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Hydro-climatic and land use/cover changes in Nasia catchment of the White Volta basin in Ghana

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Abstract

The Nasia catchment is the reservoir for significant surface water resources in Northern Ghana and home to numerous subsistence farmers engaged in rainfed and dry season irrigation farming. Yet there is little understanding of the hydro-climatic and land use /cover conditions of this basin. We analyzed 50 years of minimum (T_{min}) and maximum temperature (T_{max}), wind speed (WS), sunshine duration (S), Rainfall (R), relative humidity (RH), discharge (D) and potential evapotranspiration (PET) data, 15 years of remotely sensed normalized difference vegetation index (NDVI) data and 30 years of land use/cover image data. Results show that T_{min} , T_{max} , WS, and PET have increased significantly ($P < 0.05$). RH and S significantly declined. R, D and NDVI have insignificantly decreased ($P > 0.05$). A significant abrupt change in almost all hydroclimatic variables started in the 1980s, a period that coincides with the occurrence of drought events in the region except WS in 2001, R in 1968 and D in 1975. Also, D showed a positive significant correlation with RH, R and PET, but insignificant positive relationship with S. D also showed negative insignificant correlation with T_{min} , T_{max} and WS. Areas covered with shrubland and settlement/bare lands have increased to the disadvantage of cropland, forest, grassland and water bodies. We conclude that climate change impact is quite noticeable in the basin; indicating water scarcity and possibilities of droughts. The analysis performed herein is a vital foundation for further studies to simulate and predict the effect of climate change on the water resources, agriculture and livelihood in the Nasia basin.

Keywords: Hydroclimatology; landuse/cover; Trends; Ghana; White volta; catchment

1. Introduction

Climate change presents the most pressing challenge of the 21st century, with extraordinary impact on natural ecosystems, economic sectors, society and water resources (Arnell, 2004; Khaliq et al. 2009; Sabbaghi et al. 2017; de Hipt et al. 2018; Schilling et al. 2020; Baarsch et al. 2020). Climate change is unequivocal, manifested by rapid warming of the globe and increasing the frequency of extreme events, such as floods and droughts (IPCC, 2014). Africa, for example, is expected to experience negative climate change impacts, contributing to already present problems of widespread poverty and

low development (World Bank, 2010; Mikulewicz and Taylor, 2020). At the background of climate change is the variability of the hydro-climatic parameters, such as temperature, rainfall, relative humidity, discharge, potential evapotranspiration, radiation etc., both in their long-term average and by an increase over time. The already high temperatures and largely erratic rainfall are expected to increase in sub-Saharan Africa over the 21st century (Speranza, 2010; IPCC, 2014; Serdeczny et al. 2017; Codjoe and Atiglo, 2020).

Variations in climatic conditions are important determinants of vegetation growth and density across the world and, especially, in tropical and subtropical Africa (Warburton et al., 2012; Schmidt et al. 2014). Also, feedbacks from land surface processes and vegetation dynamics influence local and regional climate variability (Wang and Eltahir, 2000), especially in West Africa and the Sahel Zone (Long et al. 2000; Nicholson, 2000; Los et al. 2006; Paeth et al. 2009). Changes in land cover, particularly vegetation, is likely to aggravate the climate change situation in a way that the hydrological cycle will be altered, resulting in an increase in frequency and severity of droughts and floods which in turn, influences agriculture, water supply, environmental sustainability and protection from floods (Aduah et al., 2017). The combined effects of climate variability, land use/cover changes and unsustainable water management practices have led to a significant alteration in the water balance of the river basins (Buma et al. 2016)

Analysing the direction and magnitude of the variation in the hydro-climatic variables is considered valuable for understanding climate change and providing a basis for determining future scenarios of climate impact (Chaouche et al. 2010; Reiter et al. 2012; Unal et al. 2012; Asfaw et al. 2018; Meshram et al. 2020). Detecting the historical trend of vegetation, often expressed in Normalized Difference Vegetation Index (NDVI), land use/cover changes particularly improve our understanding of the changing planet and provides a clue about the productivity of lands (Tian et al. 2015; Gichenje and Godinho, 2018; Frédérique et al. 2019; Rezende et al. 2020). Trend analysis of hydro-climatic variables and vegetation is particularly relevant for water resource decision makers as they prepare to deal with the possible effects of climate variability and change on water availability (Sahoo and Smith 2009; Oguntunde et al. 2006; Zhou et al. 2015; Tehrani et al. 2019).

Many regions of the world are increasingly facing a decline in freshwater resource, due to both natural and man-made causes. Climate and land use/cover change are likely to aggravate this situation in a way that the hydrological cycle will be intensified resulting in an increase in frequency and severity of droughts and floods which influences agriculture, water supply, environmental sustainability and protection from floods and infrastructure (Aduah et al., 2017). Depending on the severity, water deficits can result in catastrophic consequences (Amisigo, 2006).

The availability of freshwater in sub-Saharan Africa is fundamental to economic growth and social development (Kankam-Yeboah et al., 2013). In the Volta Basin of West Africa, where Ghana is situated, there are competing demands for water use both within and among the riparian countries of the basin. This is manifested in the numerous dams and reservoirs constructed throughout the basin for various purposes including industrial, agricultural and domestic water supplies (Amisigo, 2006).

The Ghana Water Research Institute of the Council for Scientific and Industrial Research (CSIR-WRI) reports that all river basins in Ghana will be vulnerable and the whole country will face acute water shortage by the year 2020 (Kankam-Yeboah et al., 2011). It also reported a general reduction in annual

river flows in Ghana by 15-20 % for the year 2020 and 30-40 % for the year 2050, due to an increased irrigation water demand of 40-150 % for 2020 and 150-1200 % for 2050 and a reduction in hydropower generation of 60 % for 2020 (Kankam-Yeboah et al., 2011). According to Abdul-Ganiyu et al. (2011), the main surface water resources in Northern Ghana are concentrated in the White Volta and the Nasia River systems, which flows only three or four months during the year, causing seasonal deficits across the region. This poses serious problems for traditional rain-fed agriculture, especially as food demand grows, thus slowing down rural development. Also, the authors mention that the seasonal shortage of water affects irrigation during the dry season for the Nasia Irrigation Project, which operates as a run-of-river scheme for all year-round crop production.

Given the above pressing issues, understanding the hydro-climatic variability and land use/cover changes in Nasia River Basin is important in Northern Ghana, because the availability of water resources is a significant factor in this highly productive agricultural region. While the causes and the mechanisms of this changes is a matter for other studies, the relevant question for West Africa and Ghana for this case is how has climate change affected the trends of these hydroclimatic variables? Therefore, the objective of this study was to determine the historical trends in selected hydro-climatic variables (minimum and maximum temperature, wind speed, sunshine duration, rainfall, relative humidity, discharge and potential evapotranspiration), NDVI and land use cover/change in Nasia sub-basin and to establish the relationship between these parameters and discuss the possible implications of the observable changes in the Nasia catchment to agriculture in the region.

2. Methodology

2.1 The Nasia River basin

The Nasia basin (Figure 1) is a tributary of the White Volta in the Northern Region of Ghana, with a catchment area of about 5,400 km² and a mean annual runoff of 550 million m³ (WRCG, 2008). It is geographically positioned between latitudes 9°55' and 10°40' N and longitudes 1°05' W and 0°15' E (Adu, 1995). The area is characterised by unimodal rainfall, with an annual average between 1000 - 1300 mm, which peaks between late August and early September (Elikplim et al., 2018). Temperatures in this region are consistently high. The hottest month in the year is March or April, just before the beginning of the rainy season, while the coolest month is July or August. The average maximum and minimum temperatures of 34°C and 23°C, respectively, are recorded (Abdul-Ganiyu et al., 2011). The floodplain soils vary in texture, from very fine sands to heavy clays and are developed over levees, old river beds, sloughs and low river terraces. Most of the Nasia basin is very gently undulating. It has broad, poorly-drained valleys and extensive floodplains adjacent to the Volta and Nasia rivers, where altitudes vary between 108 and 138 m above mean sea level (Abdul-Ganiyu et al., 2011). It has a relatively short rainy period, stretching from May – October, with estimated reference evapotranspiration (ET_o) above 1600 mm/annum (Kranjac-Berisavljevic, 1999). The remaining months of the year are very dry, posing challenges to domestic and agricultural activities, due to water unavailability in the basin. The people of the area are engaged in subsistence agriculture mainly on “compound farms” which lie immediately around the houses and “bush farms”, which may border on the compound farm or are located several kilometres away from the main communities. Rice, maize, legumes and vegetables are cultivated in the rainy season, whilst tomatoes and onions are cultivated in the dry season under irrigation. Many householders’ sheep and goats, as well as chickens and guinea fowls, but few others keep cattle. The animals are kept for security reasons or as a capital investment (Abdul-Ganiyu et al., 2011).

