Modeling Future Water Deficit Trends under Varying Climate Change Projections in Huai-SamMor Basin, Thailand

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Abstract. *This study, two global climate change predictions (RCP4.5 and RCP8.5) are used to forecast severity of drought occurrence in Huai-SamMor basin. The study examines severity of future drought conditions using Generalized Monsoon Index (GMI) which is separated into four future periods: near future, middle future 1, middle future 2 and far future. The research finding indicated that for RCP8.5 scenario, CESM1_CAM5 and NorESM models were identified as most suitable. In contrast, for RCP4.5 scenario, CNRM and Miroc5 models were selected as most suitable. These selections were made using CMIP5 model as basis for evaluation. When considering GMI index and global climate change forecasts for both southwest and northeast monsoon scenarios, RCP8.5 projection indicate greater severity than RCP4.5. The findings suggest that frequency of drought occurrences increases by approximately 15–34% under RCP8.5 compared to RCP4.5, particularly during dry season and in far future. Additionally, in RCP8.5, dryness is significantly exacerbated by elevated temperatures and reduced precipitation at critical periods. In contrast, northeast monsoon scenario exhibits highest degree of drought severity in far future in both RCP4.5 and RCP8.5 when comparing different time periods. Examinations of spatial and temporal patterns during northeast monsoon reveal a progressive intensification of drought severity over time, with most pronounced effects anticipated in far future. The basin's western and upper sections emerge as areas of elevated risk, underscoring notable regional variations in drought vulnerability. These observations suggest that global warming expedites hydrological cycles, contributing to an increased frequency and intensity of droughts. However, no existing studies have specifically utilized Generalized Monsoon Index (GMI) to forecast drought-prone areas under future climate scenarios, leaving a critical gap in understanding severity of monsoon-induced droughts. This research addresses that gap and reveals a 15-34% increase in drought frequency under RCP8.5 relative to RCP4.5, with upper and western sections of Huai-SamMor basin facing the highest vulnerability.*

Keywords: GMI, Generalized Monsoon Index, Future Drought, Global Climate Models, CMIP5

1. Introduction

A significant challenge in this century is widespread effect of global climate change on water resources and sustainability of agriculture. These changes can be recognized by change in intensity, duration, and spatial distribution of rainfall, which result in substantial fluctuations in water availability [10]. Variation in occurrence and intensity of drought are among most important effect of climate change, and they present serious threats to ecosystems, economies, and human live [33]. Prolonged drought, characterized by inadequate precipitation, it may result in significant water shortages, diminished agricultural production and heightened food insecurity risk. [14]. Region that are heavily dependent on monsoon rainfall are particularly susceptible to these effects, as variability and unpredictability of monsoon pattern can result in either severe drought or devastating flooding [7]. Prolonged rainfall deficit result in drought, which consequently restrict ecosystem function and present substantial socioeconomic obstacle. There are several primary factors that contribute to drought, including duration of drought, size of afflicted area, extreme temperatures during summer, low air humidity, and prolonged period of little or no rain during rainfall season. Rainfall, most significant of all meteorological variable, largely influences severity and impact of drought. Droughts are generally classified into three main types: When the quantity of rainfall is substantially lower than average or when there is a substantial reduction in precipitation days throughout an extensive region for an extended duration, a meteorological drought occurs. A hydrological drought is a condition in which availability of water is impacted by a reduction in water levels in rivers, canals, lakes, reservoirs, or groundwater sources. Agricultural drought results from both climatic and hydrological calamities [42]. It occurs when soil moisture is inadequate due to insufficient rainfall and inefficient distribution. When actual evapotranspiration is higher than potential evapotranspiration, groundwater replenishment and surface water sources are both lower. This makes farming less productive [22]. Drought has widespread impacts. Government expenditure on calamity relief increases as a result of decreased agricultural production, which in turn raises food prices. In addition, drought results in an increase in unemployment rate. especially among farmers who were later forced to move to urban areas This results in worsening social and economic problems. Insufficient water storage infrastructure the amount of rainfall is irregular and uneven, and soil's water storage capacity is insufficient. All of these are factors that cause these droughts. Deforestation and lifestyle changes have contributed to environmental degradation, which has exacerbated global warming. This has exacerbated climate change, resulting in extreme weather fluctuations, with some years experiencing excessive rainfall and others experiencing droughts. The subsequent water shortages affect not only households but also agriculture, industry, and ecosystems. This has contributed to climate change, which has led to extreme weather patterns. While some years see abundant rainfall, others suffer from severe drought. The majority of droughts in Thailand are result of prolonged arid spells or irregular rainfall [10]. For example, droughts impacted 71 of 76 provinces in 2008, resulting in destruction of 5.48 million acres of agricultural land. The lack of tropical cyclones and its reduced exposure to southwest monsoon significantly affected northeastern region [14]. Consequently, the monsoon system significantly impacts droughts. In addition, drought results in an increase in unemployment rate. Especially among farmers who later had to move to urban areas. Huai-SamMor basin, situated in drought-prone region of northeast Thailand, normally relies on monsoon for water supply. The inconsistency and diminishing predictability of monsoon patterns have intensified water shortages in this area. This uncertainty is impacting lives of those in river basins, agriculture, and water resources. As climate change exacerbates droughts, alters precipitation patterns, and undermines conventional water management strategies, it is more imperative to address these challenges [9]. Consequently, the appraisal and forecasting of droughts for purpose of effective resource management continue to be a multifaceted challenge. We employ multitude of methodologie, each with its own set of advantage and disadvantage to evaluate drought risk. Meteorological indices like Standardized Precipitation Index and Palmer Drought Severity Index are often used in traditional ways to measure how far moisture and precipitation conditions are from normal. Nonetheless, these indices mostly derived from historical data, may not adequately reflect complexities introduced by climate change, particularly in regions like Huai-SamMor basin, where monsoon variability is crucial. Generalized Monsoon Index (GMI) is used to examine seasonal precipitation data and evaluate dry conditions in certain locations. This measure may enhance our comprehension of monsoon activity and it is anomalies, which often indicate drought conditions. A risk index reflecting impacts of monsoon has been developed, with risk map that may be used for disaster risk reduction and management [22]. This research focuses on Huai-SamMor basin, providing valuable insights into impact of climate change on monsoon weather pattern and drought risk in the region. The findings will be crucial as they will assist policymaker, water resource manager, and local population in implementing sustainable practice that enhance basin's water resources' resilience to climate change-induced droughts [11]. One of its most critical effects is disruption of water resources due to shift in temperature and precipitation, leading to extreme weather events such as flood and drought [38]. These changes threaten water security, agriculture, and disaster resilience, necessitating effective adaptation and mitigation strategies [37]. Research highlights increasing severity of climate-induced hydrological extreme. In Indonesia's Ayung watershed, projected rainfall variation may cause both severe flood and prolonged drought. Similarly, studies in Thailand predict a rise in meteorological and agricultural drought, especially in monsoon-dependent region [39]. These findings stress importance of advanced climate modeling and risk assessment to guide water resource management [36]. Strategic Environmental Assessments (SEA) play a crucial role in integrating climate adaptation into water governance. SEA frameworks, accordance with Sustainable Development Goals (SDGs) of United Nations, provide a structured method for evaluating climate risk and implementing sustainable river basin management [40]. Incorporating perspective such as People, Planet, Prosperity, Peace, and Partnership (5Ps) enhance resilience against climate-related disaster through inclusive decision-making and equitable resource distribution [40]. Dam and reservoir management face additional challenges due to climate change. Research on Thailand's Bhumibol Dam suggests that changing precipitation pattern will affect reservoir inflow, requiring modifications in operational strategies such as adapted rule curve and hedging policies [36]. Similarly, assessments of Lam Khan Chu Dam emphasize need for groundwater monitoring and hydrological modeling to ensure dam safety under extreme climate condition. These studies highlight necessity of predictive climate model and adaptive management strategies to mitigate water-related risk [37]. Given the increasing unpredictability of hydrological pattern, bridging climate science with water resource engineering is essential to assess impacts of climate change on water availability and develop adaptive management strategies for sustainable water governance [39]. The findings will provide valuable insights for policymakers, engineers, and water resource managers, guiding them in designing effective frameworks that enhance water security and resilience [37]. The results will support evidence-based decision-making, enabling proactive response to mitigate climate-related challenge. As climate variability continue to disrupt traditional water management strategies, it will contribute to shaping effective adaptation and mitigation policies for a more sustainable future [40].

