The climate and environmental determinants of domestic water supply change at the Nasia catchment in Northern Ghana

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Abstract

The Nasia river serves as the primary source of domestic water supply for over 5000 households in the Nasia catchment. However, the river is currently experiencing water stress conditions, causing an imbalance between the demand for water and the available supply. In this study, we evaluated the impact of climate and environmental factors on changes in domestic water supply in the Nasia catchment, with the ultimate objective of providing policy direction. Our approach involved a mixed model of analyzing local perception of the drivers of domestic water supply change through focus group discussions and statistical analysis of in-situ climate and environmental data. Analysis of the local perception revealed that supernatural and mystic beliefs, changes in seasonal rainfall and environmental degradation were the causes of change in domestic water supply at the catchment. The statistical analysis of in-situ climate data revealed that mean and maximum temperatures were the main drivers, accounting for over 40% of the change in domestic water supply. Long term trends in temperature revealed positive trends with an indication of pre-warming of about 1.5^{o}C of the catchment. Analysis of land use/cover change revealed that built-up/bare land has increased by 58.44% whereas farmland, vegetation, and water have reduced by 34.10%, 22.85%, and 1.48% respectively. The increase in bare lands had significant influence on the rate of warming and evapotranspiration in the Nasia catchment. The study's outcomes hold significant practical relevance for Ghana's Water Resources Commission and the Water and Sanitation Agency sector, as they endeavour to meet the nation's water-related targets and sustainable development goal six. Additionally, it will offer valuable guidance for climate service provision and Nasia river catchment protection, as well as the implementation of alternative water sources to complement its usage.

1 Introduction

According to the Fifth Assessment report of the Intergovernmental Panel on Climate Change, IPCC, the anticipated escalation of the global average temperature to 1.5°C above the pre-industrial level, along with an increase in extreme precipitation events, is expected to exacerbate the detrimental effects of climate change on water resources by 2050 [1]. Further, the IPCC report indicates that 93% of the associated impact of the changing climate will be felt on surface and groundwater resources [1, 2]. This climate influence in addition to anthropogenic activities would reduce water availability for domestic and other water applications [3]. Sub-Saharan Africa (SSA) is projected to suffer most of the domestic water shortage ensuing from climate change [4]. According to Olajire [5], about three hundred (300) million people in this region live in waterscarce environs and most of them spend more than an hour per round trip to collect water. In some circumstances, the disruption of water supplies due to change in climate in the region has incited domestic and cross-border violence [6]. In Northern Nigeria for instance, over 1000 lives were claimed in 2014 due to water-related violence between farmers and herders[5].

In Ghana, this issue of interrupted access to household water supply has persisted, raising significant concern [7]. This problem is widespread throughout the country, but particularly acute in the northern region especially along the White Volta basin and its sub-catchments such as the Nasia Catchment [8]. The Nasia river is the primary source of domestic water supply for inhabitants of the Nasia catchment, supporting the livelihood activities of over 5000 households including cooking, washing, fishing and dry-season farming [9, 10]. The Nasia river, however, is currently experiencing water stress conditions where the demand for water has outpaced the supply [11]. This situation is having a wide-ranging consequence, affecting everything from human health and economic well-being to environmental sustainability and social equity in the area [12]. Women and children are unduly affected as they have to spend several hours before getting a round trip of water for their household use [13].

Previous studies conducted within the Nasia catchment provide a dearth of evidence on climate and environmental drivers of domestic water supply change in the area. For instance, Abagale et. al. [14] assessed the level of suspended sediments produced in the Nasia river basin using hydrological, water samples and meteorological data. Addai et. al. [9] examined groundwater recharge processes in the Nasia sub-catchment focusing on the porewater characteristics in the unsaturated zone. Shaibu et. al. [15] analysed some hydrological parameters of the Nasia river catchment to determine its potential for irrigation and socio-economic development with focus on the flow characteristics of the catchment. Recently, Nyadzi et. al. [11] investigated trends in hydro-climatic variables and their relationship with Nasia river discharge using linear correlation. Even though correlation statistic measures the strength of the relationship between two variables, it does not provide evidence of a causal relationship nor account for the influence of other variables that may affect the relationship [16, 17]. Besides, for climatic variables that have non-linear relationship with river discharge such as temperature, correlation may not accurately reflect the strength of the relationship [16, 17]. On the basis of the foregoing information, determining the climate and environmental drivers of the domestic water supply change in the catchment will help inform policy direction, promote water conservation, encourage the efficient use of water, and advocating for investments in water infrastructure.

In this study, therefore, we addressed this knowledge gap by determining the climate and environmental variables driving domestic water supply change at the catchment and their relative contributions. Unlike previous studies, the current work considered both the perception of the inhabitants of the catchment and evidence from statistical analysis of in-situ data to unearth the drivers of domestic water supply changes. To our knowledge, this is the first study to use a mixed model framework. Consistent with the UN's Sustainable Development Goals (SDGs) [18], Ghana has set forth several targets to attain its aim of providing universal access to safe and affordable drinking water while promoting equitable water resource management[18]. Our findings are, therefore, intended to support Ghana attain these targets of universal and equitable access to safe and affordable drinking water and increase water-use efficiency across all sectors, and guarantee sustainable withdrawal and supply of fresh water in the face of water scarcity. Achieving these targets would lead to communities having access to hygienic water sources, which would enhance their quality of life, stimulate economic growth, and bolster sustainable water resource management.

2 Materials and methods

2.1 Study area

Figure 1. The map of the Nasia catchment showing the Nasia river, its tributaries and study communities.

The Nasia catchment (see Fig 1) is located in northern Ghana, geographically positioned between latitudes 9°55' and 10°40'N and longitudes 1°05' W and 0°15' E. It is a tributary of the White Volta and has a total area of approximately 5,326 km^2 [19].