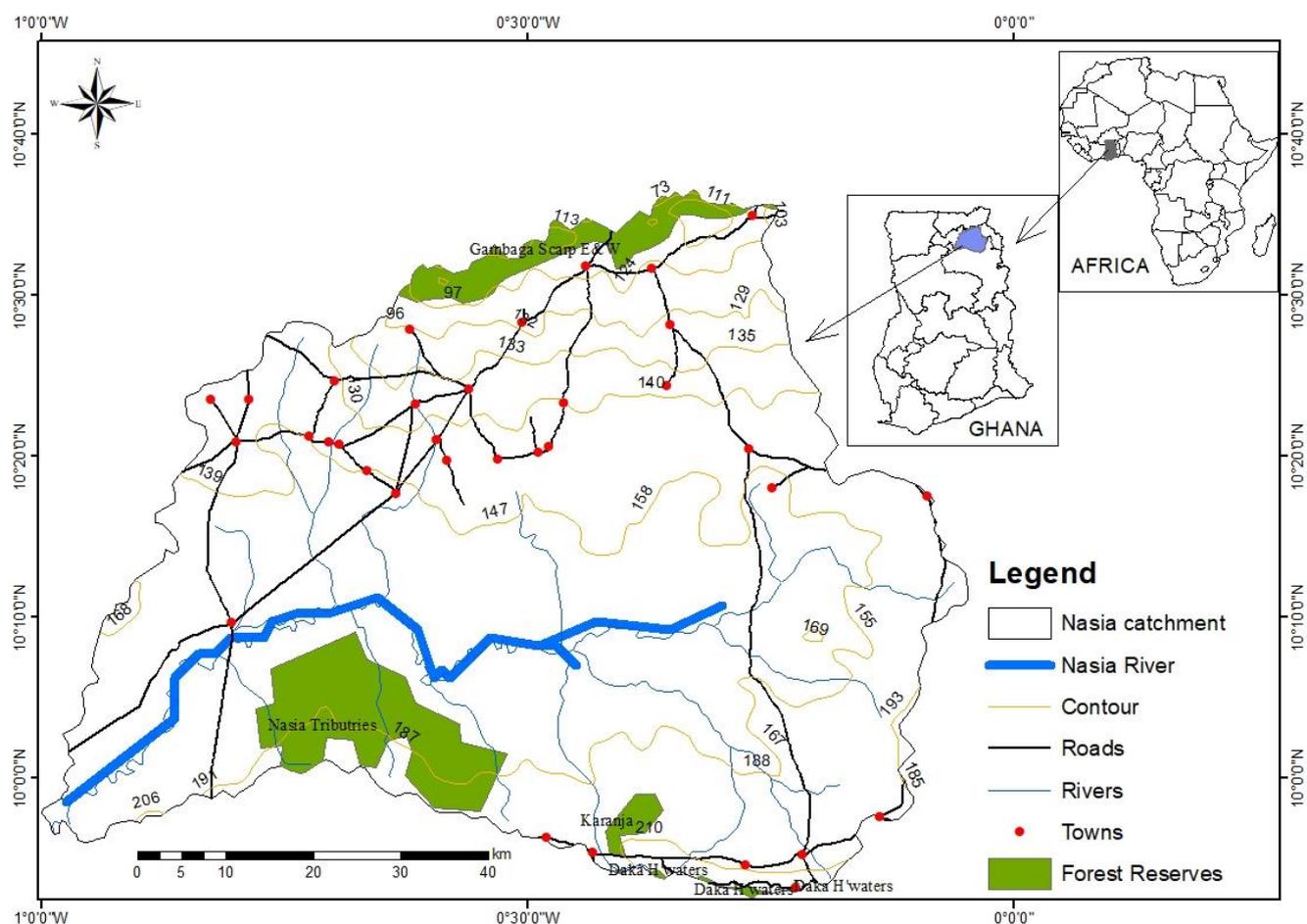


Figure 1: Map of Nasia catchment

2.2 Data collection and quality assurance

This study utilised climate, hydrological and land use/cover (LULC) data (Table 1). Fifty (50) years of daily hydro-climatological data were collected from relevant government institutions. The hydrological data, i.e. river discharge was obtained from the Ghana Hydrological Services Department (GHSD), while the climatic data i.e. Rainfall, minimum temperature and maximum temperature, relative humidity, wind speed and sunshine were collected from Ghana Meteorological Agency (GMET) for the Tamale synoptic station. Also, annual NDVI data was collected from NASA Giovanni website. LULC maps of 2000 and 2010 were obtained from the GlobeLand30 map generated by the Chinese Government and 2020 LULC map generated from Landsat 8 image acquired from the US Geological Survey GLOVIS website.

Table 1: Summary of data types, timesteps and sources

Parameter	Period	Source of data
Rainfall	1961-2010	GMET
Minimum temperature	1961-2010	GMET
Maximum temperature	1961-2010	GMET
Wind speed	1961-2010	GMET
Sunshine	1961-2010	GMET

Relative humidity	1961-2010	GMET
Discharge	1961-2010	GHSD
NDVI	2002-2017	NASA Giovanni
LULC map 1	2000	GlobeLand30
LULC map 2	2010	GlobeLand30
LULC map 3	2020	GLOVIS (Landsat 8 image)

Missing values of the data were handled with the “na_interpolation” function in an R package called imputeS. The package estimates Missing Value by Interpolation (Moritz and Bartz-Beielstein, 2017).

2.3. Data analysis

2.3.1 Analysis of hydroclimate and NDVI variables

The hydro-climatic and NDVI data were analysed using the R statistical software. The datasets were first separately analysed to determine trends and subsequently together to describe the relationship between the variables. The analysis generally followed three main steps. First, analysis of basic statistical properties of the variables was determined using the mean, median, mode, skewness and kurtosis, variance and standard deviation.

Secondly, The Mann-Kendall trend test (Mann, 1945), a non-parametric method, was used to investigate the trends in annual rainfall (mm), annual discharge (m^3s^{-1}), relative humidity (%) and minimum and maximum temperature ($^{\circ}C$), wind speed (km/day), sunshine (hrs) and NDVI data. The presence of a breakpoint in the time series of annual averages of the variables was examined using the non-parametric test of Pettitt (Pettitt, 1979). Pettitt’s test allows detection of abrupt changes, whether artificial or natural, in the mean of the time series (Mallakpour and Villarini, 2015).

The null hypothesis was tested at a 95% confidence level ($\alpha = 0.05$) for all the variables. We selected the Mann-Kendall trend test because it accommodates missing data and outliers, and does not require the data to be normally distributed (Partal and Kahya, 2006). At the same time, it has low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari et al., 2011). This test has been extensively and successfully used to detect trends in hydro-climatic studies (Xu et al., 2010; Sun et al., 2013; Zhang et al., 2015; Mwangi et al., 2016) and NDVI (Forkel et al., 2013; Osunmadewa et al., 2014).

The null hypothesis H_0 assumes that there is no significant trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1 , which assumes that there is a significant trend (Onoz and Bayazit, 2012). The test statistic Z_s is used as a measure of the significance of the trend. This test statistic is used to test the null hypothesis, H_0 . Kendall's tau was used to measure the strength of the trend. In addition to the Mann-Kendall test, we compared the results in linear trend lines and plotted for each variable. Mann-Kendall test statistic (S) is given as follows (Gocic and Trajkovic, 2013; Kambombe, 2018):

$$S = \begin{cases} (S - 1/\sqrt{Var(S)}) & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ (S + 1/\sqrt{Var(S)}) & \text{if } S < 0 \end{cases} \dots\dots\dots\text{eqn. 1}$$

Where

$$sgn(x_j - x_k) = \begin{cases} 1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{cases} \dots\dots\dots\text{eqn. 2}$$

When S is greater than 0, it implies a positive trend, and a negative S indicates a decreasing trend. The S is approximately normally distributed for $n \geq 8$, with the variance given as:

$$Var(S) = \frac{1}{18} [n(n-1)(2n+5)] \dots \dots \dots \text{eqn. 3}$$

In case of tied ranks in the data, the statistic $Z_s = 0$ and variance of S, $Var(S)$ is calculated by:

$$Var(S) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5) \right] \dots \dots \dots \text{eqn. 3}$$

Where q is the number of tied groups and t_p is the number of data values in the P^{th} group. The standardised Z value is used to determine the significance of any trend in the data set. The null hypothesis stating that there is no trend in the dataset is rejected $|Z_c| > Z_{1-\alpha/2}$ or if the p-value is less than the level of significance ($p < \alpha = 0.05$). The Sen's slope technique which estimates the magnitude of monotonic trends in N pairs of data was used in this study (Hirsch et al., 1982). A monotonic upward or downward trend for a variable implies that there is a consistent increase or decrease in the variable through time, but the trend may or may not be linear (Kafumbata et al., 2014). The Sen's slope is given as:

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for } i =, \dots, N, \dots \dots \dots \text{eqn. 4}$$

In which Q_i is the Sen's slope while x_j and x_i are data values in years j and i; where $1 < j < i < n$. A positive Q_i value indicates an upward trend while a negative value indicates a downward trend.

Thirdly, Pearson's correlation analysis was used to determine the relationship between the variables.

2.3.2 Image Processing and Land Use Land Cover Mapping

The LULC maps of 2000 and 2010 were extracted from the GlobeLand30 maps produced by the Chinese Government (global land cover map at a spatial resolution 30 m) (Jun *et al.*, 2014). Two scenes of the GlobeLand30 dataset covering Ghana, that is, N30_05 and N30_10 were mosaicked since the basin fell within both scenes. The 2020 map classification was performed by the authors. The classes in the 2000 and 2010 maps were adopted for the 2020 classification i.e. Cropland, Forest, Grassland, Shrubland, Waterbodies and Settlement/bare areas. Bare areas were combined with settlement due to the dryness of the basin located in the Guinea Savannah zones. Moreover, most of the settlement are farming communities with less reflective roofs (thatch roof) to depict settlement.

Landsat 8 images at 30 m spatial resolution and cloud cover criterion of less than 10% acquired on 26 February 2020 from path 194 row 53 were acquired freely from the United States Geological Survey's (USGS) GLOVIS. Atmospheric correction for temporal analysis was done in QGIS under the Semi-Automatic Classification Plugin (SCP). The Random Forest Algorithm Machine Learning was used to classify the image in R software (Thanh Noi and Kappas, 2018). The 2016 European Space Agency (ESA) Climate Change Initiative (CCI) S2 prototype land cover map at 20 m of Africa was acquired from ESA and combined with Google earth image of 2020 and observation or knowledge of the basin

were references used for the classification (Forkuo and Frimpong, 2012). Both pixel-based and area-based error matrix was done to assess the accuracy of the classification (Olofsson *et al.*, 2013).

The overall accuracy of the 2000 and 2010 GlobeLand30 is 78.6% and 80.33% respectively, was validated by over 150,000 points in 80 out of 853 tiles for the 2010 land cover map (Chen *et al.*, 2015). The overall accuracy for the 2020 LULC maps was 90.53% and 77.15% for the pixel-based and area-based error matrix assessment (See appendix 1 for details of the pixel-based and area-based error matrix for 2020).

3. Results

In this section, we present the findings of our analysis in three main ways. Firstly, the descriptive statistics of the 8 variables (climate, hydrological and NDVI data) are shown. Secondly, the results of the trends in the variables are also presented. Thirdly, the relationship between these variables and how they influence river discharge was established using a multivariate regression model.

3.1 Temporal characteristics of the variables in Nasia Catchment

Over 50 years (1961-2010), Nasia catchment received an annual total rainfall (R) ranged from 695 mm to 1666 mm, with a mean value of 1093 mm. Discharge (D) of the Nasia river ranged from as low as 7.83 m³/s to 20757.3 m³/s with a mean flow of 6931.6 m³/s. Also, within the 50 years, the catchment recorded an average minimum (Tmin) and maximum (Tmax) temperature of 22.6⁰C and 34.1⁰C, the average sunshine (Sun) in hours per day of 7.3, with relative humidity (RH) of 57.98%. The average wind speed (WS) over 26 years is 3.25 kt. Also, the average NDVI for the 16 years is 0.47. Table 2 provides descriptive statistics of the selected variables.