This study is essential as climate change increasingly disrupt monsoon patterns, leading to greater drought risk and challenges in water resource management. While previous studies have relied on traditional drought indice such as SPI and PDSI [17], there has been no specific research utilizing Generalized Monsoon Index (GMI) to predict future drought-prone area under climate change scenarios. Recent research has indicated that drought conditions in Thailand are becoming more severe due to unpredictable monsoonal variation and shifting climate patterns [39] . Furthermore, sustainable river basin management strategies still lack analytical frameworks that fully integrate dynamic nature of monsoon variability [40] . This study aims to bridge this research gap by employing GMI, comprehensive index incorporating multiple climatic factor such as atmospheric pressure, wind patterns, and temperature anomalies to enhance accuracy of drought risk assessment (Wang et al., 2001). The findings from this research will contribute to developing sustainable water management strategies, improving agricultural planning and strengthening community resilience against intensifying drought conditions in future.

2. Methodology

A. Study area and Data

Huai-SamMor basin part of larger Chi watershed in Thailand is characterized by its rectangular shape as seen in Figure 1. Bordered on western, southern, and eastern sides by ridges of Lan Kha, Phu Khong, and Phu Meng mountain ranges, watershed has elevation ranging from 400 to 800 meters above mean sea level. central portion of watershed consists of lowland plain with elevation between 100 and 200 meters. Flowing northwest to southeast, Huai-SamMor basin eventually empties into Chi River. Study area is situated between latitudes 15° 58' and 16° 16' North, and longitudes 102° 05' and 102° 25' East, encompassing total area of 746.88 square kilometers. Huai-SamMor basin extends across two province and four districts: Phu Khiao and Kaeng Khoi districts in Chaiyaphum Province and Khon Sawan and Kok Pho Chai districts in Khon Kaen Province. The region receives average annual rainfall of approximately 1,100 millimeters contributing to an estimated average annual natural runoff of 149 million cubic meters. The majority of agricultural land within watershed is allocated to rice cultivation, which primarily depends on rainfall.

Meteorological data for Huai-SamMor area, including rainfall and number of rainy days, was acquired for 2009 to 2023. Monthly precipitation data was obtained from Meteorological Department situated in Huai-SamMor basin and its surrounding area. Rainfall stations were selected for analysis of drought conditions in Huai-SamMor basin. The selection criteria were that stations must have a long data record and be distributed throughout watershed. Which has the following selection steps: 1) Check continuity and duration of data at each station to ensure that data is complete. 2) After verifying continuity and duration, select stations with sufficient data for further analysis. Assess accuracy of data by reviewing annual rainfall records at each station to identify any anomalies. 3) Select stations for analysis based on coverage of study area. In addition, normal ratio method is used to estimate missing rainfall. normal ratio is a statistical technique used to estimate missing rainfall based on assumption that ratio of missing values to normal annual rainfall at a station will be approximately same as average ratio of normal annual rainfall at surrounding stations.

