatres.2011.01.008

Yéo, W. E., Goula, B. T. A., Diekkrüger, B., & Afouda, A. (2016). Vulnerability and adaptation to climate change in the Comoe River Basin (West Africa). *SpringerPlus*, *5*(1), 847. https://doi.org/10.1186/s40064-016-2491-z

Zhang, Y., Guan, D., Jin, C., Wang, A., Wu, J., & Yuan, F. (2011). Analysis of impacts of climate variability and human activity on streamflow for a river basin in northeast China. *Journal of Hydrology*, *410*(3–4), 239–247. https://doi.org/10.1016/j.jhydrol.2011.09.023

Zhang, Y. K., & Schilling, K. E. (2006). Effects of land cover on water table, soil moisture, evapotranspiration, and groundwater recharge: A Field observation and analysis. *Journal of Hydrology*, *319*(1–4), 328–338. https://doi.org/10.1016/j.jhydrol.2005.06.044

APPENDIX

Appendix 1: Questionnaire: Water users vulnerability to climate change

(À administrer aux usagers de l'eau)

Date :…………………………………………………………………………………………….

Localisation

Région :…………………………………………………………………………………………….

Département :………………………………………………………………………………………

Commune :………………………………………………………………………………………….

Sous-préfecture :……………………………………………………………………………………

Village :……………………………………………………………………………………………..

Zone climatique :…………………………………………………………………………………...

Longitude :………………………………………………………………………………………….

Latitude :……………………………………………………………………………………………

Usager

Dénomination :……………………………………………………………………………………...

Nombre de participants :……………………………………………………………………………

Informations socioculturelles

Quelles sont les différentes communautés vivant dans cette localité ?

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Quelle est la représentativité de chacun de ces groupes ? (représentativité = nombre/proportion des membres) :

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Chaque communauté est-elle organisée ? Si oui, décrire le mode d'organisation.

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Existe-t-il des associations dans cette localité ? Si oui lesquelles ?

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Quelles sont les maladies que vous rencontrez le plus souvent chez les enfants ?

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Quelles sont les maladies que vous rencontrez le plus souvent chez les hommes ?

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Quelles sont les maladies que vous rencontrez le plus souvent chez les femmes ?

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Existe-t-il une augmentation apparente des cas de :

Paludisme ? Oui : □ Non : □

Onchocercose (cécité des rivières) ? Oui : □ Non : □

Schistosomiase (bilharziose) ? Oui : □ Non : □

Autres (maladies dues aux vers intestinaux, amibiases, infections virales ou bactériennes) ?

Oui : □ Non : □

Si oui, précisez :

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Contexte Climat : Risques de changement climatique

Avez-vous déjà entendu parler de changement climatique ?

Oui : □ Non : □

Si oui, qu'en savez-vous ?

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Si non, qu'est ce que cela pourrait être selon vous ?

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Quels sont les risques liés au climat ? Citez-en trois.

Risque 1 :…………………………………………………………………………………

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Comment influence-t-il votre activité ?

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Risque 2 :…………………………………………………………………………………

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Comment influence-t-il votre activité ?

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Risque 3 :……………………………………………………………………………………

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Comment influence-t-il votre activité ?

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Quels sont les impacts (observés / prévus) ? Citez-en trois.

Impact1 :…………………………………………………………………………………….

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Impact2 :…………………………………………………………………………………….

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Impact3 :…………………………………………………………………………………….

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Quelles sont les stratégies d'adaptation dans votre localite ?

Strategie1 :……………………………………………………………………………………

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Est-elle efficace ? Oui : □ Non : □

Est-elle durable ? Oui : □ Non : □

Quelle est la stratégie d'adaptation alternative ?

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Strategie2 :……………………………………………………………………………………

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Est-elle efficace ? Oui : □ Non : □

Est-elle durable ? Oui : □ Non : □

Quelle est la stratégie d'adaptation alternative ?

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Strategie3 :…………………………………………………………………………………

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Est-elle efficace ? Oui : □ Non : □

Est-elle durable ? Oui : □ Non : □

Quelle est la stratégie d'adaptation alternative ?

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Les autorités locales ont-elles accès aux informations sur les risques climatiques présents et futurs ?