Table 2: Summary statistics of selected hydro, climate and vegetation variables in Nasia catchment

Statistic	Tmin (⁰ C)	Tmax (⁰ C)	WS (kt)	S (Hrs/day)	R (mm/year)	RH (%)	D (m ³ /s)	PET (mm)	NDVI
No of observations	50	50	50	50	50	50	50	50	16
Minimum	21.7	33.01	2.47	5.7	695.30	25.45	7.83	1111.10	0.43
Maximum	23.5	36.20	4.19	8.6	1579.80	65.67	20757.3	2329.30	0.57
1st Quartile	22.2	33.64	2.86	7.1	996.63	57.28	2785.5	1994.50	0.46
Median	22.6	34.11	3.16	7.4	1076.05	59.67	6869.5	2092.61	0.47
3rd Quartile	22.9	34.44	3.49	7.6	1162.30	61.39	10301.5	2187.93	0.48
Mean	22.6	34.10	3.25	7.3	1093.99	57.98	6931.6	2009.51	0.47
Standard deviation (n)	0.44	0.59	0.47	0.43	181.81	6.87	5312.2	317.43	0.03
Variation coefficient (n)	0.02	0.02	0.14	0.06	0.17	0.12	0.8	0.16	0.06

Skewness (Pearson)	0.13	0.67	0.32	-0.92	0.43	-2.76	0.5	-2.05	2.31
Kurtosis (Pearson)	-1.04	1.33	-0.80	3.48	0.41	8.99	-0.3	3.22	6.14

3.2 Annual trends in the selected variables

The observed slope for D, R, S, RH, and NDVI was negative, indicating a decreasing trend while Tmin, Tmax, WS and PET showed an increasing trend. The decreasing trend in R and D was insignificant ($p > 0.05$) at a rate of -0.086 mm/year and -35.485 m³/year, respectively. S, RH and NDVI were, however, significant ($p < 0.05$) at a rate of -0.007 hrs/day/year, -0.084% and -0.002 , respectively. A significant ($p < 0.05$) increasing trend was observed for the remaining variables [Tmin (0.022°C), Tmax (0.028°C) and PET (4.233 mm)] except for WS which increased at an insignificant rate of 0.008 kt.

R recorded an earlier but insignificant change in mean value in the year 1968, which was consistently followed by an insignificant change in D in 1975. A significant breakpoint of Tmin, Tmax, S, RH, PET occurred within the 1980s a period that coincides with the occurrence of drought events in the region. Specifically, Tmax and S observed abrupt changes in the years 1980 and 1981, respectively. Also, a close breakpoint in Tmin and PET were identified in the years 1986 and 1987, respectively. WS and NDVI recorded a breakpoint in the years 2001 and 2014, respectively. Results of the trend and breakpoint year estimates are presented in Table 3. Annual time series and anomalies for all variables are shown in Figures 2 and 3, respectively.

Table 3: Results of trend and breakpoint detections analysis for the selected variables

Variables	Mann–Kendall’s test for trend					Pettitt’s test for breakpoint	
	Kendall's tau	p-value	Kendall Statistic(S)	Sen's slope	Trend direction	Breakpoint year	P-value
Tmin	0.508	<0.0001	622	0.022	Up	1986	< 0.0001
Tmax	0.537	<0.0001	658	0.028	Up	1980	< 0.0001
WS	0.174	0.075	213	0.008	Up	2001	0.024
S	-0.232	0.018	-283	-0.007	Down	1981	0.009
R	-0.004	0.967	-5	-0.086	Down	1968	0.117
RH	-0.249	0.011	-305	-0.084	Down	1980	0.001
D	-0.048	0.622	-59	-35.485	Down	1975	0.154
PET	0.278	0.004	341	4.233	Up	1987	< 0.0001
NDVI	-0.417	0.026	-50	-0.002	Down	2014	0.226

NB: At P -value > 0.0 , the null hypothesis (H_0) indicating there is no significant trend in the series or data are homogeneous is rejected. At P -value < 0.05 the alternative hypothesis (H_a) indicating there is a significant trend in the series or there is a date at which there is a change in the data is accepted.

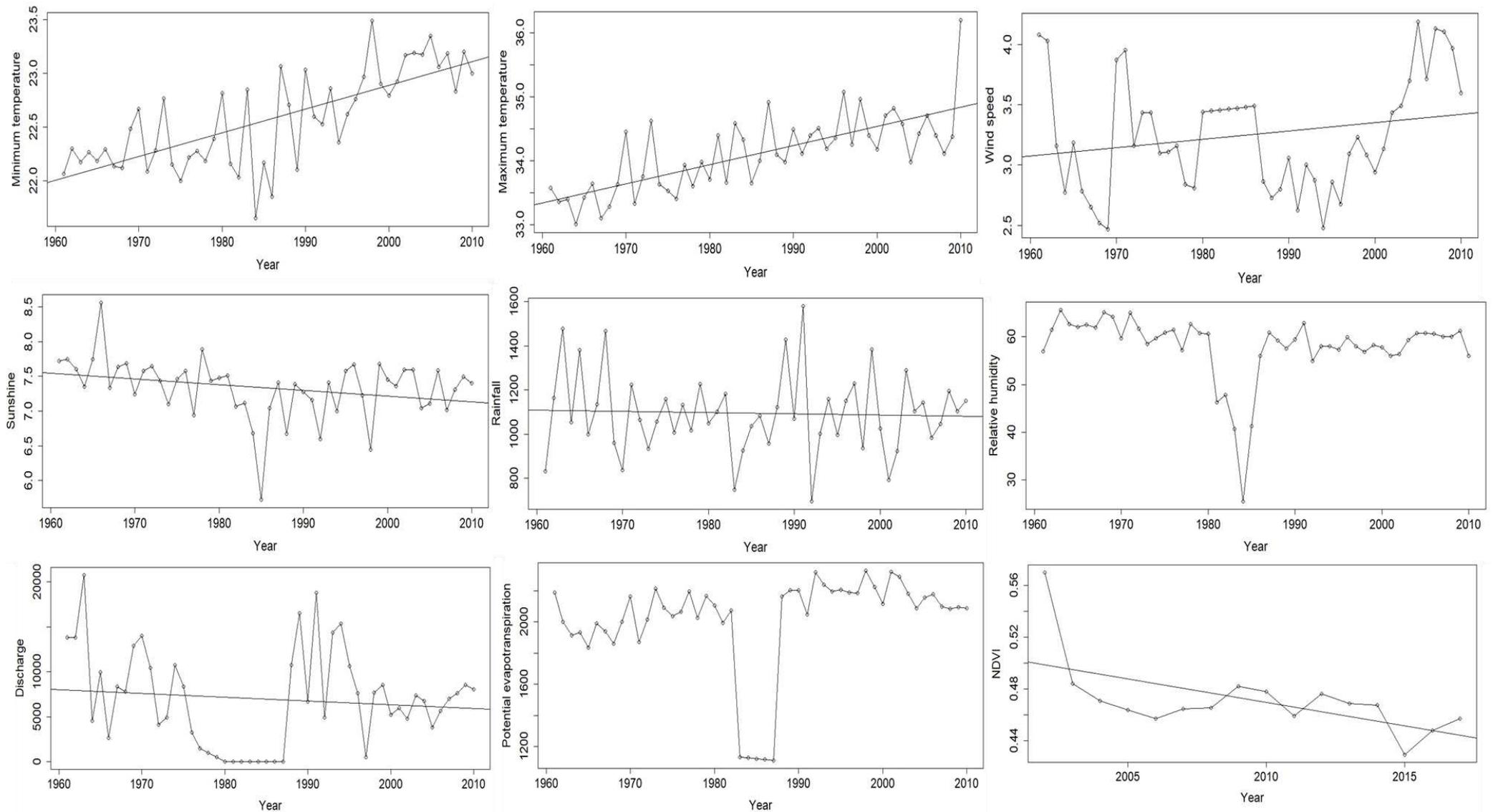


Figure 2: Time series plots of D = Total Discharge (m³/s); S= Sunshine (Hrs /days); Tmax= maximum Temperature (°C); WS= Wind speed (Km/hr); RH= relative humidity (%); Tmin= Mean minimum Temperature (°C); R= Rainfall (mm); NDVI= Normalized difference vegetation index