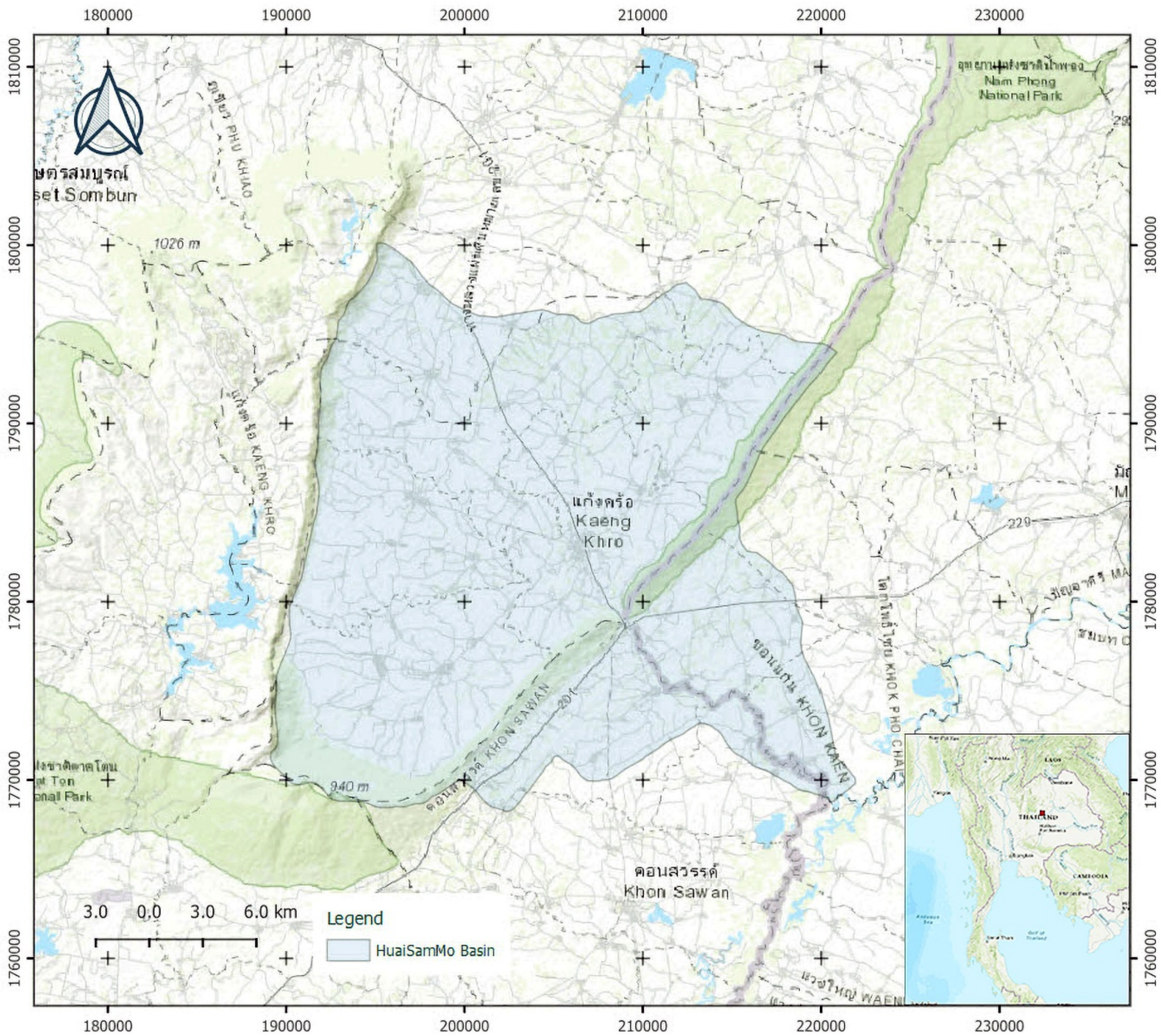

Figure 1. The Huai-SamMor basin

B. Climate Change Couple Model Intercomparison Project Phase 5 (CMIP5)

Climate change denotes the transformation of climatic conditions caused by human behaviors that modify the composition of the Earth's atmosphere. This phenomenon goes beyond natural fluctuations of climate seen in similar historical periods, including important factors like temperature, humidity, precipitation, and seasonal changes. These factors are essential for survival of living organism, as they are required to adapt to climatic conditions of their ecosystems. Intergovernmental Panel on Climate Change: IPCC, 2000 The dialogue about climate change has become increasingly pressing in recent years reflecting swift advancement of its impacts and gravity of its repercussions. The majority of academic think that this phenomenon is brought on by burning of fossil fuels, which for past 200 years have served as primary energy source for growth of industry. The heavy reliance on fossil fuels has significantly increased concentration of greenhouse gases in atmosphere, which in turn exacerbates effects of greenhouse gases and contributes to global warming. Global warming presents serious challenges to survival of living organism by raising average temperature, disrupting established seasonal patterns and compelling species to adapt, migrate, or confront extinction. The effects on human populations are just as severe as those on other groups. Certain regions may be transformed into arid deserts as result of increasing temperature, which could lead to substantial food and water shortage. On the other hand, depending on amount of rainfall that occurs, some areas may experience flooding that is both more severe and more frequent. In addition, fast melting of polar ice caps and glaciers is a contributor to increasing sea levels which is putting coastal communities at risk and making it possible that low-lying places may be permanently flooded. Because of wide-ranging effects, climate change is a pressing global problem that call for concerted action from nation all over the world. The reduction of emissions of greenhouse gases and enhancement of resilience via implementation of adaptive method are both needed in order to address these concerns.

The evaluation of future climate change impact necessitates application of Global Climate Models (GCMs), which are employed to simulate climate conditions arising from variations in atmospheric greenhouse gas concentration. GCMs replicate physical processes occurring within atmosphere, oceans, sea ice and terrestrial systems by utilizing mathematical formulations to model atmospheric and oceanic circulatory dynamics. These models are built from Navier-Stokes equation that applies to the world that spins. They use basic thermodynamic concepts such as latent heat transfer, to show how these systems interact. To show how these systems interact, GCM uses numerical computational principles to integrate different types of fluid dynamics, chemical reactions and biological processes. The way these equations interact with each other makes it possible to run complex computer programs that let us model global climate systems. These models are very important for better understanding and predicting how climate will change in future. These tools are utilized to forecast weather pattern and analyze impact of climate fluctuation. In GCMs, vertical resolution includes 10 to 20 layers within atmosphere and exceed 30 layers in ocean, whereas horizontal resolutions vary between 100 and 300 kilometers. Climate representation in GCMs is achieved through use of three-dimensional grid cells. GCMs' relatively coarse spatial resolution, despite their utility, limits scope of detailed studies and impact assessments, particularly in regions where fine-scale climate processes are prominent. Also, real events like cloud dynamics happen at size that are much smaller than model's grid precision. Consequently, direct modeling is an impractical alternative. Parameterizations are employed to address and integrate grid cell processes, such as convection, land surface interactions, reflectivity, drainage and cloud coverage, in order to effectively address this challenge. Significant challenges arise when attempting to forecast future global climate scenarios, particularly due to reliance on parametrizations that struggle to accurately depict small-scale processes such as cloud formation and movement. Given existing uncertainties, GCMs should develop and improve their methods to increase accuracy and reliability of their predictions.