Oui : □ Non : □

Quelle frange de la population souffre du fait des risques climatiques ?

Hommes Oui : □ Non : □

Femmes Oui : □ Non : □

Jeunes Oui : □ Non : □

Toutes Oui : □ Non : □

Quel est le secteur économique/groupe d'usager de l'eau le plus affecté par les effets des changements climatiques ?

Agriculteurs : □

Éleveurs : □

Pêcheurs : □

Commerçants : □

Autres : □ Précisez :………………………………………………………………………

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Les populations locales comprennent-elles les risques des changements climatiques ?

Oui : □ Non : □

Si oui, font-elles la promotion des stratégies d'adaptation ?

Oui : □ Non : □

Contexte : Moyens d'existence

Quelle est la principale source de revenus des populations ?

Agriculture : □

Elevage : □

Commerce : □

Autres : □ Précisez :…………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

Quelle est la principale source d'énergie domestique ?

Bois : □

Charbon : □

Gaz : □

Électricité : □

Autres : □ Précisez :…………………………………………………………………………

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Quelles sont les différentes ressources dont disposent les populations pour lutter contre les catastrophes naturelles ?

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Quelles sont les infrastructures de base pour la gestion de l'eau ?

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Évènements extrêmes / Fréquence

Occurrence

Année	**Manque d'eau**	**Sécheresse**	**Pluviométrie variable**

Quelle compréhension avez-vous des catastrophes/évènements extrêmes des 10 dernières années ?

Catastrophes/évènements extrêmes	Croissant	Décroissant	Invariable
Sécheresse			
Inondation			
Trop de pluie			
Pluie précoce			
Pluie tardive			
Vent violent			
Extrême chaleur			
Maladies des plantes et parasites			

Perte de production agricole/animale

Pendant une année d'extrême sécheresse, quelle quantité de votre production agricole/animale perdez-vous ?

Production agricole : Un tiers : ☐ Moitié : ☐ Deux tiers : ☐ Toute : ☐

Production animale : Un tiers : ☐ Moitié : ☐ Deux tiers : ☐ Toute : ☐

Pendant une année de manque d'eau extrême, quelle quantité de votre production agricole/animale perdez-vous ?

Production agricole : Un tiers : ☐ Moitié : ☐ Deux tiers : ☐ Toute : ☐

Production animale : Un tiers : ☐ Moitié : ☐ Deux tiers : ☐ Toute : ☐

Pendant une année de grande variabilité de la pluviométrie, quelle quantité de votre production agricole/animale perdez-vous ?

Production agricole : Un tiers : ☐ Moitié : ☐ Deux tiers : ☐ Toute : ☐

Production animale : Un tiers : ☐ Moitié : ☐ Deux tiers : ☐ Toute : ☐

Qu'est-ce qui a changé ces dernières années concernant le paysage dans cette zone ?

Forêt : ☐

Savane : ☐

Sol : ☐

Cours d'eau : ☐

Autres : ☐ Précisez :………………………………………………………………………………

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Selon vous quelles sont les conséquences majeures pour les risques identifiés ?

Absence de pluie : ☐

Désertification : ☐

Pluviométrie variable : ☐

Autres : ☐ Précisez :………………………………………………………………………………

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Merci pour votre coopération !

Appendix 2: Questionnaire: Water users vulnerability to climate change
(À administrer aux décideurs du secteur de l'eau)

Date :…………………………………………………………………………………………….

Complétez les informations sur la personne interrogée:

Nom :…………………………………………………………………………………………….

Profession :……………………………………………………………………………………….

Institution :……………………………………………………………………………………….

Département :…………………………………………………………………………………….

Adresse :………………………………………………………………………………………….

Téléphone :……………………………………………………………………………………….

Fax :……………………………………………………………………………………………...

E-mail :…………………………………………………………………………………………...

Site internet :……………………………………………………………………………………..

PARTIE A: EVALUATION DES IMPACTS FUTURS

Quelle est la sensibilité des ressources en eau des différentes zones du bassin de la Comoé, ci-dessous mentionnées, aux changements climatiques?