The Nasia river traverses through the West and East Mamprusi Municipalities in North East Region, and Savelugu and Karaga Districts in Northern Region. The inlet of the Nasia catchment is located in Karaga District and the outlet in the West Mamprusi Municipality. The catchment experiences the warm tropical climate and a unimodal rainfall season spanning from May to September with peak rainfall in August [20]. The catchment also experiences a long dry season from October to April, which is mostly characterised by the harmattan winds and high temperatures ranging between 26^{o}C and 38^{o}C [20].

2.2 Data

2.2.1 Primary data

A Focus Group Discussion (FGD) guide was used to obtain the primary data from communities that depend predominantly on the Nasia river for their domestic water. Four (4) FGDs were convened at the following communities: Nasia, Sooba, Namburugu and Kpubo, each group composing six members (three women and three men) including the community heads but excluding the researchers. A FGD of six to eight members is optimum for effective and efficient discussions [21, 21]. The discussions were centered on the sources, availability and drivers of change in water supply for domestic applications relative to the past decades. The main local dialect (Mampuli) was used in the discussions, making it possible for each participant to eloquently articulate his/her contributions. All discussions were tape-recorded in addition to recording in the field notebook for cross-checking. Prior to using this data collection instrument, its validity and reliability was pre-tested in Buipe, a community in the Central Gonja District in northern Ghana, which has similar physical characteristics to the study area. The pretesting helped identify potential problems such as ambiguous questions and response biases allowing necessary revisions to improve the quality of the FGD guide.

2.2.2 Ethical consideration

The primary objective of the FGD was to gather comprehensive insights into the human perception of the drivers of change in domestic water supply at the Nasia catchment. To ensure transparency and ethical practices, the FGD guide was accompanied by a cover letter that clearly explained the objectives of the study and how the collected data would be used. This step helped establish informed consent and allowed participants to understand the purpose of their involvement. Privacy and confidentiality were prioritized throughout the study. The participants were assured of the absolute commitment to securing their privacy and confidentiality regarding the information they provided. It's important to note that the collected information was solely used for academic purposes and that the participants' names were withheld, further ensuring their anonymity. Additionally, participation in the study was voluntary, and participants were free to withdraw at any time including information they provided.

2.2.3 River discharge

Figure 2. Percentage of daily discharge data available per month and year

Daily records of Nasia river discharge covering the period 1960 - 2010 was obtained from the Hydrological Service Division at Tamale, the regional capital of northern regional. Fig 2 shows the percentage of daily discharge data available on monthly scale over the entire period. The gaps in the observed data were filled using a simple long-term averaging technique. First a gap was defined as any day, X, of a month and year without data. To fill this gap of day X, the corresponding days of other months and years through out the period with data were averaged. The averaged value was then used to fill the gap of day X. These steps were then repeated for other days without data. The final data without gaps was then aggregated into monthly totals and used for the analysis.

2.2.4 Meteorological data

Complete daily rainfall (RR) and temperature (Minimum (T_{min}), Mean (T_{mean}) and Maximum (T_{max}) data for West Mamprusi and Karaga Districts spanning the period 1980-2020 were obtained from the Ghana Meteorological Agency (GMet). These data were also aggregated into monthly values before being used in the analysis.

2.2.5 Satellite imagery

Landsat 4 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper plus (ETM+) sensor, and Landsat 8 Operational Land Imager (OLI) were obtained from the United State Geological Survey (USGS) at their earth explorer website. The images for this study were obtained at 30m x 30m spatial resolution. The study used cloud-free imagery captured during the dry season (November). Detailed information on satellite images used in the study is shown in Table 1.

Table 1. Satellite images for the study

Year	Satellite image	Date Acquired	No of Bands	Spatial Resolution
1980	Landsat4tm	22nd November	7	30mx30m
2000	Landsat7etm+	26th November	7	30mx30m
2020	Landsat8ols	20th November	7	30mx30m

Table 2. Land use/cover classes and Descriptions

LULC class	Description
Built-up/Bare land	Bare Exposed Grounds, Built-up Land.
Farmland	Includes all arable land
Vegetation	pasture, bush and shrub, and grassland
Water	Portion of the area covered by rivers, lakes and streams

2.3 Analysis

2.3.1 Perception of domestic water supply change drivers

The primary data was first transcribed from Mampuli (the local dialect of the study area) to English and manually analyzed qualitatively based on the thematic analytical framework. Where necessary, verbatim quotations from interview transcripts were used to illustrate relevant themes. The analysis were centered on the sources, availability and drivers of change in domestic water supply at the Nasia catchment.

2.3.2 Climate drivers of domestic water supply change

Here, the study examined the relative contribution of RR, T_{min}, T_{mean} and T_{max} to changes in the Nasia river discharge. The analysis model outlined in Yamba et. al. [22]

was adopted as follows:

$$D \sim RR + T_{\mathrm{max}} + T_{\mathrm{min}} + T_{\mathrm{mean}} \tag{1}$$

where D is the Nasia river discharge (the response variable) whereas RR, T_{min}, T_{mean} and T_{max} are the climate predictors. The predictive capability of each regression was calculated in two-folds using the R package "relaimpo" [22, 23]. First, the contribution of each regressor is calculated relative to the dependence of other regressors in the model. In this case, the *lmg* metric of the "relaimpo" package was invoked. It calculates the relative contribution of each predictor considering the sequence of predictors appearing in the model. It intuitively decomposes the total R^2 by adding the predictors to the regression model sequentially. Then, the increased R^2 is considered as the contribution by the predictor just added. In the second fold of the calculation, what each regressor alone is able to explain without the dependence of other regressors in the model is examined. The metric *first* of the "relaimpo" package was invoked. It compares the R^2 value of regression model with one regressor only without considering the dependence of others unlike the *lmg* metric. Since the metric *first* does not decompose R^2 into contributions like *lmg*), the contribution of the individual regressors alone do not naturally add up to the overall R^2. The sum of these individual contributions is often far higher than the overall R^2 of the model with all regressors together. The mathematical descriptions of lmg and first metrics are fully described in Yamba et. al. [22]. Whether *lmg* or *first*, each metric's outcome were bootstrapped to ensure that the contributions of the regressors (RR, T_{min}, T_{mean} and T_{max}) to changes in D were clearly defined. Bootstrapping in "relaimpo" was done using the function boot in the package. Prior to calculating the *lmg* and *first* metrics, all data series (i.e. the discharge (D), RR, T_{min}, T_{mean} and T_{max} were log transformed. The essence of the log transformation was to decrease the variability in the data pairs and make them conform more closely to normal distribution with similar variance and standard deviation [24]. The analysis also included an examination of the changes in long-term trends in river discharge, temperature and its anomalies to ascertain the rate and level of warming of the catchment.