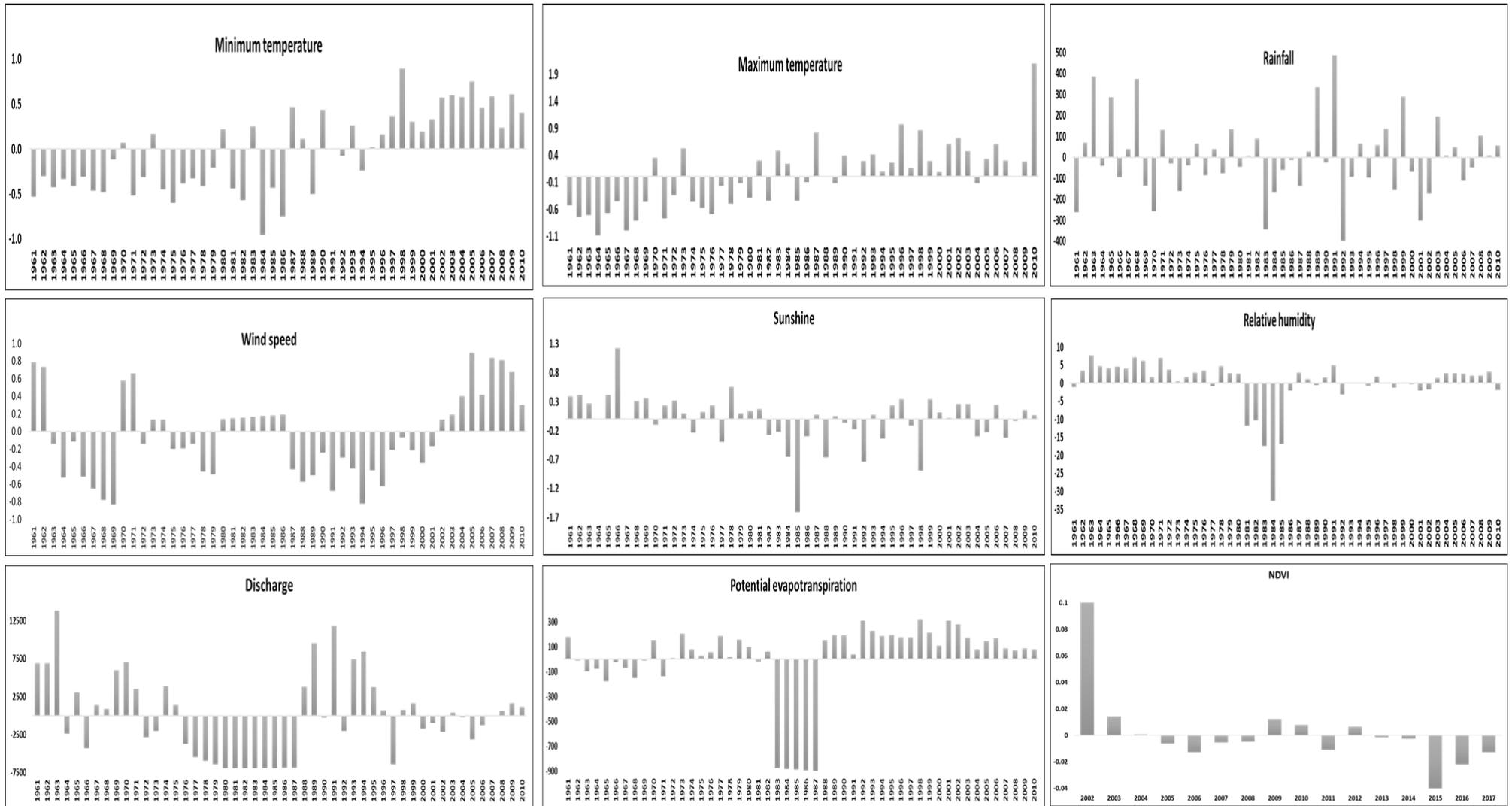


Figure 3: Inter-annual anomalies of the hydro-climate and NDVI variables: Total Discharge (m^3/s); Sunshine (Hrs /days); maximum Temperature ($^{\circ}\text{C}$); Wind speed (Km/hr); Relative humidity (%); Mean minimum Temperature ($^{\circ}\text{C}$); Rainfall (mm); NDVI=Normalized difference vegetation index).

3.3 Relationship of the hydro-climatic variables

Results show that rainfall contributes significantly to relative humidity and discharge throughout the year, showing a positive relationship. Rainfall also has a positive but insignificant relationship with potential evapotranspiration and sunshine, and an insignificant negative correlation with wind speed and minimum and maximum temperatures. Potential evapotranspiration has a significant positive relationship with minimum temperature, relative humidity and discharge, but insignificantly increases with maximum temperature, sunshine and rainfall. Potential evapotranspiration also has an insignificant negative relationship with wind speed. When both minimum and maximum temperature increase, discharge, duration of sunshine, relative humidity and rainfall insignificantly decrease, meanwhile wind speed increased but insignificantly. Both maximum and minimum temperature have a significantly positive relationship.

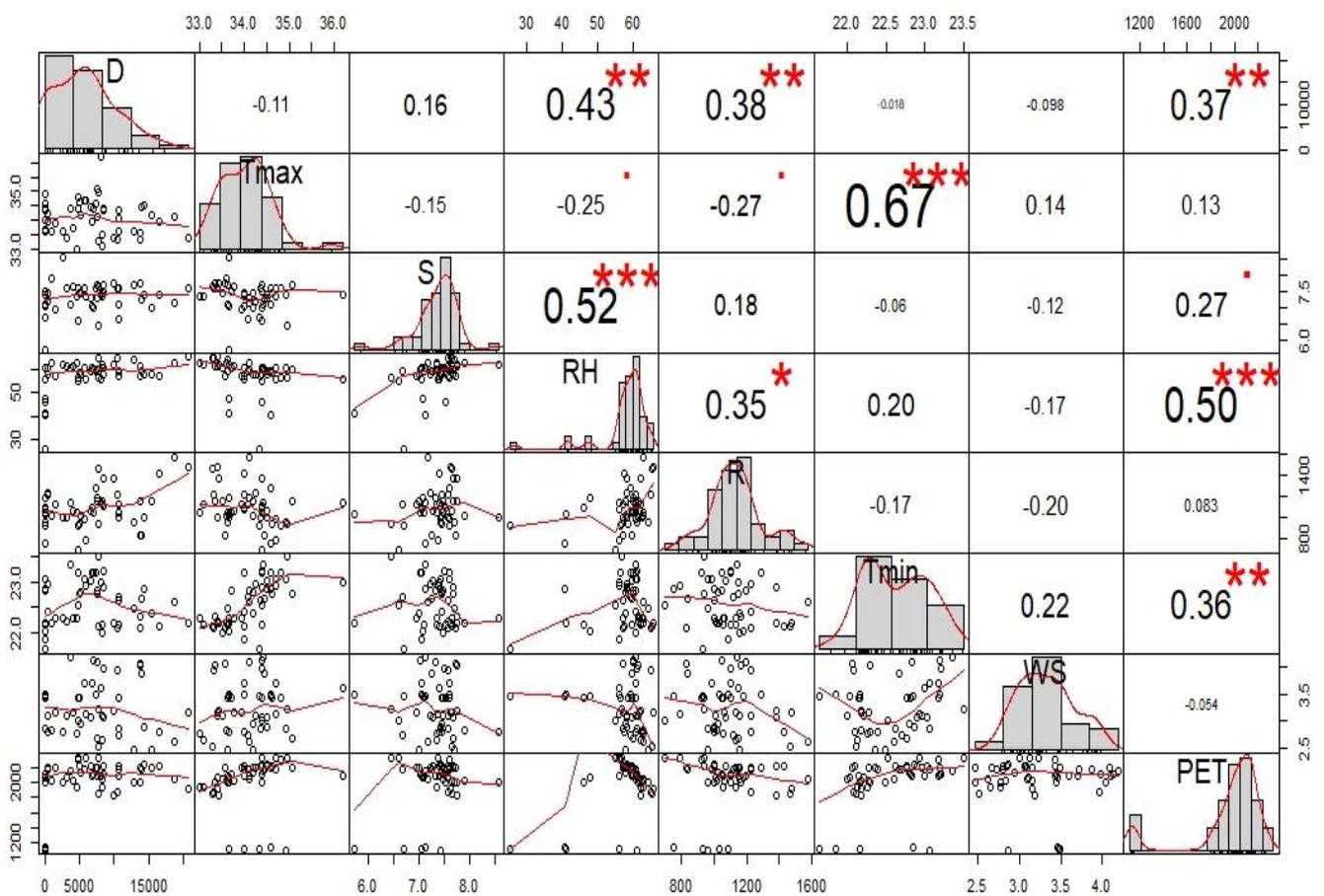


Figure 4: Correlation values of the hydro-climatic variables in the catchment shown on the top of the diagonal with the significance level as stars (***, **, and * represent for $P < 0.001$, $P = 0.001$ to 0.01 , $P = 0.01$ to 0.05). The distribution of each variable is shown on the diagonal. On the bottom of the diagonal: the bivariate scatter plots with a fitted line are displayed.

3.4 Land Use/ Cover Changes over the last 3 decades

The landscape dynamics over 30 years in the Nasia Basin was assessed from 2000 to 2020 at decadal intervals [interval 1 (2000-2010) and interval 2 (2010-2020)] (Figure 5). Table 4 presents the land use/cover class sizes in percentage and their changes during the two intervals.

Table 4: Land Use / Cover Classes in the Nasia Basin (%)

LULC	Year 2000	Year 2010	Year 2020	Interval 1 (2010-2000)	Interval 2 (2020-2010)
Cropland	32.72	27.17	27.40	-5.55	0.22
Forest	11.61	1.92	6.15	-9.69	4.23
Grassland	53.70	58.75	43.99	5.05	-14.76
Shrubland	1.33	11.79	18.96	10.46	7.17
Water bodies	0.42	0.09	0.19	-0.34	0.1
Settlement/ bare areas	0.22	0.28	3.32	0.07	3.04
TOTAL	100	100	100		

The total land area of the Nasia catchment is 534,252 hectares. From 2000 to 2010, waterbodies decreased by 0.34% and increased by 0.10% from 2010-2020. Forest coverage also decreased by 9.69% during the first interval and increased by 4.23% in the second interval.