Zone côtière

Très sensible : ☐ Sensible : ☐ Moins sensible : ☐ Pas sensible : ☐

Ces informations sont basées sur :

Les connaissances d'un Expert : ☐

Des travaux de recherches : ☐ Donnez les références :..

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Autre : ☐ à préciser :
…………………………………………………………………………………………………
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Zone urbaine

Très sensible : □ Sensible : □ Moins sensible : □ Pas sensible : □

Ces informations sont basées sur :

Les connaissances d'un Expert : □

Des travaux de recherches : □ Donnez les références :...

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Autre : □ à préciser :
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Zone agricole

Très sensible : □ Sensible : □ Moins sensible : □ Pas sensible : □

Ces informations sont basées sur :

Les connaissances d'un Expert : □

Des travaux de recherches : □ Donnez les références :...

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Autre : □ à préciser :
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Zone industrielle

Très sensible : □ Sensible : □ Moins sensible : □ Pas sensible : □

Ces informations sont basées sur :

Les connaissances d'un Expert : □

Des travaux de recherches : □ Donnez les références :...

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Autre : ☐ à préciser :
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Autres zones, spécifiez

Très sensible : ☐ Sensible : ☐ Moins sensible : ☐ Pas sensible : ☐

Ces informations sont basées sur :

Les connaissances d'un Expert : ☐

Des travaux de recherches : ☐ Donnez les références :...

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Autre : ☐ à préciser :
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Quels seront, dans le futur, les perturbations dues aux changements climatiques dans les ressources en eau du bassin de la Comoé? Quantifiez ces perturbations en pourcentage sur la base de vos connaissances personnelles. Précisez la région ou la saison durant laquelle ces perturbations seront les plus prononcées.

	Perturbation	**Région Spécifique /saison**
Augmentation de la pluie de	__%	
Diminution de la pluie de	__%	
Augmentation des écoulements de	__%	
Diminution des écoulements de	__%	
Augmentation de la recharge des eaux souterraines de	__%	
Diminution de la recharge des eaux souterraines de	__%	
Augmentation de la fréquence des inondations de	__%	

	Perturbation	**Région Spécifique /saison**
Diminution de la fréquence des inondations de	__%	
Augmentation de la fréquence de la sécheresse de	__%	
Diminution de la fréquence de la sécheresse de	__%	
Augmentation du niveau de la mer	__cm	
Diminution du niveau de la mer	__cm	
Autres, spécifiez:		

Quel est l'impact des éventuelles perturbations causées par les changements climatiques sur les différentes composantes des ressources en eau ? Dans le cas où les effets varieraient dans l'espace, spécifiez la région la plus affectée.

	Très négatif	**Négatif**	**Pas d'effet ou négligeable**	**Positif**	**Très positif**	**Région particulièrement affectée**	**Source d'information**
Augmentation des précipitations							
Diminution des précipitations							
Augmentation de la variabilité des précipitations							
Diminution des écoulements							
Augmentation des écoulements							
Augmentation de la variabilité des écoulements							
Diminution de la recharge des eaux souterraines							

	Très négatif	**Négatif**	**Pas d'effet ou négligeable**	**Positif**	**Très positif**	**Région particulièrement affectée**	**Source d'information**
Augmentation de la recharge des eaux souterraines							
Dégradation de la qualité des eaux de surface							
Dégradation de la qualité des eaux souterraines							
Augmentation des risques d'inondation							
Augmentation des risques de sécheresse							
Augmentation du niveau de la mer							
Autres, spécifiez							

Donnez une estimation des impacts que les changements dans le climat et des composantes des ressources en eau auront sur les différents secteurs économiques. Complétez de –2 à +2 selon le cas (-2 = effet très négatif; -1 = effet négatif, 0 = pas d'effet ou négligeable; +1 = effet positif, +2 = effet très positif).