2.3.3 Environmental drivers of domestic water supply change

Land use/cover changes (LULC) at the Nasia catchment was assessed to ascertain the level of conversion of one land cover type to another and its impact on the micro-climate and water supply changes at the Nasia catchment. The satellite images data were processed using the Semi-Automatic Classification Plugin (SCP) tool in the Quantum Geographical Information System (QGIS) software. They were then analyzed for three different years (1980, 2000, and 2020) and classified into four macro classes employing the technique of land cover signature classification shown in Table 2. The Region of Interest (ROIs) tool was used to choose pixels from a particular land cover class with the help of color composites. This method assigns non-thermal bands to the appropriate macro classes in the training input. The macro-class classification process used the maximum likelihood algorithm. The results were analysed quantitatively in hectares on comparative basis to assess the pattern of change using 1980 as the base year.

3 Results

3.1 Domestic water supply change perception

The FGD participants reported that the Nasia river was the primary water source for the area, and that standpipes, boreholes, and wells were alternatives albeit to a lesser extent. For instance, a female participant aged 48 from Namburugu said this: “We have been depending on the Nasia river for all our domestic water needs including cooking since time immemorial, which sometimes looks very reddish, but we have no option than to use”. We found that the populace showed disinclination to use water from boreholes, standpipes, and wells with reasons being insufficient volume of water supplied by these sources coupled with their unpleasant taste. For instance, a male participant aged 42 from Nasia said this: “Currently, we still depend on the Nasia river for drinking and other domestic applications because the number of standpipes and boreholes are inadequate for us, and do not function in most cases due to break ups”. Another female participant aged 43 from Nasia had this to say: “Most of us in this community do not like the taste of the water from the standpipes; hence, we completely depend on the river for drinking and other domestic applications. When we use the water from standpipes to prepare "Tuo zaafi", (Local food), it is as if we have added saltpeter to it, but the water from the Nasia river is not like that. This is why we don't like to use water from the standpipes for domestic purposes".

With respect to the water availability over time, findings from the FGD unveiled that the Nasia river no longer maintains a consistent flow throughout the year. Although water was historically available year-round, recent times have witnessed a shift in this trend. FGD participants highlighted that there is abundance of water in the river during the wet season (June-October), but woefully inadequate during the dry season (November-May). During the dry season, residents and animals in the area mostly contend for water from the river. For instance, a female participant aged 51 from Namburugu said this: "Our greatest hurdle is water. The Nasia river, which we depend on has been drying up in the dry season for some years now. So, in such a time, we find it tough to get water from the river, and sometimes have to compete with cattle for it". A male participant aged 50 from Kpubo had this to say: "Growing up, we were not facing this challenge because the water from the Nasia river was not drying up, but we don't know what we have done to God that rain does not come like the way it used to, causing the river to dry up in the dry season, affecting our domestic water supply".

In the case of the drivers of change in domestic water supply, FGD participants had diverse ideas. Some attributed it to supernatural or mystical causes. They believe that their water body is drying up as a result of some sins they have committed and this has made the gods take their water. A female participant aged 74 from Sooba had this to say "I see our water drying up as a punishment and warning from the gods. The young people of today go to the river to engage in unspeakable activities such as engaging in illicit sex in the bush. This has brought the wrath of the gods and ancestors on us". Other participants also attributed the change to changes in seasonal rainfall patterns. This is what a female participant aged 57 had to say: "rainfall in recent times is more like family planning, where rain seems to be controlled and birthed at some specific times". In all, there was a general consensus that the change could be due to environmental degradation along the river. They indicated that decades back the river environment was forested but now all the flora and fauna in the area have disappeared.

For instance, this is what one participant had to say "We grew up resting under the trees along the Nasia river after we come back from farming, however, we are unable to do that now because the place feels warm and uncomfortable".

3.2 Climate drivers of change in domestic water supply

Table 3. The relative contribution of RR, T_{min}, T_{mean} and T_{max} in predicting changes in Nasia river discharge bootstrapped at confidence interval of 95%. R^2 represents the total proportion of variance in discharge explained by all the climate predictors. lmg values show the individual contribution of each predictor to R^2 relative to others. *First* is the contribution of each predictor alone to R^2 with complete ignorance of other predictors.

District	R^2 [%]	Variable	lmg [%]	First [%]
Walewale	**47.46**	RR	2.57	3.04
		T_{min}	7.40	16.63
		$\mathbf{T_{mean}}$	**19.79**	**46.69**
		$\mathbf{T_{max}}$	**17.70**	**41.19**
Karaga	**41.34**	RR	2.10	1.28
		T_{min}	8.82	18.70
		$\mathbf{T_{mean}}$	**17.30**	**41.01**
		$\mathbf{T_{max}}$	**13.13**	**30.62**

Table 3 shows the contributions of climate variables to changes in the Nasia river discharge and their relative importance. The overall contributions of rainfall, minimum, mean and maximum temperatures account for about 47% of change in the domestic water supply in Walewale and about 41% in karaga. It can be observed that out of these climate variables, mean and maximum temperatures are contributing significantly to the change in domestic water supply while rainfall and minimum temperature are having minimal contributions.

Figure 3. Trends in Nasia river discharge and climate variables. Panel a shows seasonality in river discharge and climate variables. Panel b shows long-term changes in Nasia river discharge.