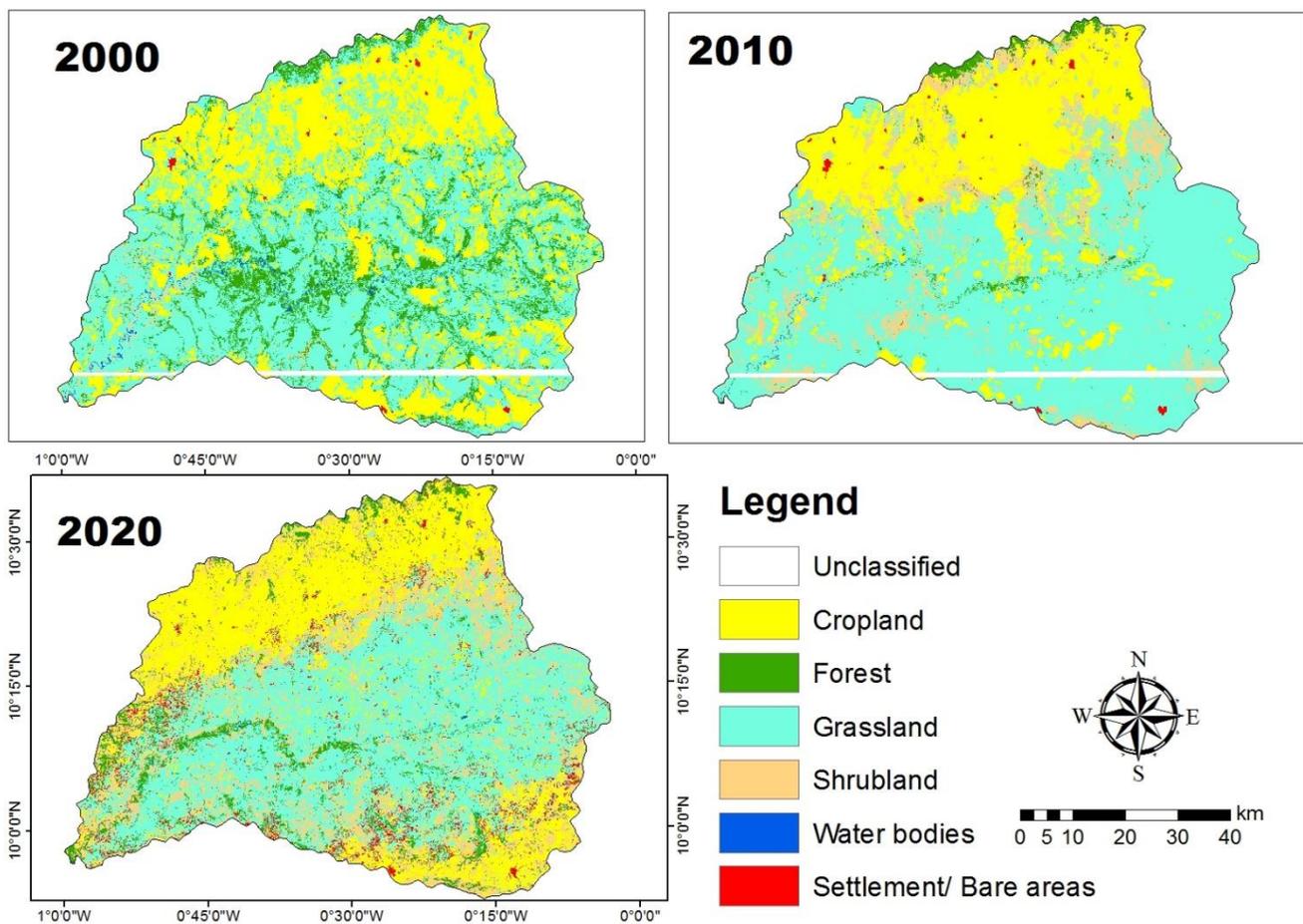


Figure 5: Land use/cover changes in Nasia Catchment for the year 2000, 2010 and 2020.

Grassland and Shrubland increased by about 5.05% and 10.46%, respectively in the first interval. During the second interval Grassland decreased at 14.76% while Shrubland again increased by 7.17%. Settlement/bare areas increased in both intervals with a higher increase from 2010 to 2020 (3.04%). Cropland decreased by 5.55% in the first interval and marginally increased (0.22%) in the second interval. Over the entire 30 years period, Shrubland and Settlement/bare lands have increased by 17.62%

and 3.1%, respectively, while all other land covers have decreased (5.32% cropland, 5.46% forest, 9.71% grassland and 0.24% water bodies) (Figure 6).

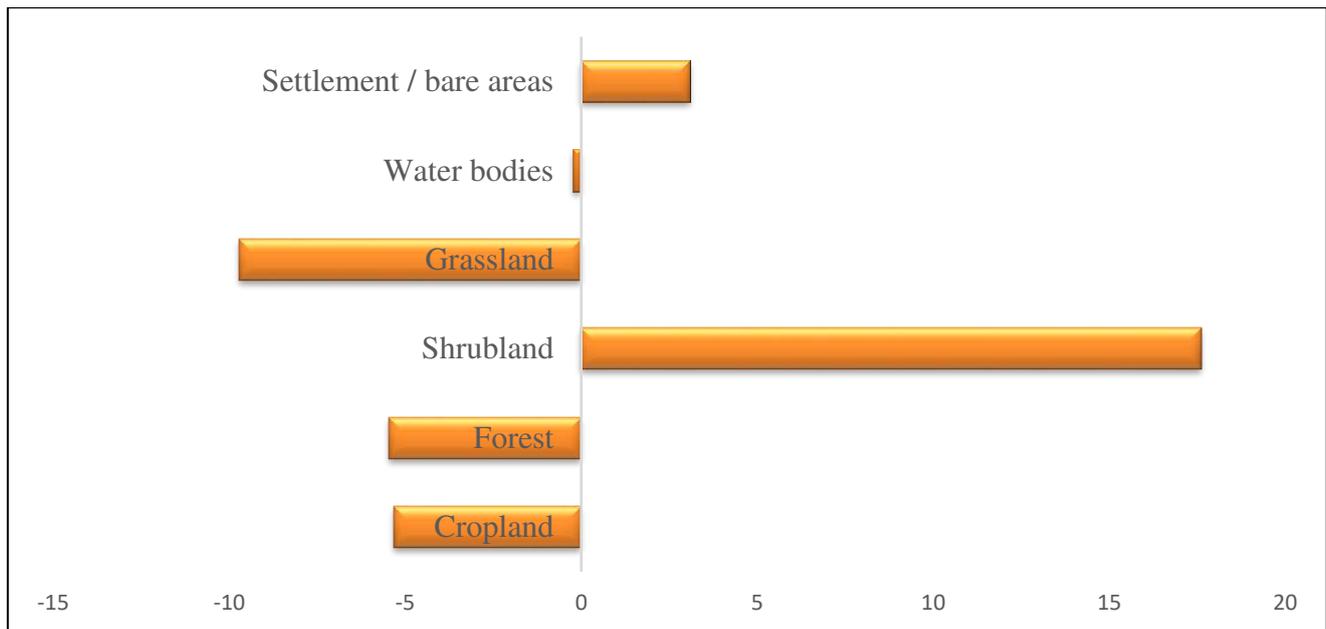


Figure 6: Changes in land use/cover over the entire 20 years period expressed in percentages

4.0 Discussions

This paper sets out to understand the trends and relationship between the hydroclimatic variables and land use/cover changes in the Nasia catchment. Here, we discussed the implications of the results and their impacts on agriculture and the livelihood of the people in the basin.

The occurrence of a significant increasing trend in both maximum and minimum temperature over the study area highlights the existence of a warming climate in the Nasia Catchment in the Northern region of Ghana. Rainfall within the basin shows a decreasing but insignificant trend. Similar trends of temperature and rainfall have been discussed in studies performed in Northern Ghana, where Nasia basin is located (Amikuzuno and Donkoh, 2012; Frimpong et al., 2014; Issahaku et al., 2016; Nyadzi, 2016; Awuni et al., 2018). Rainfall variability over West Africa is naturally high with studies showing rainfall shortage of about 10–15% during the 1980s, relative to the 1950s (Mahe, 2006). At the same time Temperature is found to increase over Africa with significant changes since the late 1970s (Hulme et al., 2001). The negative impact of increasing temperatures (minimum and maximum) and decreasing rainfall has implications for soil and water management and agriculture productivity in general. An increase in temperature coupled with warm nights and reduced rainfall will in particular affect crops and weeds growth, and also increase the prevalence of insect, pests and diseases (Hatfield et al., 2011).

The duration of sunshine within the basin has significantly declined. Sunshine duration remains an important climatic factor driving crop productivity especially because it drives photosynthesis which greatly influences plant growth (Wu et al., 2006; Alemu et al., 2017). Agronomic studies have shown that sunshine plays a critical role in crop water demand (Baskerville and Emin, 1969; Ritchie and Nesmith, 1991). In a study conducted by Guo et al. (2020), the authors found that the impact of sunshine duration on agricultural water use is statistically significant and that a 1% increment of sunshine duration hours will partially lead to a 0.145 % decrement in agricultural water use. Stanhill and Cohen (2001)

also report that a decrease in solar radiation would impact crop water balance and evapotranspiration of crops with a limiting effect on crop productivity.

Our findings show that potential evapotranspiration in the Nasia basin has significantly increased over the last 50 years. This implies that open water evaporation, bare soil evaporation, rainfall interception evaporation, and vegetation transpiration could also be increasing within the basin (Zeng et al., 2018; Tadese et al., 2020). Potential evapotranspiration is an important constituent of the energy and hydrological cycles at the land surface and a vital regulating factor for agricultural water management and calculating crop water requirements (Ma et al., 2012; Paparrizos et al., 2017; Han et al., 2018). Apart from sunshine duration as mentioned earlier, the significantly increasing wind speed and temperatures and decreasing in relative humidity at a significant rate might have contributed to the rapid increase in potential evapotranspiration which could impact ecological changes, the hydrological cycle and agriculture irrigation management in the basin (King et al., 2015; Ning et al., 2016).

The increase in wind speed and decrease in relative humidity will not only affect agriculture in the basin but also have harmful impacts on the health of the inhabitants (Csavina et al., 2014) and when breathed this can have negative impacts on the human respiratory and cardiovascular systems, due to the spores and contaminants associated with dust and aerosols (Ghio and Devlin, 2001; Low et al., 2006; Quintero et al., 2010; Csavina et al., 2011; Degobbi et al., 2011). The combination of wind speed and relative humidity could increase the presence of dust and aerosols in the basin. Wind speed remains the primary factor in dust generation with soil structure and vegetation cover also playing significant roles (Zobeck and Fryrear, 1986; Zobeck, 1991; Yin et al., 2007). Also, the threshold velocity for aeolian erosion is dependent on relative humidity due to its impact on soil surface moisture content which, in turn, affects interparticle cohesion (Ravi and D'Odorico, 2005; Ravi et al., 2006; Neuman and Sanderson, 2008). Already, the North of Ghana is known to be very dusty, as a result of local and regional aeolian erosion due to the nature of the soils materials dominated by the clay mineral kaolinite (Tiessen et al., 1991; He et al., 2007). The concentration of dust and aerosols in the air gets worst during the harmattan where the dry dust-laden continental wind from the Bodélé Depression in the Chad basin blows over the West African countries along the Gulf of Guinea (Sunnu et al., 2008; Lyngsie et al., 2011).

The insignificant decrease in annual discharge of the Nasia river with the corresponding insignificant decrease in rainfall and significant rising temperatures and evapotranspiration are indicating water scarcity and possibilities of droughts in the basin (see also Sheffield et al., 2008; Dai, 2008; Seneviratne, 2012). Some studies have shown that for almost all the rivers of West Africa, discharge has decreased after 1970. Yet the changes in the rainfall and discharge relationships are unproportional presenting a paradoxical situation (Mahe et al., 2000; Mahe, 2006). The decreasing trend in the discharge of the Nasia river is bad news for inhabitants of the basin who depend on its water for both agriculture (irrigation) and domestic use. The water crisis in the basin will significantly impact the livelihood of people as rainfed agriculture remains the main economic activity challenged by a long period of dry season. Abdul-Ganiyu et al. (2011) however mention that the flow of Nasia river may not be attributed to climatic factors alone but also influenced by the physical characteristics (such as topography, soil, and vegetation) as well as human activities in the catchment. Adeyeri et al. (2020) however reported that the contribution of human activity to annual discharge variation can be remarkably larger than the contribution of rainfall variability in several regions of the world.