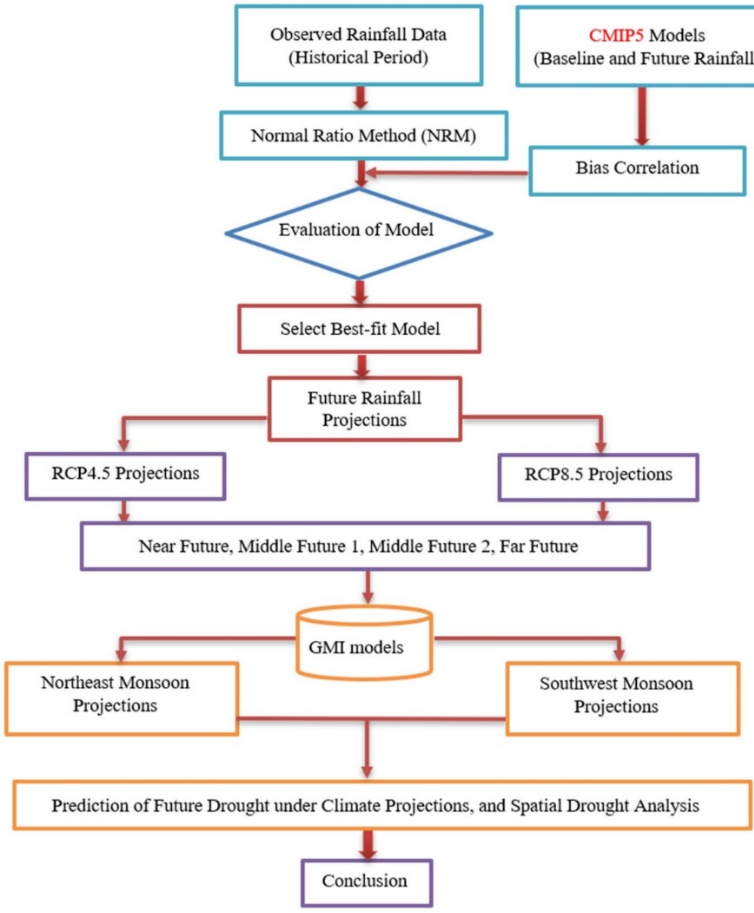

Figure 2. Schematic framework of research methodology

According to 5th Assessment Report of the Coupled Model Inter-comparison Project Phase 5 (CMIP5) by Intergovernmental Panel on Climate Change (IPCC), projected climate change impacts are categorized into pathways known as Representative Concentration Pathways (RCPs), which detail different levels of greenhouse gas emissions. The pathways include four distinct projections: RCP2.6, RCP4.5, RCP6.0, and RCP8.5, each signifying varying levels of greenhouse gas emissions. Every projection shows a clear increase in radiative forcing 2.6, 4.5, 6.0, and 8.5 watts per square meter, respectively leading to expected changes in average temperature, as well as maximum and minimum temperatures, along with average precipitation when compared to current conditions. Among these projections, RCP8.5 assumes no mitigation measures to reduce greenhouse gas emissions, while the other three incorporate varying degrees of emission reductions as outcomes of climate change mitigation policies implemented between 2000 and 2100 [12]. Nevertheless, atmospheric concentrations of greenhouse gases are projected to rise even under reduced emission projections, owing to extended timescale required for natural absorption of these gases. The relationship between current emission levels and accumulation of greenhouse gases in atmosphere, as defined by these pathways, is a critical parameter in climate models that are employed to simulate future climate conditions and assess associated impacts and vulnerabilities. RCP2.6 delineates a scenario marked by rigorous greenhouse gas reduction measures, whereas RCP4.5 and RCP6.0 signify moderate mitigation levels. Conversely, RCP8.5 represents a high-emission pathway marked by few mitigation initiatives. This research used RCP 4.5 and RCP 8.5 estimates to illustrate two future situations. This approach facilitates a more comprehensive understanding of potential impacts of future climate change, as simulated using CMIP5 model [5], and is summarized in Table 1. The anticipated future rainfall data from all models will be thoroughly examined and organized into distinct time frames. This technique allows an exhaustive assessment and precise illustration of predicted shifts in rainfall patterns throughout time, ranging from near future to far future. This framework enhances precision and lucidity of study findings, as seen in Figure 2. The study is organized into four discrete 20-year periods, delineated as follows: Period 1 (near future): 2024–2043, Period 2 (middle future 1): 2044–2063, Period 3 (middle future 2): 2064–2083, and Period 4 (far future): 2084–2100.

Table1 Name and resolution of 20 CMIP5 models used in this study

Model Name	Spatial Resolution
BCC	320x160
BNU	128x64
CanESM	128x64
CCSM4	288x192
CESM1_BGC, CESM1_CAM5	288x192
CNRM	256x128
CSIRO	192x96
EC_EARTH	320x160
FGOALS_g2, FGOALS_s2	128x60, 128x108
GFDL	144x90
IPSL_CM5A_LR, IPSL_CM5A_MR	96x96, 144x143
MIROC5, MIROC_ESM	256x128, 128x64
MPI_ESM_LR, MPI_ESM_MR	192x96
MRI_CGCM3	320x160
NorESM	144x96

C. Drought Index

Generally, drought is a complex phenomenon, influenced by both climatic and topographic factors. Drought is measured using a variety of techniques, including drought indices, surface and groundwater reduction, and rainfall deficit measurement. Drought indices are commonly used to assess drought conditions and their level of severity. Examining nature of drought Including intensity, duration, and frequency are essential for effective planning and management of water resources in basin. A number of variables and parameters are used to define drought conditions: rainfall and temperature. Volume of water in reservoir, land use, size of basin area, slope of river and soil type. These variables are integrated into statistical and mathematical models to generate drought indices. A drought index serves as a numerical depiction of severity of drought, utilizing climatic or hydrological data alongside previously mentioned indicators. By simplifying intricate environmental interactions into understandable metrics, drought indices enable quantitative evaluation of drought conditions, including severity, spatial extent, and duration. As a result, these indices serve as essential instruments for accurate and effective formulation of drought management strategies. Generalized Monsoon indicator (GMI), derived from Yield Monsoon Index (YMI) by Achutuni, Steyaert, and Sakimoto in 1982, serves as an agricultural drought indicator intended to measure effects of water deficits on plant growth. Plant development is divided into four separate stages: planting, vegetative, reproductive, and maturity, each with particular water needs. The reproductive stage is most water-intensive, followed by maturation stage. Conversely, sowing and vegetative phases require comparatively fewer water inputs. GMI evaluate total seasonal precipitation accumulated in order to evaluate efficacy of monsoon. Thailand is subject to two primary monsoon systems: southwest monsoon, this includes northeast monsoon and period from mid-May to mid-October, which lasts from mid-October to mid-February.

The analysis of Generalized Monsoon Index (GMI) values for southwest monsoon, which extends from mid-May to mid-October in Thailand, is carried out as follows:

$$GMI_{sw} = 0.125P_6+0.125P_7+0.5P_8+0.25P_9 \quad (1)$$

where GMI_{sw} represents GMI values during southwest monsoon season and P_6, P_7, P_8, P_9 represents quantity rainfall from June to September respectively.

The analysis of Generalized Monsoon Index (GMI) values for northeast monsoon, which extends from mid-October to mid-February in Thailand, is carried out as follows:

$$GMI_{ne} = 0.125P_{10}+0.125P_{11}+0.5P_{12}+0.25P_1 \quad (2)$$

where GMI_{ne} represents GMI values during northeast monsoon season and P_{10}, P_{11}, P_{12}, P_1 represents quantity rainfall from October to January respectively.

The computed GMI will be expressed in millimeters. To establish a standardized benchmark for evaluating crop condition, GMI data will be converted into percentile ranks.

$$Pct = (r \times 100) / (n + 1) \quad (3)$$

where pct represents percentile ranks, r represents rank of data in data set and n represents total number of rainfalls in data set.