	Approvisionnement en eau[1]	Gestion des eaux usées[2]	Gestion des inondations	Agriculture[3]	Energie/industrie[4]	Tourisme[5]	Navigation	Autres transport[6]	Pêche[7]	Forêts[8]
Augmentation des précipitations, écoulement élevé, augmentation de la fréquence et l'intensité des inondations										

1 Réduction de la disponibilité en eau/pénuries d'eau pour les consommateurs.
2 Pression sur le système de drainage, d'évacuation et de traitement des eaux usées.
3 Perte de production, nécessité de développement de l'irrigation
4 Diminution du potentiel hydroélectrique, dégâts des inondations.
5 Baisse du nombre de touristes du fait de l'augmentation des précipitations, chaleur ou pénuries d'eau.
6 Dégâts des infrastructures.
7 Baisse de la population de poisson ou réduction de la diversité des espèces.
8 Destruction ou perte du fait de la sécheresse, augmentation du risque de feux de brousse.

	Approvisionnement en eau[1]	Gestion des eaux usées[2]	Gestion des inondations	Agriculture[3]	Energie/industrie[4]	Tourisme[5]	Navigation	Autres transport[6]	Pêche[7]	Forêts[8]
Diminution des précipitations, faibles débits, diminution de la recharge des eaux souterraines, risques élevés de sécheresse										
Augmentation de la variabilité des précipitations et des débits										
Dégradation de la qualité des eaux de surface et souterraines										
Augmentation du niveau des mers										
Autres, spécifiez										

Quels impacts devraient avoir les changements climatiques sur les ressources en eau au niveau des secteurs non-économiques (biodiversité, santé humaine, etc.) dans le bassin de la Comoé ?

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Indiquez les impacts potentiels des changements climatiques sur la société

Perte économique : □

Diminution de la viabilité économique des activités : □

Conflits entre usagers de l’eau : □

Destruction des propriétés/infrastructures : □

Dégradation de la santé : □

Perte en vie humaine : □

Autre : □ à préciser :
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PARTIE B: MESURES D'ADAPTATION

Parmi les potentielles mesures d'adaptation mentionnées dans le tableau ci-après, indiquez celles qui ont été utilisées ou qui sont prévues dans le bassin de la Comoé comme réponse à la question du changement climatique. Quelle est, selon vous, la mesure qui est nécessaire et/ou effective dans la résolution du problème relatif aux changements climatiques ? Ajoutez d'autres mesures d'adaptation si nécessaire.

Mesures d'adaptation	**Réalisées**	**Prévues**	**Effective/-nécessaire (mais pas encore prévue)**	**Négligeable/ nécessaire**
Protection contre les inondations				
Protection technique (construction de digues, agrandissement des réservoirs, amélioration du système de drainage)				
Rétention naturelle des eaux de crue (réalisation des bassins d'orage, changement dans l'occupation du sol)				
Interdiction de construction dans les zones à risque				
Développement des prévisions, du suivi et de l'information				
Autres, précisez :				

Mesures d'adaptation	Réalisées	Prévues	Effective/-nécessaire (mais pas encore prévue)	Négligeable/ nécessaire
Protection contre la sécheresse/faibles débits				
Mesures techniques pour augmenter l'approvisionnement (retenues d'eau, transferts d'eau)				
Augmentation efficiente de l'utilisation de l'eau (réduction des fuites d'eau, irrigation efficiente)				
Instruments économiques (fixation du prix de l'eau)				
Mesures de planification du paysage (changement de l'occupation du sol, reforestation)				
Développement des prévisions, du suivi et de l'information				
Autres, précisez :				
Zone côtière				
Renforcement des infrastructures de protection de la côte				

Mesures d’adaptation	**Réalisées**	**Prévues**	**Effective/-nécessaire (mais pas encore prévue)**	**Négligeable/ nécessaire**
Autres, précisez :				
Mesures générales d’adaptation				
Cadre législatif et institutionnel				
Mesures d’incitations économiques et financières				
Campagnes de sensibilisation				
Autres, précisez :				

PARTIE C: TITRE DE L'INITIATIVE/ACTION D'ADAPTATION

Existe-t-il des actions ou mesures d'adaptation aux impacts du changement climatique dans le bassin de la Comoé ? Si oui, donnez plus d'informations pour chaque action ou mesure.

Description sommaire (quelle est l'action/initiative d'adaptation ?)