In Fig 3, panel (a) displays the seasonality in the Nasia river discharge and climate variables whereas panel (b) shows the long-term trends in monthly river discharge. In panel (a), high river discharge during the rainy season particularly from July to November with a peak in August is observed. Within this period, temperatures are characteristically low. However, the river discharge is significantly low during the dry months (December to June) and the catchment characterized by high temperatures during this dry period. A positive correlation between rainfall and discharge at a lag of one month is observed. Temperature generally anti-correlated with the river discharge. The long-term trends in river discharge (as shown in panel b) revealed a decrease in river discharge with time. High discharge values are observed within the period 1960-1974 and 1988-1995 following a significant decrease from 1996-2010. Note that discharge from 1978 to 1987 showed similar trends because of the significant data gaps within this period (see Fig 2).

Figure 4. Long-term trends in annual temperature at the Nasia catchment.

Fig 4 shows the annual trends in temperature and its anomalies at the Nasia catchment. Significant increasing trends of maximum, mean and minimum temperatures were observed with mean and minimum temperatures showing higher rates than the maximum. The temperature anomalies showed variable warming of the catchment in the last two decades than the previous two decades. For instance, the mean and minimum temperature anomalies showed a warming of about 1.5^0C in the last two decades than previous years.

3.3 Land use/cover change

Figure 5. Map of land use/cover changes at the Nasia catchment.

Fig 5 shows the map of land use/cover change (LULC) at the Nasia catchment. The analysis revealed spatial and temporal changes in LULC in the catchment. In 1980, the dominant land cover was vegetation (50.27%), followed by farmland (37.10%), water (8.25%) and built-up/bare land (4.37%). In 2000, vegetation decreased to 12.77%, farmland coverage increased to 50.97%, Built-up/bare land increased to 35.97% and Water reduced to 0.29%. In 2020, the build-up/bare lands further increased to 62.81%, farmland reduced drastically to 3%, vegetation recovered to about 27.42% and water also covered 6.77%.

4 Discussion

Our study looked at the perception of inhabitants of Nasia catchment on the source, availability and drivers of change in domestic water supply at the catchment. It then validated the perceived drivers of domestic water supply change with scientific understanding of the drivers of change. With regards to water sources, our findings agree with Addai et. al.[9] that the Nasia river remains the preferred and primary source of water for the inhabitants of the Nasia catchment. Even though the Nasia river is the go-to source of water for the inhabitants of the Nasia catchment, our study revealed that the quantity and quality of the river water has reduced over the past two decades especially during the long dry season limiting its availability and usability for domestic purposes. In other communities within the Nasia catchment such as Savelugu-Nantong and Gushiegu districts, Seidu et. al. [25] found that both surface and groundwater sources were not available all year round. Given that the Nasia river is the primary source of water supporting over 5000 households, the limited quantity and quality of water from the river has adverse impact on the quality of life and economic growth of the households that depends on it. This also suggest that the attainment of the UN's SDG six and Ghana's target to attain universal access to safe and affordable drinking water while promoting equitable water resource management[18] is still far-fetched.

While most of the local perspectives of the drivers of domestic water supply change largely corroborate scientific understanding, spiritual or mystic causes remain the point of departure from science. These superstitious perceptions are widespread in rural Ghana and reflects the cosmovision of the inhabitants. For instance File et. al. [26] found in Sissala East District of Ghana that the breakdown in spirituality and traditional religion were among the causes of climate change in the district. In Bongo district of northern Ghana, Akolgo and Ayentimi [27] reported that traditional cultural practices and social norms has been used in the management of water resource systems in the district. Our scientific analysis of the climate drivers of domestic water supply change at the catchment suggests that climate variables (rainfall and temperature) explain over 40% of domestic water supply change at the catchment of which mean and maximum temperature are the significant drivers. The long-term trends in the catchment temperature showed significant rise with temperature anomalies showing significant warming of about 1.5^0C in the last two decades. This explains the decrease in water volume and quality at the catchment over the last two decades as warming can have serious evaporation effects on the catchment. Increase in temperature has been widely reported to have dire consequences on water scarcity [28, 29] as observed at the Nasia catchment.

The perception of the inhabitants revealed that activities such as the removal of trees and other vegetation along the Nasia catchment have greatly impacted the Nasia river. This finding agrees with the results of the land use/cover change analysis. A remarkable increase in the extent of built-up/bare land was observed while farmland, vegetation, and water bodies drastically reduced in the same period. The significant increase in built-up/bare land and the decline in the vegetation cover can be associated with increasing temperatures experienced in the Nasia catchment. The decrease in vegetation cover exposes the river to direct heat, leading to increased evapotranspiration and hence a decrease in surface water [30]. Trees help to regulate the local temperature by providing shade and transpiring water into the atmosphere. When trees are removed, the land surface is exposed to direct sunlight, leading to higher temperature [31]. The removal of trees also reduces water availability as trees play an important role in regulating the water cycle by intercepting rainfall, increasing infiltration, and reducing runoff [32]. Changes in climate variables especially temperature and environmental degradation at the catchment remain the chief drivers of domestic water supply change in the area. This means that any occurrence of climate extremes such as flood and drought is likely to have a great impact on inhabitants that rely solely on the Nasia river [33].

5 Conclusion

The drivers of change in domestic water supply at the Nasia catchment in northern Ghana was assessed. The study used a mixed model framework where both the perception of inhabitants on drivers of domestic water supply change along with the scientific causes were analysed. The local perspectives on the drivers of domestic water supply change corroborated the scientific views. Our study underscores spiritual and mystical causes of domestic water supply change at the catchment as a departure from scientific understanding. Following the outcome of the scientific analysis, we concluded that mean and maximum temperature were the significant climate variables impacting the change in domestic water supply at the catchment. Land use/cover changes at the catchment impacted the microclimate of the catchment especially the rise in temperatures and evapotranspiration. For Ghana to attain its target of achieving universal access to safe and affordable drinking water while promoting equitable water resource management, there is the need to operationally include climate and environmental drivers of water supply change in policy formulation. Policy direction could focus on afforestation, water conservation, efficient use of water and rain water harvesting.