Table 2 Criteria of drought index

GMI (pct)	Drought classification
0 – 20	severe drought impact and possible crop failure
21 – 30	Moderate drought impact on crop
31 – 40	Mild drought impact on crop
41 – 60	Normal crop condition
61 – 90	Possible above normal crop
91 - 100	Possible excessive moisture

3. Results and Discussions

Rainfall data from each monitoring station was collected from 2009 to 2023 and this period was used as baseline. CMIP5 model was implemented to evaluate effects of global climate change on watershed. Its performance was compared to observed rainfall data using several kinds of statistical metrics. The metrics comprised coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE), Root Mean Square Error (RMSE) and Percent Bias (PBIAS). This comprehensive analysis enabled identification and selection of most precise model. Rainfall data from selected model was subsequently utilized to create and examine drought risk map for Huai-SamMor basin, providing important insights into potential impacts of climate change. A comparison of CMIP5 models with rainfall data that was obtained during baseline period revealed that four out of twenty models (Table 3) demonstrated coefficient of determination values that were adequate. For forecasts associated with modest greenhouse gas reduction efforts (RCP 4.5), the model that are employed are CNRM and Miroc5. On the other hand, CESM1_CAM5 and NorESM are utilized for projections that represent large greenhouse gas emissions when RCP8.5, as shown in Table 3, which presents metrics for R^2, NSE, RMSE, and PBIAS, which demonstrate satisfactory level of reliability and confidence in selected models.

Table 3 Evaluation of model performance

GCMs	Models	R^2	NSE	RMSE	PBIAS
RCP4.5	CNRM	0.678	0.672	0.365	26.74
	Miroc5	0.635	0.619	0.399	30.40
RCP8.5	CESM1_CAM5	0.667	0.657	0.357	30.19
	NorESM	0.670	0.661	0.373	29.43

This research utilized RCP4.5 and RCP8.5 projections, categorizing analysis into four temporal segments: near future, middle future 1, middle future 2 and far future. The predicted annual average rainfall for each projection, using baseline year's average annual rainfall as a reference, is illustrated in Figure 3. For RCP4.5 projection, projected average annual rainfall in near future ranges from approximately 1,209 to 1,292 mm, increasing to 1,368–1,400 mm in far future. Similarly, under RCP8.5 projection, predicted average annual rainfall in near future is estimated to range between 1,185 and 1,258 mm, rising to 1,492–1,535 mm in far future. These findings suggest that annual average rainfall under RCP8.5 projection is generally higher than that projected under RCP4.5. September is anticipated to exhibit highest rainfall levels, whereas period from November to March is likely to experience dry spells and potential water scarcity. Furthermore, RCP8.5 projection is anticipated to exhibit increased variability in annual rainfall, marked by more extreme patterns, such as wetter wet season and drier dry season. Annual rainfall exhibits significant variability, with more pronounced fluctuation anticipated under RCP8.5 projection. RCP8.5 projection shows that changes in rainfall are projected to be more pronounced and occur more rapidly compared to those under RCP4.5 projection, with more rainfall during rainy season and less rainfall during dry season. All RCP projections project an increase in rainfall during rainy season (June–October), with a particularly notable rise in mid-season months (July–September). Rainfall that occurs outside of this time, on the other hand, shows very minimal variation, but there is a possibility that some months, notably May and November, may suffer a decrease. The statistics also show that there is a large amount of variation in rainfall across all of predictions and time periods, which highlights inherent uncertainty that is linked with effects of climate change. Figure 4 illustrates variability of rainfall under both RCP4.5 (CNRM and Miroc5 models) and RCP8.5 (CESM1_CAM5 and NorESM models) projections. Average rainfall during northeast monsoon demonstrates considerable variability, with years of above-average (+) and below-average (-) rainfall occurring alternately. The CNRM model indicates an increase in occurrence of intense rainfall events, particularly post-2050, with rainfall variability ranging from -40 to +80 mm relative to baseline. Precipitation variations, as shown by Miroc5 model, fluctuate between -40 mm and +100 mm relative to baseline. There is a significant and extended trend of reduced rainfall occurrences between 2040 and 2070, indicating an increased likelihood of drought condition. NorESM model exhibits rainfall variation ranging from -50 to +100 mm compared to baseline, highlighting pattern of significant variability and underscoring model's responsiveness to climate change factors. RCP8.5 prediction, characterized by high greenhouse gas emissions, suggests that alteration in precipitation relative to baseline are more pronounced. Moreover, an examination of dry periods under RCP4.5 and RCP8.5 projections reveals that RCP4.5 experiences a 35–48% frequency of below-normal rainfall events. In contrast, under RCP8.5 projection, frequency of below-normal rainfall events ranges from 50–82%. These findings indicate that RCP8.5 is associated with a higher frequency of below-normal rainfall during dry season compared to RCP4.5, particularly with an increased likelihood of prolonged droughts persisting for multiple years. According to Table 4, projections of future rainfall for four time periods during northeast monsoon (a dry period) indicate potential for more severe droughts. In near future, under RCP4.5 projection, the average maximum rainfall can be 156.5% higher than baseline, while the average minimum rainfall can be 70.5% lower. The average maximum rainfall can be higher by 131.0% under RCP8.5 projection, while average minimum rainfall can be lower by 68.0%. The results indicate that both projections demonstrate a comparable pattern of rise in drought frequency, with RCP4.5 presenting marginally more severe maximum values. In middle future, especially in middle future 2, RCP8.5 shows more extreme rainfall variations than RCP4.5, indicating a more severe climate change trajectory. In far future, RCP8.5 continues to show a higher drought frequency. This pattern reflects an increasing likelihood of more severe droughts over long term under RCP8.5 projection. Overall, analysis indicates that RCP8.5 scenario is likely to result in more severe and frequent droughts in future than RCP4.5 projection. RCP4.5 prediction forecasts greater rainfall levels than RCP8.5 for near and middle future 1 periods when examining peak rainfall intervals. In middle future 2 and far-future periods, anticipated rainfall under RCP4.5 is less than that of RCP8.5. Furthermore, minimum rainfall level associated with RCP8.5 are reduced compared to those of RCP4.5, and there is an increased frequency of rainfall amounts falling below baseline year in RCP8.5. As a result, overall average rainfall associated with RCP8.5 tends to be less than that of RCP4.5. Projections for both RCP4.5 and RCP8.5 suggest an increase in maximum rainfall while showing a decrease in minimum rainfall. During earlier periods (near and middle future 1), RCP4.5 exhibits more significant deviations from baseline year in comparison to RCP8.5. However, in later periods (middle future 2 and far future), RCP8.5 exhibits more significant deviations from baseline year than RCP4.5. This trend reflects differing emissions pathways, with RCP4.5 resulting in less severe changes in rainfall, whereas RCP8.5 leads to more frequent and intense drought conditions, particularly with reduced rainfall during dry season. In order to evaluate potential effects of RCP4.5 and RCP8.5 projections on severity of drought in catchment, data on future maximum and lowest temperatures will be forecasted. The findings suggest that maximum temperatures under RCP4.5 are expected to rise by 1-2 degrees Celsius compared to current levels, whereas RCP8.5 may experience an increase of 3-4 degrees Celsius. RCP4.5 and RCP8.5 predict minimum temperatures to rise by 1-2 degrees Celsius and 1.5-2.5 degrees Celsius, respectively, indicating a higher likelihood of future drought conditions that are more severe. Under RCP4.5 projection, both maximum and minimum temperatures are anticipated to increase at a more gradual rate compared to RCP8.5 projection. In contrast, RCP8.5, marked by elevated greenhouse gas emissions, is expected to see a more significant rise in both maximum and minimum temperatures. Although all models show a rising trend in temperature, the exact values and rates of increase differ between them. Additionally, there is significant fluctuation in temperature from one year to next. Daily maximum temperatures are anticipated to keep increasing, especially as we approach end of projection period, leading to a higher occurrence and severity of heatwaves. Similarly, the projections indicate that present levels of nocturnal temperatures will be surpassed, as daily minimum temperatures are expected to rise. The drought conditions in various environments will be directly influenced by temperature fluctuations. Initially, elevated temperatures result in increased transpiration from both soil and water bodies. This thus reduces soil's moisture content and water accessible to plants, hence increasing danger of drought. Another possible consequence is that rainfall pattern may change due to increasing temperatures, perhaps leading to prolonged droughts. Over time, these modifications may lead to a decrease in soil quality, a reduction in water retention capabilities, and an increase in dangers associated with drought conditions. The substantial influence of temperature on deterioration of future drought conditions is underscored by the anticipated increase in temperatures, which considerably contributes to intensification of more severe and frequent droughts.