<table>
<tr><td>Objectif de la mesure</td><td colspan="2">Brève description de l'initiative d'adaptation</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="6">Secteurs clés de l'eau</td><td></td><td>Gestion de la demande</td></tr>
<tr><td></td><td>Gestion de l'approvisionnement</td></tr>
<tr><td></td><td>Gestion des risques de crue/inondation (infrastructures, système d'alarme)</td></tr>
<tr><td></td><td>Qualité des eaux</td></tr>
<tr><td></td><td>Gestion du cycle hydrologique (hydroélectricité, retenue d'eau,)</td></tr>
<tr><td></td><td>Autres (pêche, recréation)</td></tr>
<tr><td rowspan="3">Echelle administrative et de gestion</td><td></td><td>Transfrontalier</td></tr>
<tr><td></td><td>National</td></tr>
<tr><td></td><td>Local</td></tr>
<tr><td>Localisation géographique</td><td colspan="2">Quelle est le lieu de mise en place de l'initiative d'adaptation ?</td></tr>
<tr><td colspan="3"></td></tr>
</table>

Institution(s) (qui est impliqué ?)

<table>
<tr><td>Institution</td><td>Nom</td></tr>
<tr><td colspan="2"></td></tr>
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Propriété	Publique, privée ou organisation non-gouvernemental (ONG)
Partie prenante	Publique/ organisations du secteur privé, communautés, individus

Merci pour votre coopération !

Appendix 3 : Water users representatives

Region	Departement	SousPrefecture	Village	Groupe social	Representant	Tel / Cel
Me	Yakasse-Attobrou	Abongoua	Abongoua	Paysans	N'Din Yahe	(+225) 45037682 / 48326812
Me	Yakasse-Attobrou	Abongoua	Abongoua	Instituteur	Komin	(+225) 45649602 / 57680348
Me	Yakasse-Attobrou	Abongoua	Abongoua	Infirmier		(+225) 08753657
Me	Yakasse-Attobrou	Abongoua	Mbasso	Chefferie, Enseignants	YAPI Seka Theodore	(+225) 09667686 / 45470111
Me	Yakasse-Attobrou	Abongoua	Mbasso	Pecheurs	DIARRA Moumine	(+225) 07278205
Indenie-Djuablin	Abengourou	Aniassue	Aniassue	Chef Canton, Notables	Nanan KOUAME Amoikan	(+225) 08144874
Indenie-Djuablin	Abengourou	Aniassue	Aniassue	Cooperatives	Seydou Serme	(+225) 07477020
Indenie-Djuablin	Abengourou	Aniassue	Aniassue	Personnel Sante	Dr ZEOUA Bi B Daniel	(+225) 07197054
Indenie-Djuablin	Abengourou	Aniassue	Satikran	Chefferie	Nanan KOUADIO Kouakou	(+225) 46503986
Indenie-Djuablin	Abengourou	Aniassue	Satikran	Notables	Kabran Mian Kouadio	(+225) 04870724
Indenie-Djuablin	Abengourou	Aniassue	Satikran	Cooperatives	KROU Kouame	(+225) 44177166
Indenie-Djuablin	Abengourou	Aniassue	Satikran	Personnel Sante	KINI Kanga Catherine	(+225) 46204693
Indenie-Djuablin	Abengourou	Aniassue	Satikran	Personnel Sante	KOUE Nda Joanane	(+225) 06024267
Indenie-Djuablin	Abengourou	Aniassue	Satikran	Personnel Sante	SORO Nazeteni	(+225) 45082279
Indenie-Djuablin	Abengourou	Aniassue	Amangouakro	Chefferie	Nanan KRAMO Adie	