Over the last three decades, land use/cover are changing in the Nasia basin; shrubland and settlement/bare have increased while cropland, forest, grassland and water bodies have decreased. The land use/cover changes can allude to the changing hydro-climatic pattern, population growth and

economic activities in the basin (Akpoti et al., 2016; Awotwi et al., 2018). The relationship between land use/cover changes and river discharge depends on the basin's size and location, elevation, land management and LULC types (Li et al., 2001). While this study could not establish the relationship between hydro-climatic variables and land use/cover changes, we found that NDVI observed a similar declining trend just as rainfall river discharge, potential evapotranspiration, relative humidity and sunshine duration. Similarly, forest, water bodies, cropland and grassland also declined. Hao et al. (2004) concluded that a positive correlation exists between river discharge and forest cover over the Naoli Basin of China. We, therefore, speculate that the trend in hydro-climatic conditions of Nasia basin in addition to human activities plays a critical role in the land use/cover pattern of the area.

The implication of this study for farmers within the Nasia basin is that, based on the trend identified in the hydroclimatic factors, water availability is becoming a limiting factor for crop production, therefore planting drought resistant crop varieties with low irrigation water requirement in addition to sustainable water management practices is the surest way to increase yields. Also, human impacts on the environment is increasing the speed of land cover in the area. Generally in Africa, people deforest to increase croplands (Mahe, 2006). Yet in this study, we found deforestation resulting in increased settlement and shrubland compared to croplands signalling a reduction in farming activities in the basin. Excessive use of trees for charcoal and wood fires as well as uncontrolled bushfires are the main drivers of deforestation in Sub-saharan Africa (Obahoundje et al., 2018). Wood fuel accounts for 70% of Sub-Saharan Africa total energy production and due to the increase in population growth rate, and relative price changes of alternate energy sources for cooking, it is expected that the trend will continue to increase (Kebede et al., 20110).

Finally, we recognise that the major setback of the study is the inability to use robust methods to determine the impact of the changing hydro-climatic factors and land use/cover changes on agriculture and livelihood as a whole. However, the speculations made in the discussions are based on relevant existing literature. Also, another weakness of the study is that the hydro-climatic data used may not reflect the current trend of events as they ranged from 1961 to 2010. However, the lack of data did not adversely affect the results obtained from this study. Therefore, further study to examine the current and future trends as well as establish the impact on agriculture and livelihood using impact models is recommended.

5.0 Conclusion

In this study, we examined the trends of hydro-climatic variables (minimum and maximum temperature, wind speed, sunshine duration, rainfall, relative humidity, discharge and potential evapotranspiration), NDVI and land use cover/change in the Nasia sub-basin. The relationship between these parameters was also analysed in addition to the possible implications of the observable changes in the Nasia catchment.

Generally, the results as presented signal water scarcity and possibilities of droughts in the Nasia basin. The impact of climate change on the overall hydroclimatic variables is quite noticeable. At a 95% confidence level, minimum and maximum temperatures, wind speed, and potential evapotranspiration showed a significant upward trend. Relative humidity and sunshine duration showed a significant downward trend. Rainfall, river discharge and NDVI also showed a downward but insignificant trend. Almost all the trends in hydroclimatic variables started in the 1980s, except windspeed in 2001, rainfall in 1968, discharge in 1975. Discharge showed a positive significant correlation with relative humidity, rainfall and potential evapotranspiration, but an insignificant positive relationship with sunshine duration. The discharge also showed a negative insignificant correlation with temperature (minimum

and maximum) and wind speed. Finally, over the entire 30 years period, shrubland and settlement/bare have increased to the disadvantage of cropland, forest, grassland and water bodies.

The limitation of this paper resides in the fact that the combined effect of the understudied variables on water resources, agriculture and livelihood of the inhabitants were speculated, based on literature. Also, the lack of data could not allow current analysis. However, the findings of this paper could help researchers understand the annual variability of hydro-climatic variables, and land use/cover changes in the Nasia basin and therefore, become a foundation for further studies. There is a need for additional research to incorporate hydro-climatic variables, land use/cover and human activities into empirical models to identify specific cause and effect relationships, particularly on river discharge. Once these relationships are determined, impact models could be used to simulate and predict the effect of climate change on the water resources, agriculture and livelihood in the Nasia basin.

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Availability of data and material: The NDVI data that is utilized in this study are openly available in the repository: <https://giovanni.gsfc.nasa.gov/giovanni/>. The LULC maps of 2000 and 2010 are available at: <http://www.globallandcover.com/>. The 2020 LULC map also available at <https://glovis.usgs.gov/>. The data on hydroclimatic variables are available upon request.

Code availability: The codes to generate figures and analyse data in this study are available upon request.

Author contribution: The study was conceptualised by Emmanuel Nyadzi. The data analysis and writing first draft was done by Emanuel Nyadzi and Enoch Bessah. Supervision, review and writing was performed by GordanaKranjac-Berisavljevic and Fulco Ludwig.

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Appendix 1: Accuracy of generated land use/ cover map (Pixel-based error matrix) for 2020

CLASSIFIED	Cropland	Forest	Grassland	Shrubland	Water bodies	Settlement/ bare areas	Total Reference points	Total Area (pixels)	Total Area (hectares)	Stratum Weight (Wi)
Cropland	101	0	2	1	0	1	105	5229	470.61	0.04217004
Forest	0	105	0	0	0	0	105	4697	422.73	0.03787964
Grassland	2	0	103	0	0	0	105	18261	1643.49	0.1472685
Shrubland	0	0	8	90	0	0	98	17408	1566.72	0.14038936
Water bodies	0	0	0	0	104	0	104	16292	1466.28	0.13138922
Settlement/ bare areas	0	0	0	0	45	61	106	62111	5589.99	0.50090324
Total Classified points	103	105	113	91	149	62	623	123998	11160	1
Total Correct Reference Points	564									
Total True reference points	623									
Overall Accuracy (%)	90.53									
	User's Accuracy		Producer's Accuracy							
Cropland	96.19		98.06							
Forest	100.00		100.00							
Grassland	98.10		91.15							
Shrubland	91.84		98.90							
Water bodies	100.00		69.80							
Settlement/ bare areas	57.55		98.39							

Appendix 2: Accuracy of generated land use/ cover map(Area-based error matrix) for 2020

CLASSIFIED	Cropland	Forest	Grassland	Shrubland	Water bodies	Settlement/ bare areas	Total Reference points	Total Area (pixels)	Total Area (hectares)	% of Total
Cropland	0.040564	0.000000	0.002805	0.001433	0.000000	0.004726	0.049527	5229.00	470.61	4.22
Forest	0.000000	0.037880	0.000000	0.000000	0.000000	0.000000	0.037880	4697.00	422.73	3.79
Grassland	0.000803	0.000000	0.144463	0.000000	0.000000	0.000000	0.145267	18261.00	1643.49	14.73
Shrubland	0.000000	0.000000	0.011220	0.128929	0.000000	0.000000	0.140149	17408.00	1566.72	14.04
Water bodies	0.000000	0.000000	0.000000	0.000000	0.131389	0.000000	0.131389	16292.00	1466.28	13.14
Settlement/ bare areas	0.000000	0.000000	0.000000	0.000000	0.056851	0.288256	0.345107	62111.00	5589.99	50.09
Total Classified Area	0.041367	0.037880	0.158489	0.130362	0.188240	0.292981	0.849318	123998.00	11159.82	100.00
Overall Percent Accuracy	77.15									

Unbiased Accuracy	User's Accuracy	Producer's Accuracy
Cropland	81.90	98.06
Forest	100.00	100.00
Grassland	99.45	91.15
Shrubland	91.99	98.90
Water bodies	100.00	69.80
Settlement/ bare areas	83.53	98.39