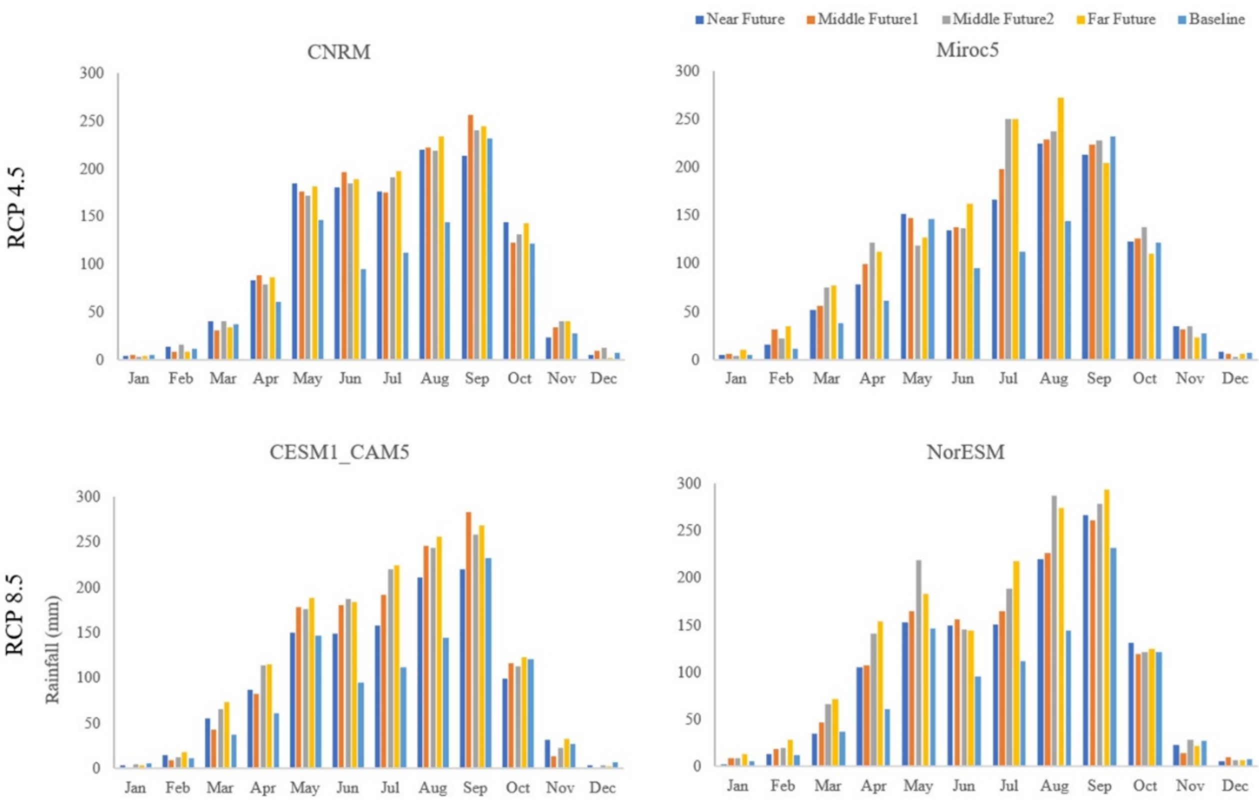

Figure 3. Future average rainfall from CMIP5 models

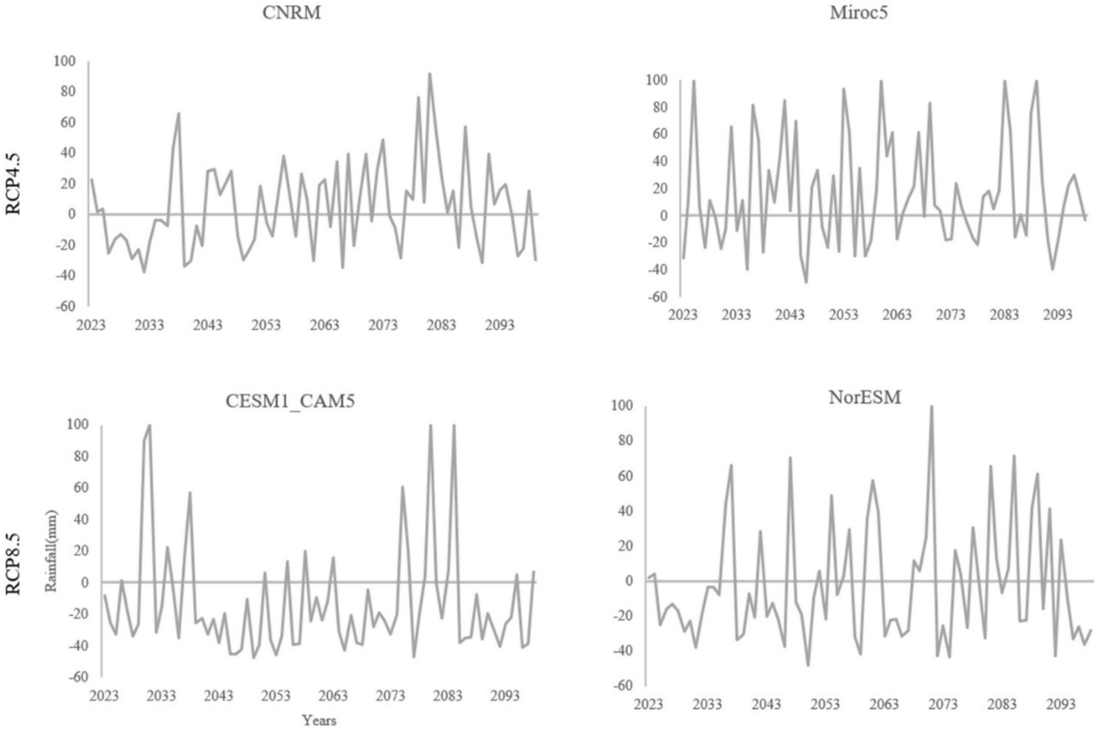

Figure 4. Comparing average rainfall from model to baseline during northeast monsoon (Dry period)

Table 3 Evaluation of model performance

Years	RCP4.5 (%diff)			Frequency of minimum (%)	RCP8.5 (%diff)			Frequency of minimum (%)
	Max	Min	Avg		Max	Min	Avg	
Near Future	156.5	-70.5	8.5	45	131.0	-68.0	-9.5	63
Middle Future1	128.0	-74.0	20.2	40	84.5	-90.0	-24.8	67
Middle Future2	164.5	-52.0	19.3	35	186.0	-84.5	-8.7	57
Far Future	145.5	-66.5	20.5	38	158.0	-78.5	-16.0	80

Figure 5. Future temperature in CMIP5 Models

Figure 7 illustrates GMI index during southwest monsoon season. RCP4.5 and RCP8.5 projections both suggest that a moderate to severe drought risk will be present in approximately 85% of basin in near future. RCP8.5 shows more severe drought conditions. RCP4.5 predicts a low to moderate drought risk in upper and western areas of basin over intermediate future 1 period, but RCP8.5 indicates a high to severe drought risk throughout whole basin. In middle future 2, RCP4.5 indicates standard conditions with little drought risk, but RCP8.5 recommends low to moderate drought risk in northern and western regions. In far future, both RCP4.5 and RCP8.5 forecast typical circumstances or little drought danger. The four models indicate that some regions within research area are expected to encounter differing degrees of drought danger. The RCP8.5 projection regularly forecasts more intense drought conditions than RCP4.5, indicating an escalation in both severity and frequency of droughts under high-emission scenarios. Nonetheless, when examining temporal variations, both RCP4.5 and RCP8.5 show a declining trend in drought occurrences throughout southwest monsoon period, presumably due to heightened precipitation during wet season. Figure 8 examines GMI index during northeast monsoon over several time intervals and under many climate models. In near future, under RCP4.5 scenario, conditions are expected to be normal or provide a low risk of drought. In RCP8.5, almost 15% of western section of basin is projected to experience moderate to severe drought conditions. During middle future 1 period, RCP4.5 predicts a low to moderate drought risk in upper region of basin, while RCP8.5 indicates a moderate to severe drought risk in western region. In comparison to imminent future, there is a marginal elevation in drought risk over this timeframe. During middle future 2, both RCP4.5 and RCP8.5 indicate standard circumstances or little drought risk. In far future, both forecasts indicate moderate to severe drought risk throughout about 90% of basin, with RCP8.5 showing more severe drought conditions. Seasonal variability engenders uncertainty on drought occurrences. The models consistently demonstrate a tendency toward more severe drought conditions under RCP8.5 prediction in comparison to RCP4.5, underscoring heightened hazards linked to elevated greenhouse gas emissions