Indenie-Djuablin	Abengourou	Aniassue	Amangouakro	Notables	ETTIAN Edoukou	(+225) 05718747
Indenie-Djuablin	Abengourou	Aniassue	Amangouakro	Jeunes	N'Guelle Kouadio	(+225) 06277720
Indenie-Djuablin	Abengourou	Amelekia	Taakro	Chefferie	Nanan Adake Kouassi Frederic	(+225) 06900289
Indenie-Djuablin	Abengourou	Amelekia	Taakro	Notables	Tanoh N'Draman Jean Claude	(+225) 47145959
Indenie-Djuablin	Abengourou	Amelekia	Taakro	Jeunes	Konin Niangoran Antoine	(+225) 47130720
Indenie-Djuablin	Abengourou	Amelekia	Elinso	Chefferie	ADOU Atahi	(+225) 07936354
Indenie-Djuablin	Abengourou	Amelekia	Elinso	Notables	Tiemele Koffi	(+225) 48913707
Indenie-Djuablin	Abengourou	Amelekia	Elinso	Jeunes	KOUADIO Assoumou Andre	(+225) 09387928
Indenie-Djuablin	Abengourou	Amelekia	Amelekia	Chefferie	Nanan ADOU Koffi	
Indenie-Djuablin	Abengourou	Amelekia	Amelekia	Notables	AKA Oiaka	(+225) 09091482
Indenie-Djuablin	Abengourou	Amelekia	Amelekia	Jeunes	KONAN Kouame Didier	(+225) 07416546
Indenie-Djuablin	Abengourou	Amelekia	Amelekia	Cooperatives	KANGAH Ebrotie Jean Baptiste	(+225) 07803898 / 01267329
Indenie-Djuablin	Abengourou	Amelekia	Amelekia	Personnel Sante	Dr KOUAME Francis	(+225) 47002764
Indenie-Djuablin	Abengourou	Yakasse-Feyasse	Sankadiokro	Chefferie	N'Gouandi	(+225) 08599931 / 01812559
Indenie-Djuablin	Abengourou	Yakasse-Feyasse	Sankadiokro	Personnel Sante	Dr Amane Olivier	(+225) 07926039
Indenie-Djuablin	Abengourou	Yakasse-Feyasse	Sankadiokro	Cooperatives	Eponon	(+225) 07301028 / 56035454
Indenie-Djuablin	Abengourou	Yakasse-Feyasse	Sankadiokro	Cooperatives	Ani Jean	(+225) 09346108

Indenie-Djuablin	Abengourou	Yakasse-Feyasse	Sankadiokro	Cooperatives	Anouble Kouao	(+225) 48034473 / 04310607
Indenie-Djuablin	Agnibilekro	Dou Flebo	Amoriakro	Chefferie	Nanan Assemien Kouakou	(+225) 09886884 / 04685356
Indenie-Djuablin	Agnibilekro	Dou Flebo	Amoriakro	Notables	Konan Josue	(+225) 08096204
Indenie-Djuablin	Agnibilekro	Dou Flebo	Amoriakro	Jeunes	KANGAH Kangah Emmanuel	(+225) 09265292 / 07427389
Indenie-Djuablin	Agnibilekro	Dou Flebo	Amoriakro	Infirmier	Kouame Kouakou Augustin	(+225) 09486147
Indenie-Djuablin	Agnibilekro	Dou Flebo	Amoriakro	Sage Femme	KOFFI Brou Anasthasie	(+225) 07326968
Indenie-Djuablin	Agnibilekro	Dou Flebo	Kokonou	Chefferie	KANGAH Anik	(+225) 48493910 / 07759990
Indenie-Djuablin	Agnibilekro	Dou Flebo	Kokonou	Notables	KRAMO N'Guessan Justin	(+225) 58485388
Indenie-Djuablin	Agnibilekro	Dou Flebo	Kokonou	Infirmier	KONAN Louis Olivier	(+225) 07266995
Indenie-Djuablin	Agnibilekro	Dou Flebo	Agninikro	Chefferie	KONE Ouahogninlin	(+225) 49190276 / 03047083
Indenie-Djuablin	Agnibilekro	Dou Flebo	Agninikro	Personnel Sante	YAO Koffi	(+225) 01864850
Indenie-Djuablin	Agnibilekro	Dou Flebo	Comoe N'Danou	Chefferie	KOUAKOU Kangah Christophe	(+225) 47685545
Indenie-Djuablin	Agnibilekro	Dou Flebo	Comoe N'Danou	Infirmier	N'GORAN Jean	(+225) 07765403
Indenie-Djuablin	Agnibilekro	Agnibilekro	Yobouakro	Chefferie	Kouassi Koumi	(+225) 48518001
Indenie-Djuablin	Agnibilekro	Agnibilekro	Yobouakro	Notables	Agnimou Abe Bernard	(+225) 07345616
Indenie-Djuablin	Agnibilekro	Agnibilekro	Yobouakro	Infirmier	KOUADIO Paul Herve	(+225) 01995056
Indenie-Djuablin	Agnibilekro	Agnibilekro	Yobouakro	Cooperatives	Ouedraogo Alidou	(+225) 55419737