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Competing Interest

The authors have declared that no competing interests exist.

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Fig 1: The map of the Nasia catchment showing the Nasia river, its tributaries and study communities.

Fig 2: Percentage of daily discharge data available per month and year.

Fig 3: Trends in Nasia river discharge and climate variables. Panel a shows seasonality in river discharge and climate variables. Panel b shows long-term changes in Nasia river discharge.

Fig 4: Long-term trends in annual temperature at the Nasia catchment.

Fig 5: Map of land use/cover changes at the Nasia catchment.

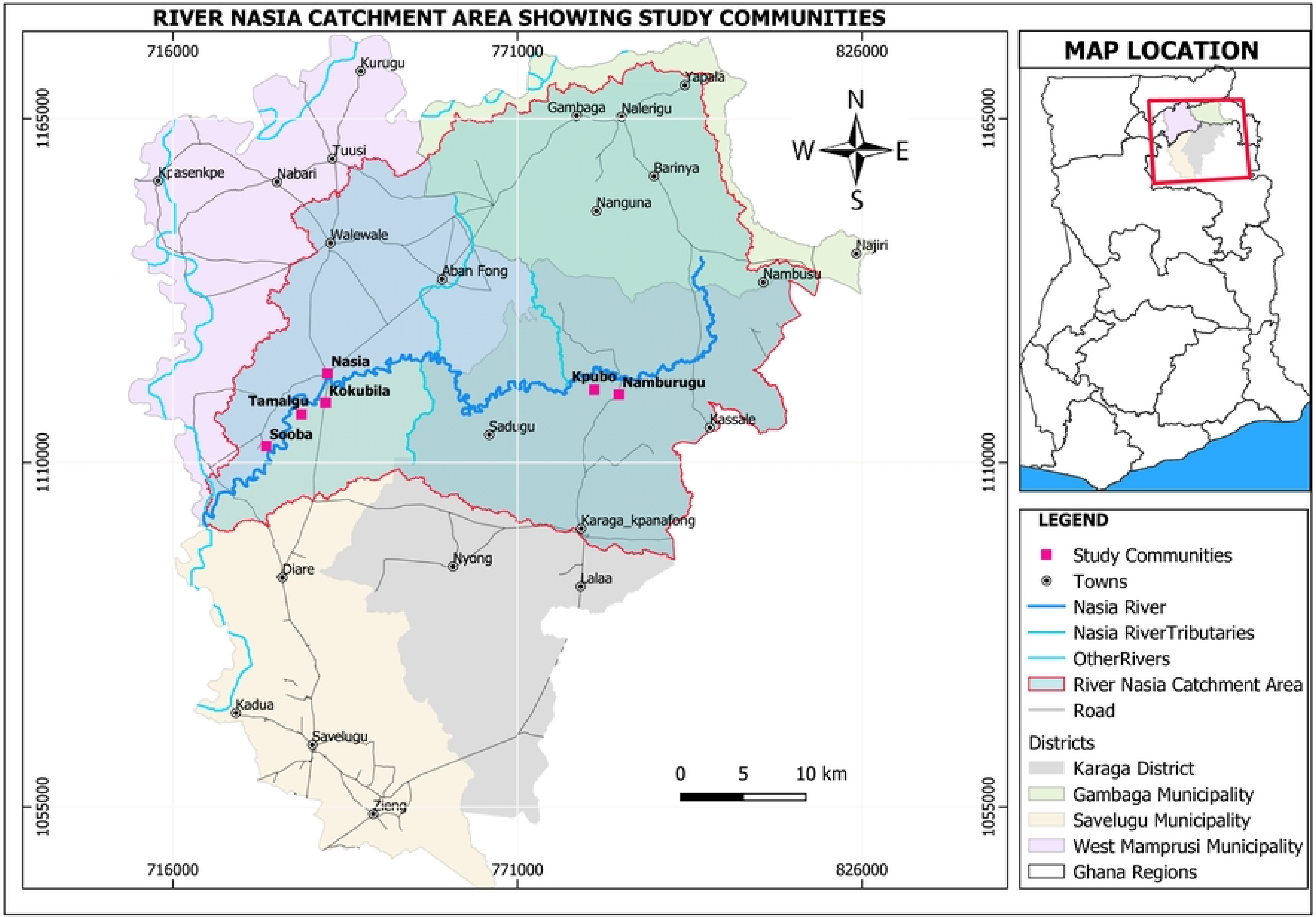

RIVER NASIA CATCHMENT AREA SHOWING STUDY COMMUNITIES
716000
771000
826000
1165000
1110000
1055000
Kurugu
Yapala
Gambaga
Nalerigu
Tuusi
Kpasenkpe
Nabari
Barinya
Nanguna
Walewale
Najiri
Aban Fong
Nambusu
Nasia
Kpubo
Namburugu
Kokubila
Tamalgu
Sooba
Sadugu
Kassale
Karaga_kpanafong
Nyong
Diare
Lalaa
Kadua
Savelugu
Zieng
N
S
E
W
0
5
10 km
MAP LOCATION
LEGEND
Study Communities
Towns
Nasia River
Nasia RiverTributaries
OtherRivers
River Nasia Catchment Area
Road
Districts
Karaga District
Gambaga Municipality
Savelugu Municipality
West Mamprusi Municipality
Ghana Regions