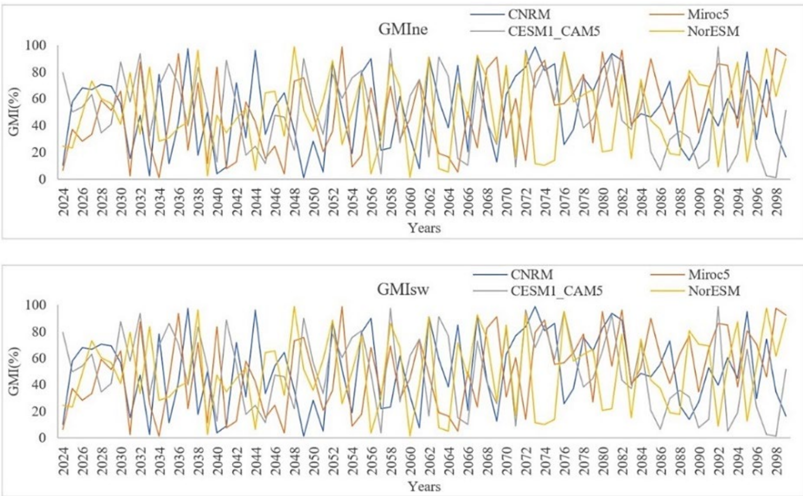

Figure 6. Predicting GMI drought index under climate change

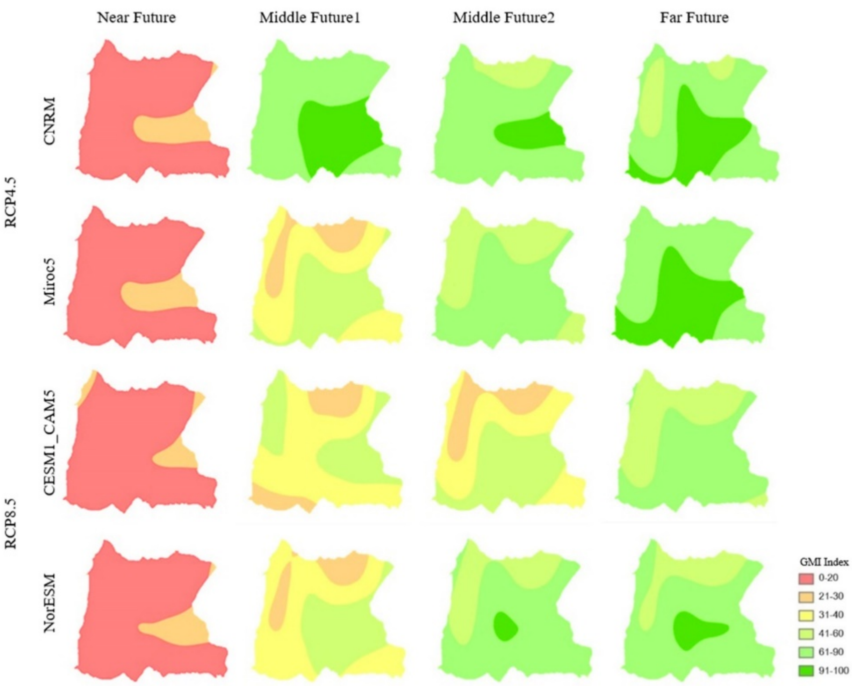

Figure 7. Predicting drought conditions during southwest monsoon

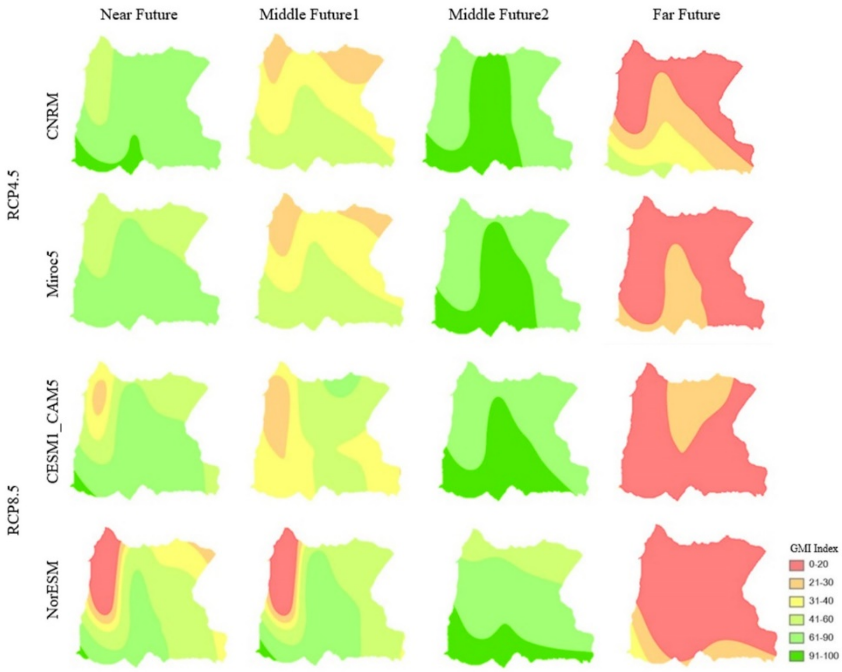

Figure 8. Predicting drought conditions during northeast monsoon

The examination of drought maps for southwest and northeast monsoon seasons, using CNRM, Miroc5, CESM1_CAM5 and NorESM models under RCP4.5 and RCP8.5 scenarios, reveals an increasing trend in drought severity under RCP8.5 projection. The intensity and frequency of droughts are anticipated to increase over time, with drought conditions in RCP8.5 scenarios are consistently worse than those in RCP4.5 scenarios. Moreover, there is significant unpredictability in precipitation patterns and a marked rise in temperatures over time, which further complicates assessment of future drought threats. In imminent future, during southwest monsoon season, when precipitation is not anticipated to rise much, drought conditions are forecast to intensify. In far future, projected rises in precipitation could decrease likelihood of drought occurrences. Drought conditions are more prevalent during northeast monsoon season compared to southwest monsoon season. The dry season, frequently shaped by northeast monsoon, is marked by cool and arid air. In foreseeable future, when precipitation during this timeframe is comparatively minimal, drought conditions may be mitigated. In far future, a forecasted decline in rainfall during northeast monsoon is anticipated to exacerbate drought conditions.

An extensive analysis of four models indicates that study region will experience differing degrees of drought conditions. The drought conditions predicted by RCP8.5 projection is more serious than those predicted by RCP4.5 projection across many time periods, indicating an increasing trend in drought severity. The severity of droughts, however, may differ depending on specific projection, with RCP8.5 projection particularly projecting a notable increase in both the intensity and frequency of future droughts. As illustrated in Figure 7, all four models predict increased rainfall during wet season, resulting in a decline in drought incidence and frequency over time. In far future, most regions are anticipated to exhibit a minimal risk of drought, with RCP4.5 scenario indicating a reduced overall risk relative to RCP8.5. Conversely, Figure 8 illustrates that during arid season, diminishing precipitation coupled with increasing temperatures would result in an augmented danger of drought over time. The majority of region is anticipated to experience significant drought conditions in far future, based on RCP8.5 estimate, which faces a very high risk of drought when compared to RCP4.5 projection. Furthermore, upper part of region is projected to experience a higher risk of drought relative to lower region.

4. Conclusions