Iffou	Daoukro	Daoukro	Amoikonkro	Chefferie	Koffi Dra Rene	(+225) 49292803
Iffou	Daoukro	Daoukro	Amoikonkro	Jeunes	Kouadio Laurent	(+225) 57741156
Gontougo	Koun Fao	Tankesse	N'Dakro	Chefferie	Nango Brou Antoine	
Gontougo	Koun Fao	Tankesse	N'Dakro	Notables	Adou Kangah Rufin	(+225) 57998039
Gontougo	Koun Fao	Tankesse	N'Dakro	Jeunes	KOFFI Yao Roger	(+225) 03658994
Gontougo	Koun Fao	Tankesse	N'Dakro	Personnel Sante	OBOUTE Sako Sylvain	(+225) 07827554 / 04645426
Gontougo	Koun Fao	Koun Fao	Yomankro	Chefferie	Nanan Kouakou Koffi	(+225) 77503968
Gontougo	Koun Fao	Koun Fao	Yomankro	Jeunes	KOUASSI Assoumou	(+225) 08672860
Gontougo	Koun Fao	Krakro	Abokossou	Chefferie	Nanan KOUADIO Arouna Bile	
Gontougo	Koun Fao	Krakro	Abokossou	Jeunes	Adingra Sinan	(+225) 07135079
Gontougo	Sandegue	Dimandougou	Logotan	Chefferie	OUATTARA Issouf	
Gontougo	Sandegue	Dimandougou	Logotan	Jeunes	OUATTARA Adama	(+225) 05088865
Iffou	Prikro	Famien	Serebou	Chefferie	Brahima	(+225) 48454185
Iffou	Prikro	Famien	Serebou	Jeunes	Anjoumane Simon	(+225) 57777946
Gontougo	Tanda	Tchedio	Essikro	Chefferie	Adama Kobenan	
Gontougo	Tanda	Tchedio	Essikro	Jeunes	Koffi Gregoire	(+225) 57402353 / 46884968
Gontougo	Tanda	Tchedio	Essikro	Personnel Sante	Karl Kodja	(+225) 09416649

Appendix 4: Stakeholder representatives

Localite	Profession	Institution	Nom	Tel / Cel	Email	Adresse
Abongoua	Technicien Agronome	ANADER	TRAORE Seriba			
Tanda	DD Abengourou	Eaux et Forets	Lt Ehui Boniface	(+225) 07788324	ehuilapaix@yahoo.fr	
Tanda	Chef de zone	ANADER	KOFFI Ahou Colette Epse KACOU		zonetanda@yahoo.fr	
Tanda	Chef de service	ANADER	BENIE Emmanuel	(+225) 01511192 / 08681476	bkmanou@gmail.com	
Tanda	Agent d'Agriculture	DD Agriculture	KOUAKOU Koffi Samuel	(+225) 35918005 / 08827170		BP 53
Agnibilekrou	Specialiste Organisation Professionnelle Agricole	ANADER	KOUAME Felix	(+225) 03490555 / 09028132	kokofelix41@gmail.com	
Agnibilekrou	Assistante des Productions Vegetales et Animales	DD Agriculture	AHUA Danan Eugenie	(+225) 35910016 / 07229498		BP 49
KounFao	Officier Eaux et Forets	Cantonnement Forestier	Capitaine Adingra Adaye	(+225) 07881470		
KounFao	Agent Developpement Rural	ANADER	MOZOU Theophile	(+225) 07525728		
Abengourou	Ingenieur Agro-Economiste	DR Agriculture	ABONZAN Brou	(+225) 35913684 / 47047339		
Abengourou	Chef de Service Production et Controle de la Qualite		KONAN Brou	(+225) 07648199	attagloinbrou@yahoo.fr	
Abengourou	Chef de zone	ANADER	AHOU Mathurin	(+225) 35913345 / 01079792	alloumath@yahoo.fr	
Abengourou	Agent	DR Agriculture	BROU			
Abengourou	Geometre	SODEFOR	PLO Bernard	(+225) 07793723	plobernard@yahoo.fr	BP 464