Figures

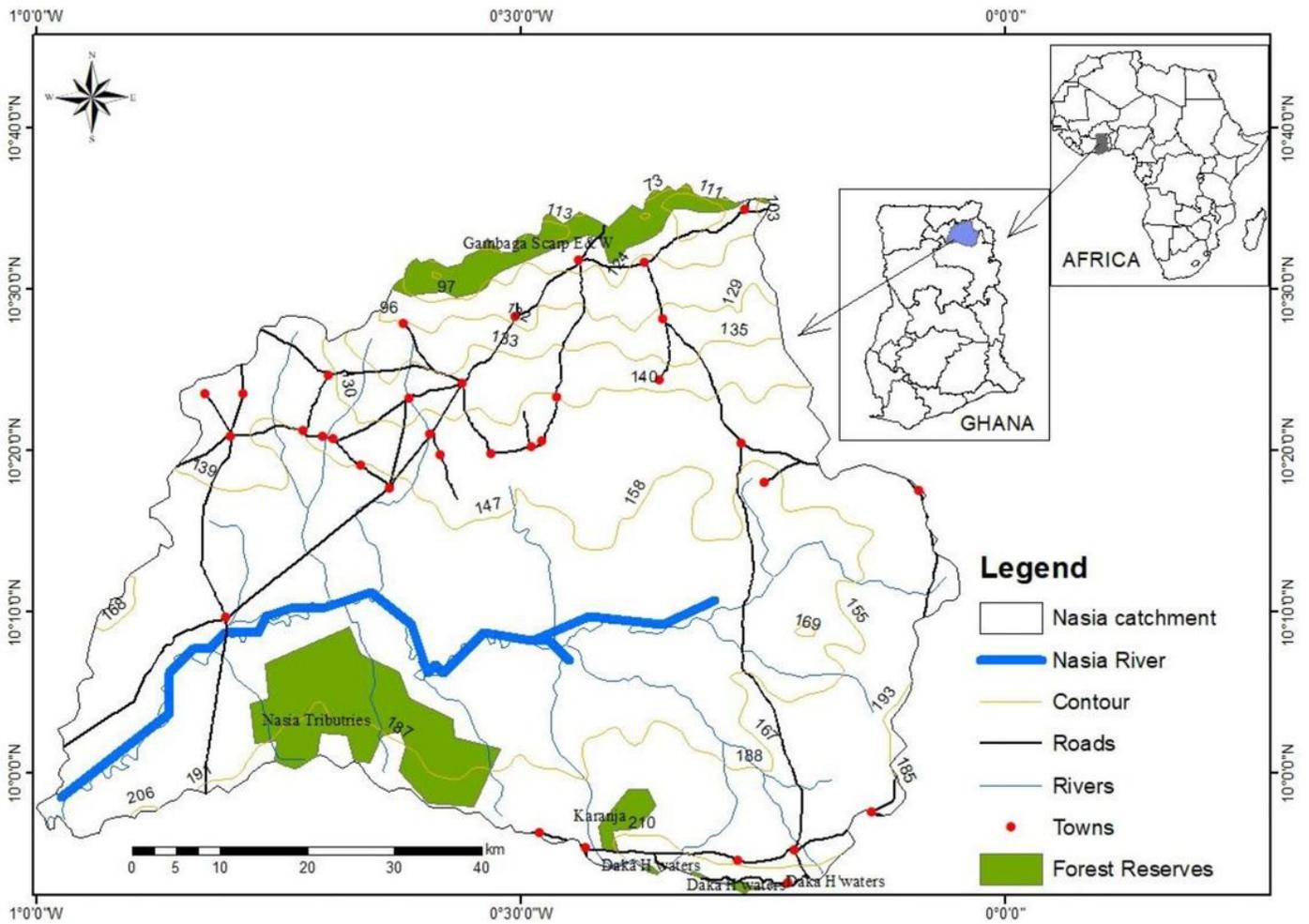


Figure 1

Map of Nasia catchment Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

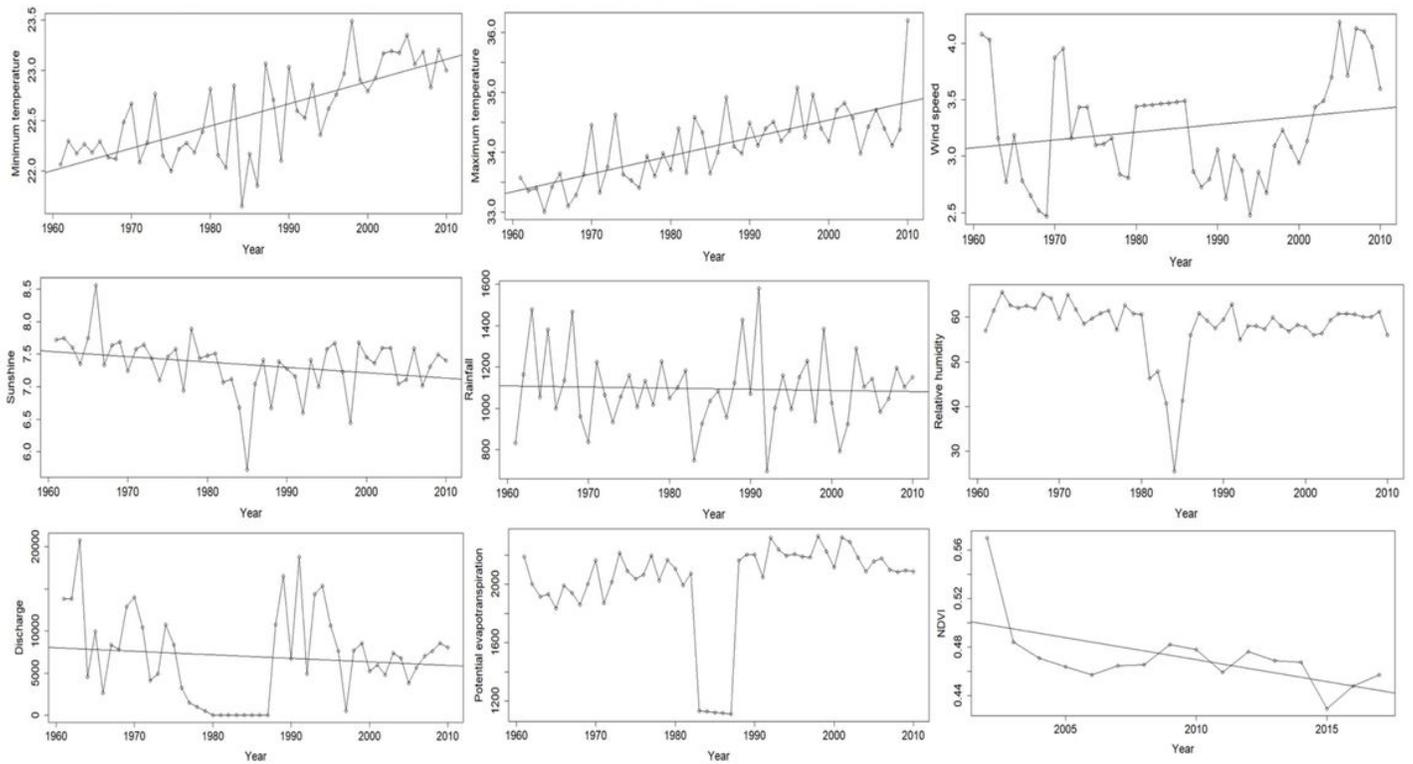


Figure 2

Time series plots of D = Total Discharge (m³/s); S= Sunshine (Hrs /days); Tmax= maximum Temperature (0C); WS= Wind speed (Km/hr); RH= relative humidity (%); Tmin= Mean minimum Temperature (0C); R= Rainfall (mm); NDVI= Normalized difference vegetation index

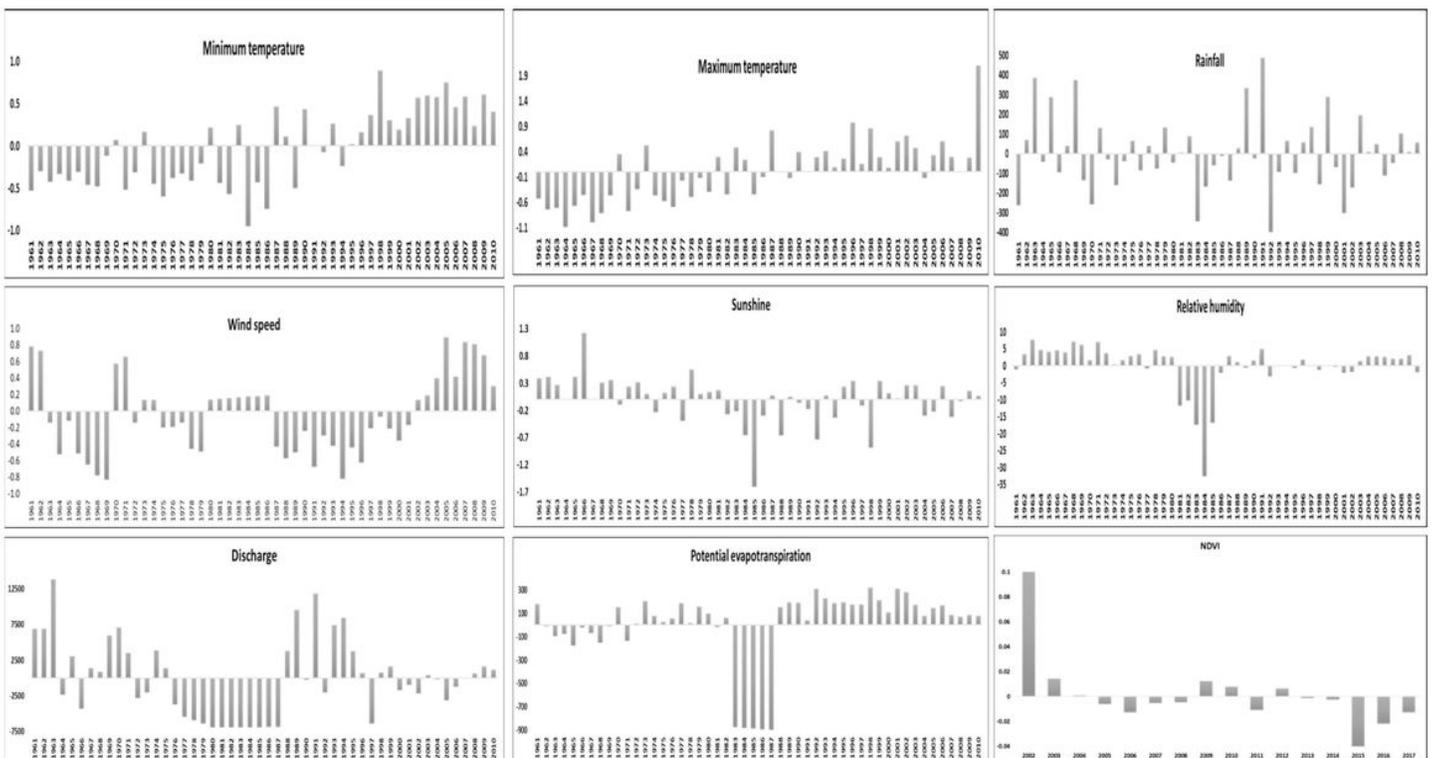


Figure 3

Inter-annual anomalies of the hydro-climate and NDVI variables: Total Discharge (m³/s); Sunshine (Hrs /days); maximum Temperature (0C); Wind speed (Km/hr); Relative humidity (%); Mean minimum Temperature (0C); Rainfall (mm); NDVI=Normalized difference vegetation index).