This study analyzes climate change's effects on rainfall, temperature, and drought risk in Huai-Sam Mor basin using climate change model under RCP4.5 and RCP8.5 projections. Using General Monsoon Index, drought conditions are analyzed in four future periods: near future, middle future 1, middle future 2 and far future. The CMIP5 model outputs informed selection of best-fit climate models for each projection, with CNRM and Miroc5 models chosen for RCP4.5 and CESM1_CAM5 and NorESM models chosen for RCP8.5. The findings indicate that rainy season is expected to increase, accompanied by a rise in maximum and minimum temperatures, particularly under high-emission RCP8.5 projection. These changes will lead to raised evaporation and transpiration rates, exacerbating drought hazards in dry season. The severity and frequency of droughts were analyzed using these models during southwest and northeast monsoon periods, and results were significant depending on projection and time frame. The results consistently show that RCP8.5 demonstrates greater drought severity and frequency compared to RCP4.5, with an estimated 15–34% increase in drought events, particularly during dry season and far future. Rising temperatures and reduced rainfall under RCP8.5 exacerbate water scarcity and accelerate hydrological processes, increasing intensity and frequency of droughts. The temporal investigation indicates ongoing escalation of drought severity over time, with far future being most impacted, especially during northeast monsoon season. The spatial analysis reveals notable regional disparities, with western and upper sections of watershed classified as high-risk zones due to their vulnerability to severe drought conditions. The findings highlight considerable influence of global warming on altering monsoonal patterns and hydrological cycles, resulting in a rise in both frequency and intensity of droughts. The study emphasizes essential need for adaptable strategies in managing water resources, including enhancements to water storage systems, promotion of efficient water use, and integration of advanced climate models into regional planning initiatives. To lessen effects of severe droughts, it is essential for planners and policymakers to focus on strong mitigation strategies, including reducing greenhouse gas emissions, developing resilient infrastructure and adopting conservation practices. The forecasts offer essential insights into future of water resource management, emphasizing necessity for proactive and sustainable strategies to tackle drought risks and improve resilience across region. However, CMIP5 climate models, although dependable, possess intrinsic uncertainty in precipitation forecasts, particularly regarding precipitation patterns and regional-scale climate dynamics. While Generalized Monsoon Index (GMI) provides a valuable tool for drought assessment, its reliance on historical precipitation trends may not fully account for other climate-related factors. This study primarily focuses on climatological and hydrological aspects of drought risk, without incorporating socioeconomic variables.

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