Appendix 5: Publication

Yéo, W.E., Goula, B.T.A., Diekkrüger, B. et al., 2016 Vulnerability and adaptation to climate change in the Comoe River Basin (West Africa). SpringerPlus (2016) 5: 847. doi:10.1186/s40064-016-2491-z

Born in Napie - Cote d'Ivoire, YEO Wonnan Eugène was a PhD student in the GRP CCWR at University of Abomey Calavi (Benin) in a framework of WASCAL Project. He is currently Deputy Director of Studies and Planning at the Ministry of Economic Infrastructures (Cote d'Ivoire). He is also member of the national Comity of Reducing emissions from deforestation and forest degradation (REDD+), the Hydrology Research Group of the University of Bonn and the National Water Partnership of Cote d'Ivoire (National Section of GWP- West Africa). He completed two masters respectively in Hydrogeology and Integrated Water Resources Management (IWRM) respectively at the University of Felix Houphouet Boigny - Cote d'Ivoire and the International Institute for Water and Environment Engineering (2iE) of Ouagadougou – Burkina Faso.

Abstract:
This study was carried out on the Comoe River Basin (78,000 km2) in West Africa where climate change is supposed to affect many sectors like water resources, biodiversity, food, energy, housing, tourism, transportation and health. This study used the GR4J model and three RCM, namely, the COnsortium for SMall scale MOdeling Climate Limited-area Modeling-Community, the KNMI Regional Atmospheric Climate Model and the Rossby Centre Atmospheric model 4 to assess the robustness of a lumped hydrological model in modelling streamflow and to examine climate change effects on streamflow in the Comoe River Basin using the RCP 4.5 and 8.5 scenarios. Future period's streamflow were simulated under these scenarios using the GR4J model. The comparison of mean yearly discharge for 2041-2060 and 2081-2100 periods to 1981-2000 at M'Basso revealed that flows will decrease respectively for 2041-2060 and 2081-2100 periods about 41% and 45% according to the scenario RCP 4.5 KNMI-RACMO22T model. The decrease of flows following RCP 8.5 for the same periods is about 46% and 44%. High flow and low flow periods are quit the same for the three RCM. The two scenarios and the three RCM reveal an increase of temperature up to 5.6°C for 2041-2060 and 2081-2100 periods at Abidjan, Adiake, Dimbokro, Bondoukou and Bobo Dioulasso stations. Also, temperatures for 2081-2100 are higher than the ones of 2041-2060 period. The highest values are generally observed in January. Findings from this study revealed an underestimation of mean annual rainfall, 0.4 to 0.6 for RCP4.5 and 0.5 to 0.8 for RCP8.5 for 2041-2060 and 2081-2100 periods. Whereas, SMHI-RCA4 and KNMI-RACMO22T are overestimating mean annual rainfall, 0.2 to 0.3 for RCP4.5 and 0.1 to 0.5 for RCP8.5. Hydrologic and climatic parameters comparison at M'Basso for 1981-2000, 2041-2060 and 2081-2100 periods revealed an increase of potential evopotranspiration for the two horizons and for the three RCM and a decrease of discharge. The vulnerability of water users to climate change was assessed and communities' adaptation strategies were defined. Results revealed that 95% of water users are perceiving changes in climate. They have heard of climate change and they attested that there is an increasing occurrence of this phenomenon. Reduced water level in rivers, delay in cropping season, crop failure, new pests and diseases, drop in income and decline in crop yield, food insecurity, changes in economic activity and cropping pattern are different ways that they are experiencing climate change. Findings also revealed that water users use many adaptation strategies like agroforestry, substitution and calendar redefinition, increasing fertilizer application, crops diversification, borrowing from friends and money lenders.

Key words: Climate change, Vulnerability, Water user, Adaptation strategy, Comoe River Basin.

PhD

YEO Wonnan
Eugène

EFFECTS OF CLIMATE CHANGE AND HUMAN ACTIVITIES ON WATER RESOURCES IN THE COMOE RIVER BASIN (WEST AFRICA)

GRP/CCWR/INE/WASCAL – UAC August, 2017