Fig1

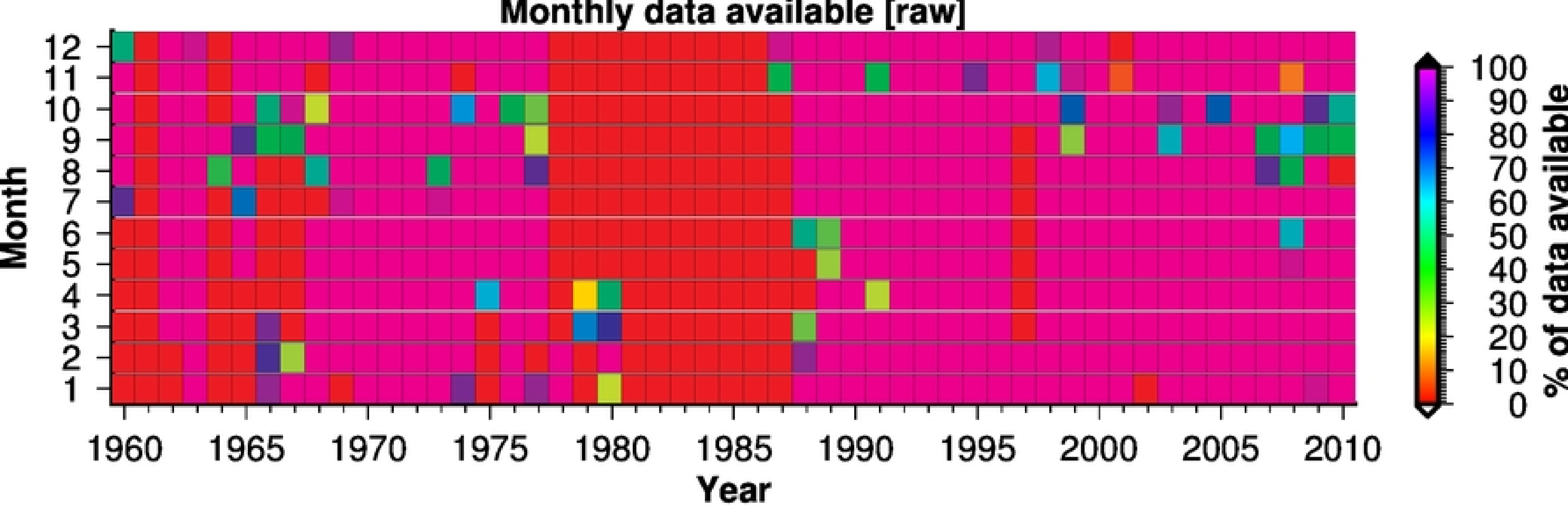
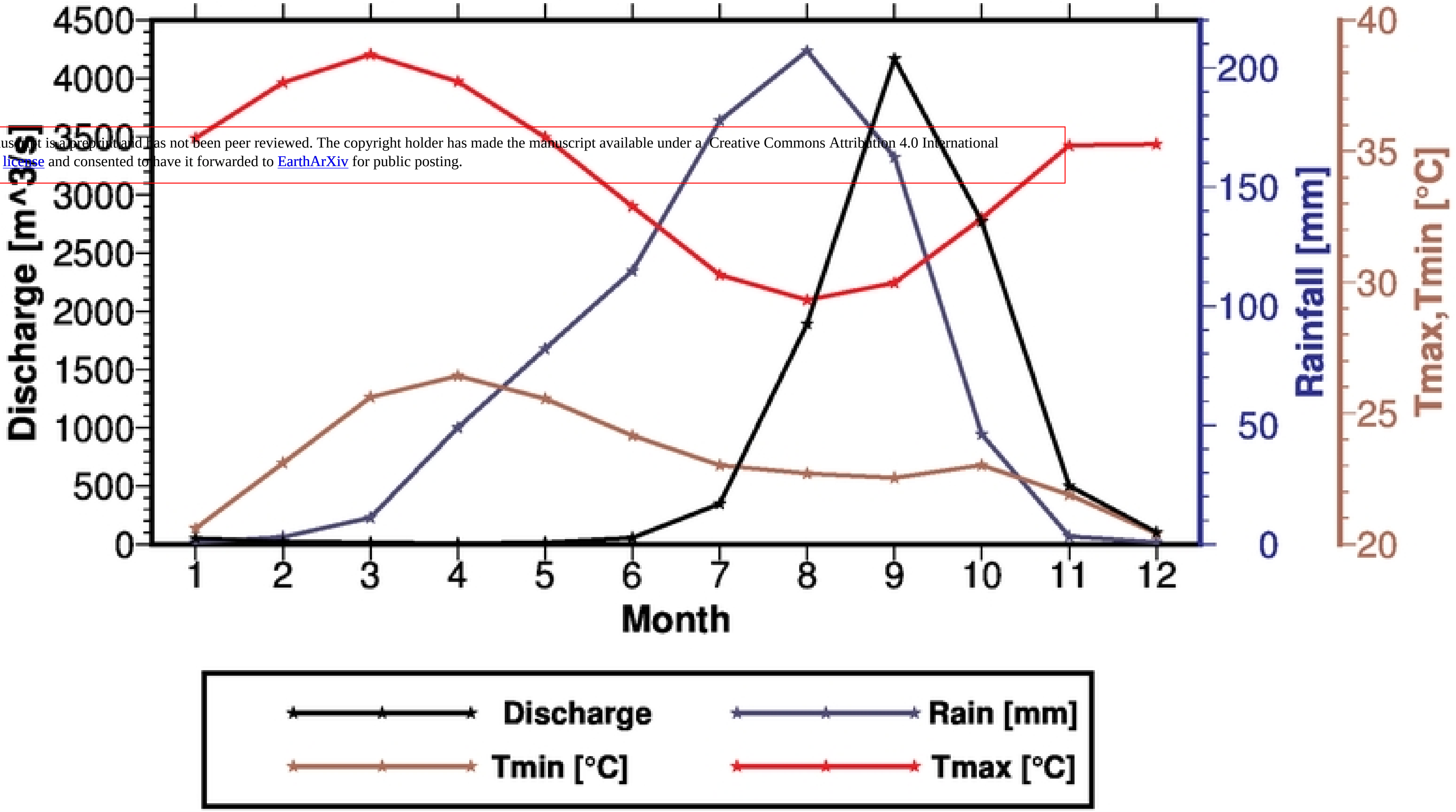

Monthly data available [raw]
Month
12
11
10
9
8
7
6
5
4
3
2
1
Year
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
% of data available
100
90
80
70
60
50
40
30
20
10
0