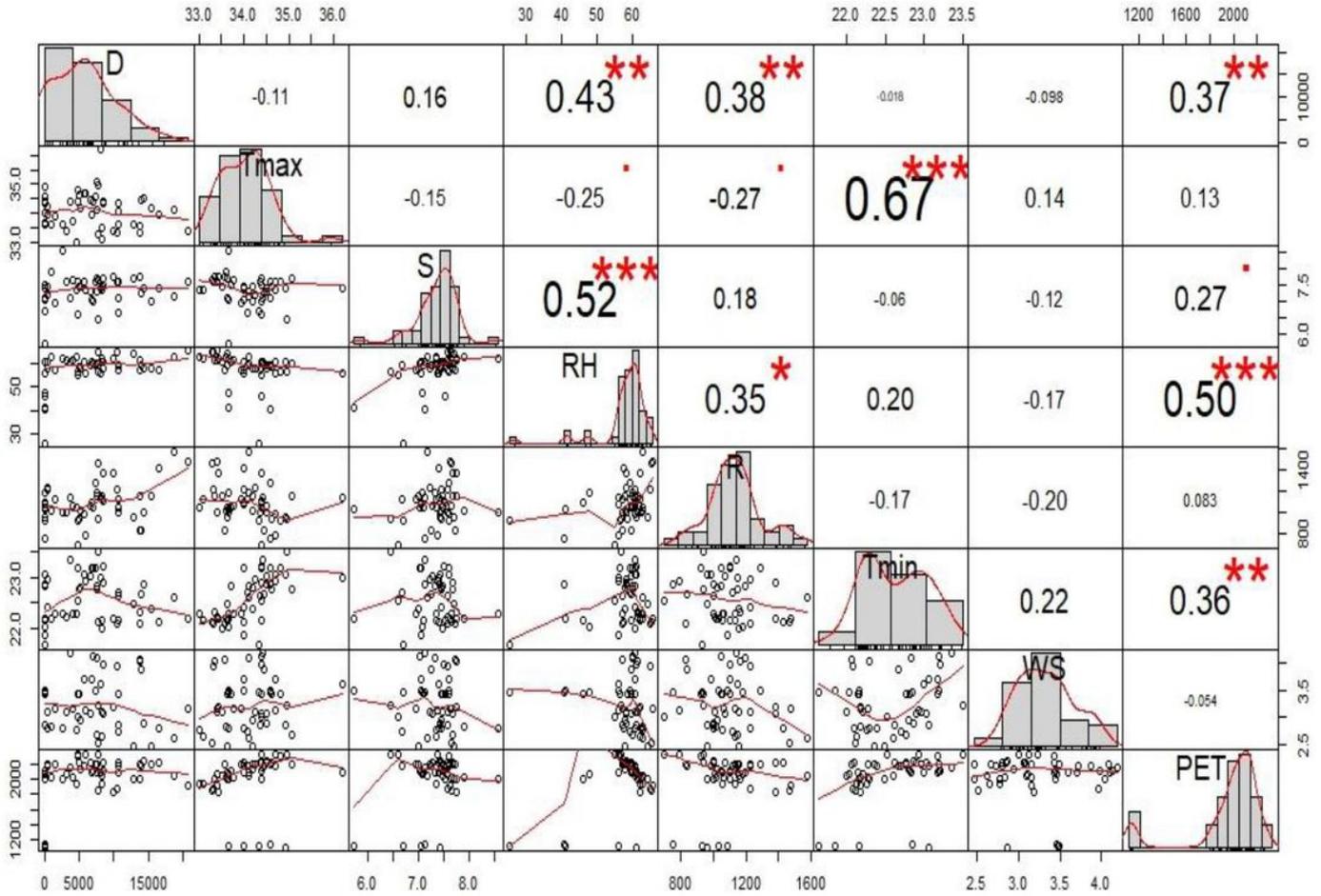


Figure 4

Correlation values of the hydro-climatic variables in the catchment shown on the top of the diagonal with the significance level as stars (***, **, and * represent for $P < 0.001$, $P = 0.001$ to 0.01 , $P = 0.01$ to 0.05). The distribution of each variable is shown on the diagonal. On the bottom of the diagonal: the bivariate scatter plots with a fitted line are displayed.

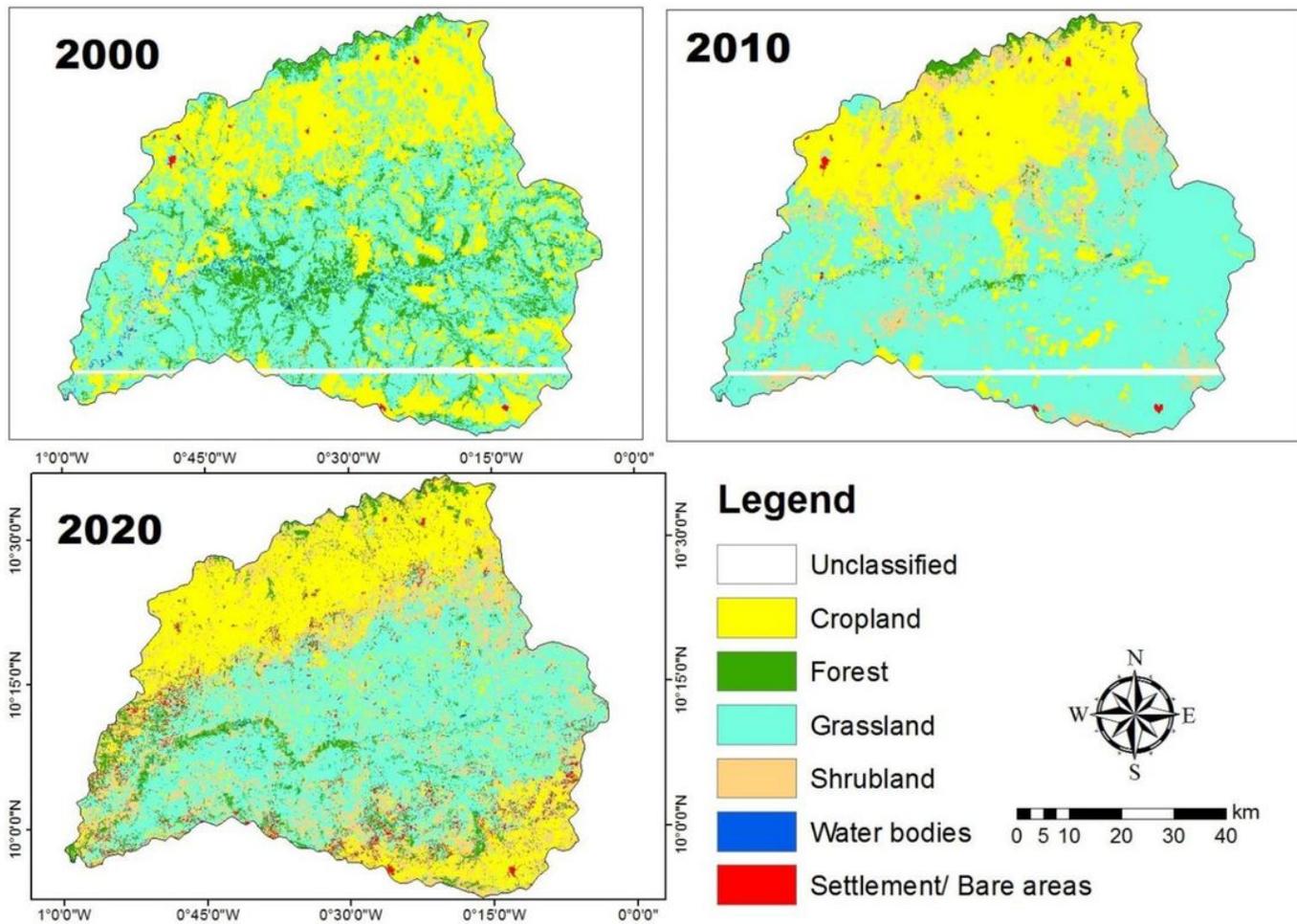


Figure 5

Land use/cover changes in Nasia Catchment for the year 2000, 2010 and 2020. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

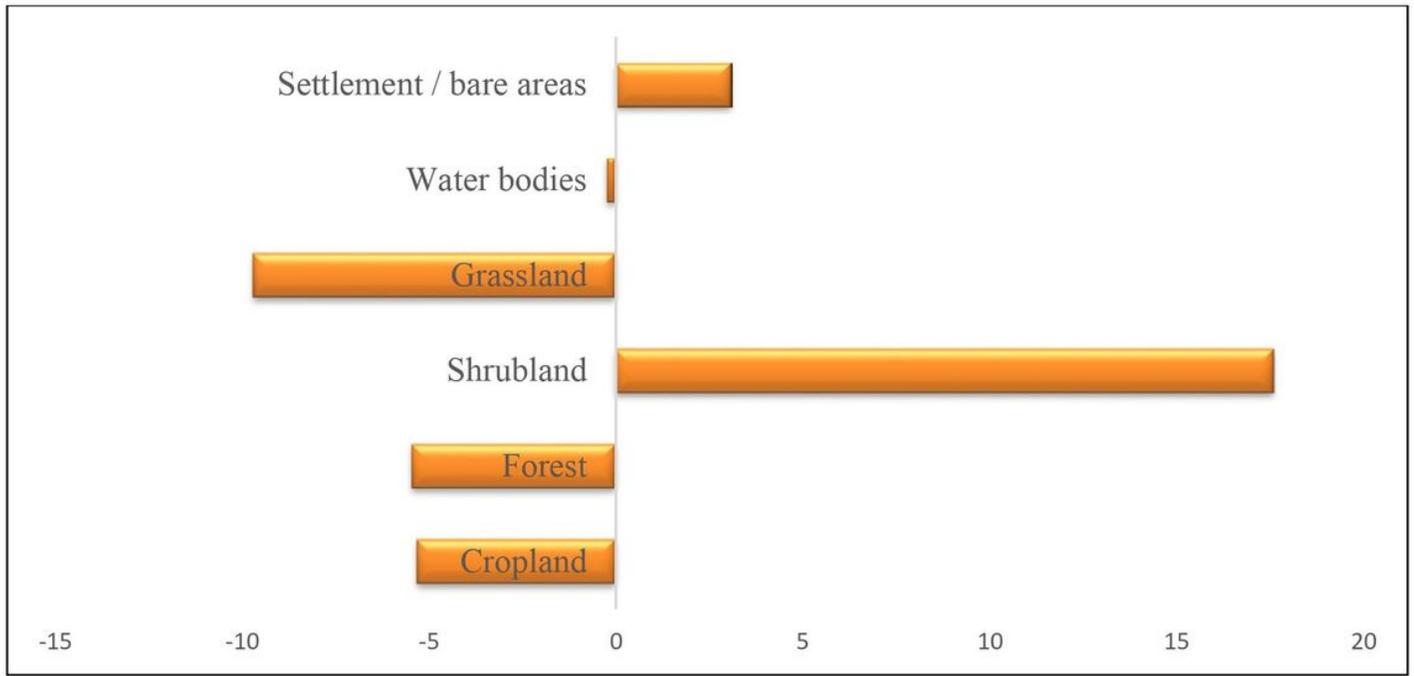


Figure 6

Changes in land use/cover over the entire 20 years period expressed in percentages