Fig2

(a) Average monthly discharge and climate variables



(b) Long term monthly discharge trends

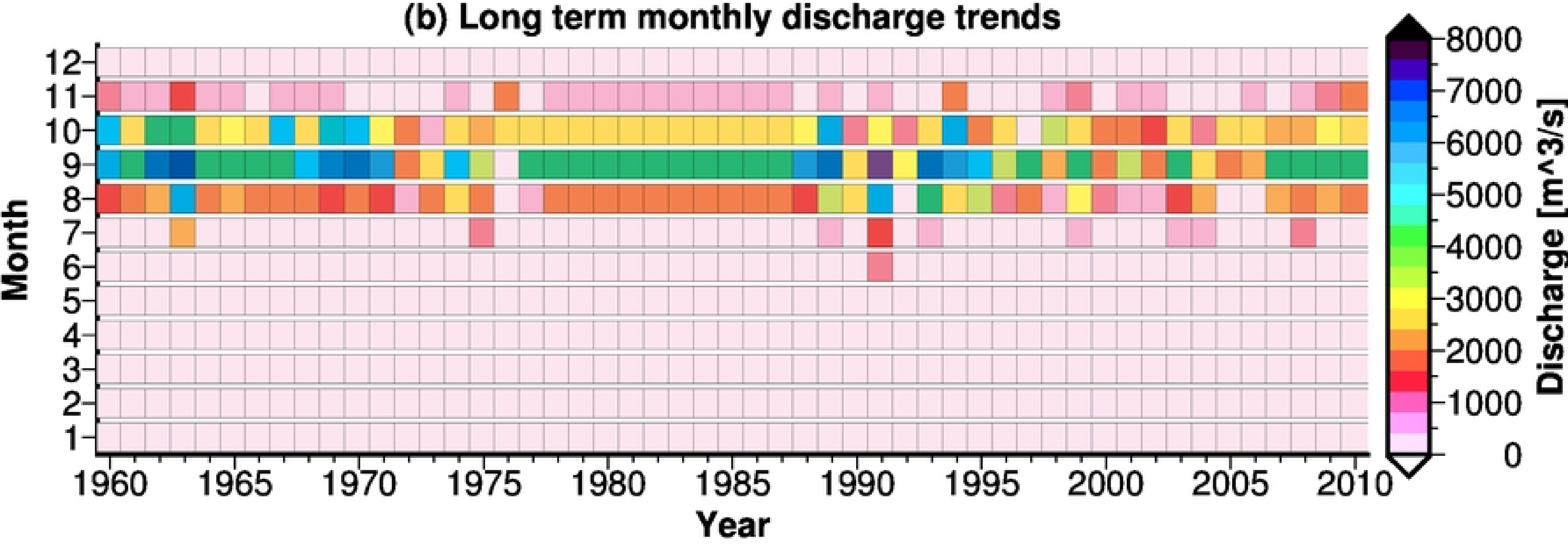


Fig3

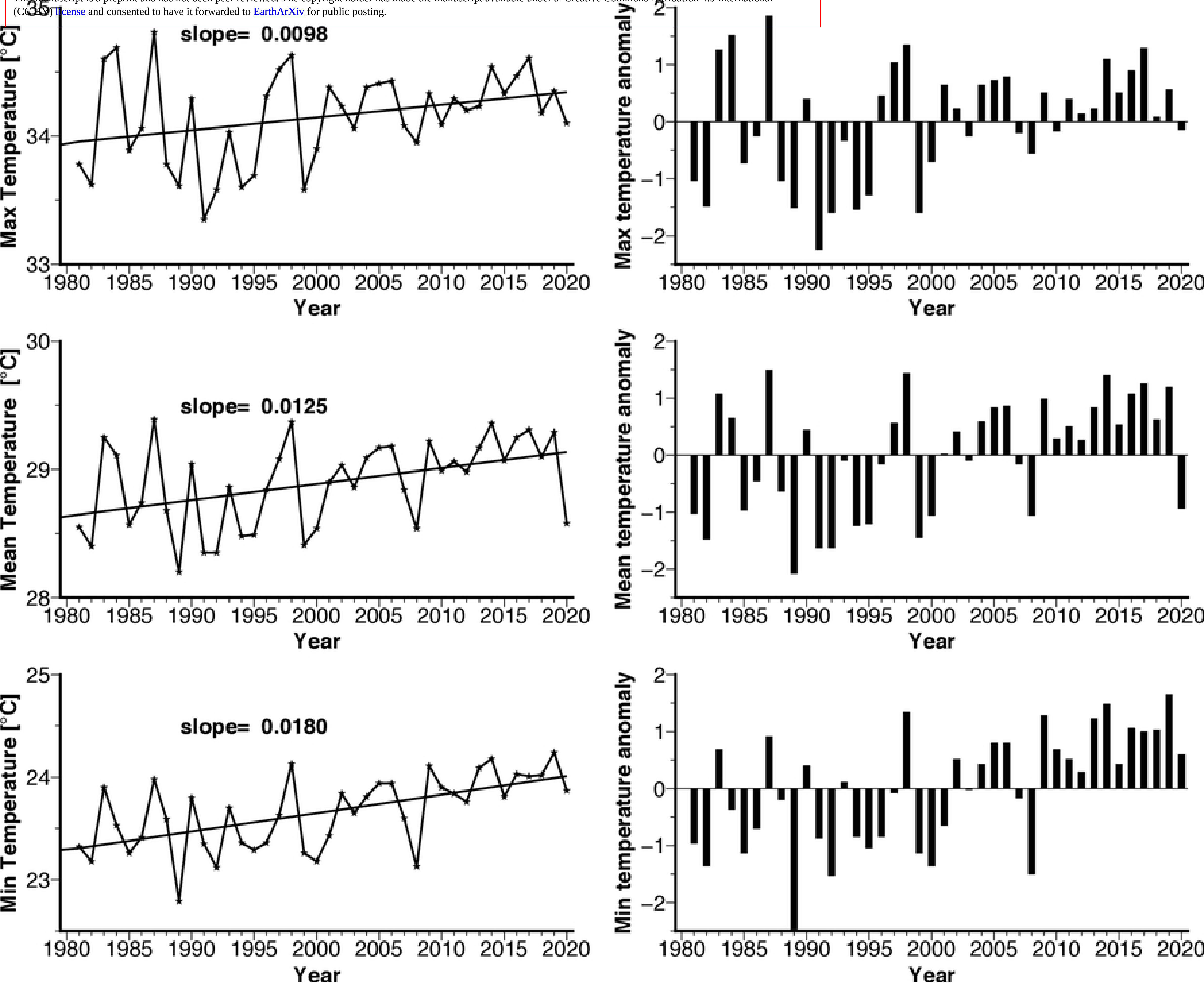
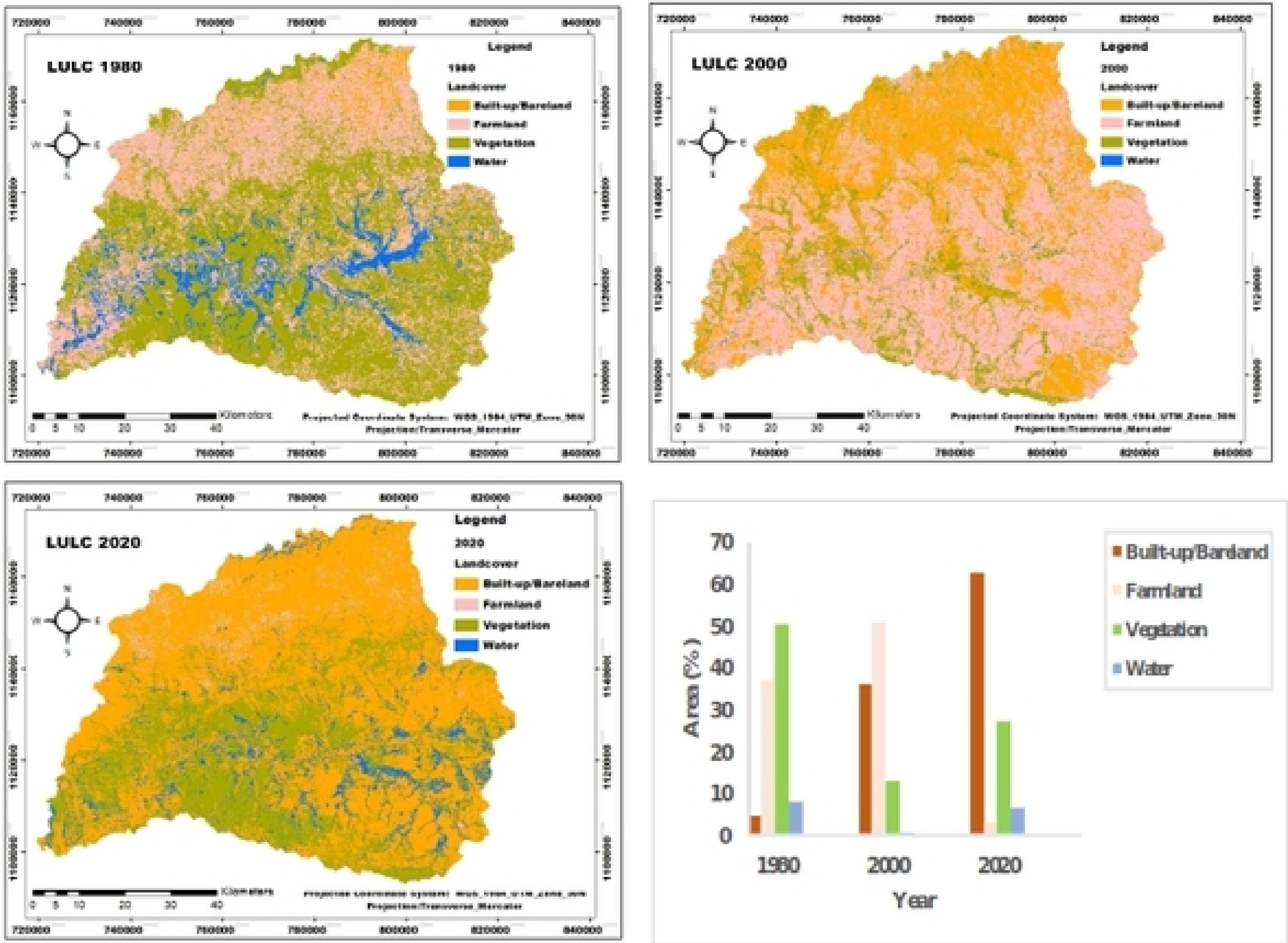

Max Temperature [°C]
slope= 0.0098
35
34
33
1980 1985 1990 1995 2000 2005 2010 2015 2020
Year
Max temperature anomaly
2
1
0
−1
−2
1980 1985 1990 1995 2000 2005 2010 2015 2020
Year
Mean Temperature [°C]
slope= 0.0125
30
29
28
1980 1985 1990 1995 2000 2005 2010 2015 2020
Year
Mean temperature anomaly
2
1
0
−1
−2
1980 1985 1990 1995 2000 2005 2010 2015 2020
Year
Min Temperature [°C]
slope= 0.0180
25
24
23
1980 1985 1990 1995 2000 2005 2010 2015 2020
Year
Min temperature anomaly
2
1
0
−1
−2
1980 1985 1990 1995 2000 2005 2010 2015 2020
Year

Fig4



LULC 1980
Legend
1980
Landcover
Built-up/Bareland
Farmland
Vegetation
Water
LULC 2000
2000
LULC 2020
2020
Kilometers
0 5 10 20 30 40
Projected Coordinate System: WGS_1984_UTM_Zone_30N
Projection:Transverse_Mercator
720000 740000 760000 780000 800000 820000 840000
1160000 1140000 1120000 1100000
Area (%)
0 10 20 30 40 50 60 70
1980 2000 2020
Year
Built-up/Bareland
Farmland
Vegetation
Water

Fig5