A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science

Assessment of the Impacts of Climate Change on the Hydrology of the Kura River Basin

Shahana BILALOVA

July, 2019

Budapest

Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Shahana BILALOVA

CENTRAL EUROPEAN UNIVERSITY

ABSTRACT OF THESIS submitted by:
Shahana BILALOVA
for the degree of Master of Science and entitled: Assessment of the Impacts of Climate Change on the Hydrology of the Kura River Basin

Month and Year of submission: July, 2019.

Impacts of climate change on hydrology is inevitable due to the direct and indirect linkages. Therefore, considering the significance of the hydrology of the Kura River and its tributaries for the basin countries and increasing intensity of the climate change, the research aimed at assessing the climate change impacts on the hydrology of the basin. To achieve this research aim, statistical methods were utilized to identify the trends and change points in hydroclimatic variables, and to detect the correlation between hydrological and climatic indices. Based on the results of the trend analysis, certain patterns both in terms of streamflow and climatic indices were captured. While in Georgia streamflow of Kura River experienced an increasing trend, especially during cold months, a serious decrease was detected in Azerbaijan for most months. Furthermore, the analysis of climatic indices also signals certain patterns aligning with climate change characteristics such as increase in precipitation in cold months as well as increase in temperature generally. Correlation analysis further carried out also highlighted the impacts of these changes since the early snowmelts caused by the increasing temperature and precipitation, Kura River experienced an increase in streamflow for the cold months, while for the dry months certain decrease is the case due to the increase in temperature of the region. To conclude, the results explain that impact of climate change on hydrology of the study area is already observed and by time, it is more likely to be intensified due to the increasing temperature and changes in rainfall.

Keywords: hydrology, climate change, trend analysis, impact assessment, Kura River Basin, water resources

Acknowledgements

First and foremost, I would like to envoy my endless gratitude to my supervisor, Dr. Viktor Lagutov for his endless support, valuable guidance, encouragement as well as immense knowledge.

I also would like to thank Prakrut Kansara for his help with Phyton and R and explaining the basis of the Java coding.

Finally, I would like to thank my lovely family and kind friends who always supported and cherished me during this process. Without them, it would be extremely hard.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

UN	United Nations
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Production
ENVSEC	Environment and Security Initiative
IPCC	Intergovernmental Panel on Climate Change
GLDAS	Global Land Data Assimilation Systems
NASA	National Aeronautics and Space Administration
MENR	Ministry of Ecology and Natural Resources of Azerbaijan Republic
NEA	National Environmental Agency
GRDC	Global Runoff Data Center
CRU TS	Climate Research Unit Time Series
WEF	Water-Energy-Food

1. Introduction

"The sage's transformation of the World arises

from solving the problem of water." (Lao Tze)

Water problems existed for ages and now with an increasing population growth coupled with a huge risk of our time, climate change, water resources face a great threat. There are numerous reasons for us to take a serious action for the protection of water resources. Along with the fact that water is a requirement for a survival of all living organisms and its substitution is impossible for most of water consuming activities, water is finite on Earth and amount of water the Earth possesses never changes (Postel, 2000). This fact is quite essential especially within the discourse of population growth and increasing water demand.

The world population is in a steady increase reaching 7.6 billion as of mid-2017 and is estimated to reach 13.2 billion in 2100 according to Revision of United Nations (UN) (2017) (Figure 1)

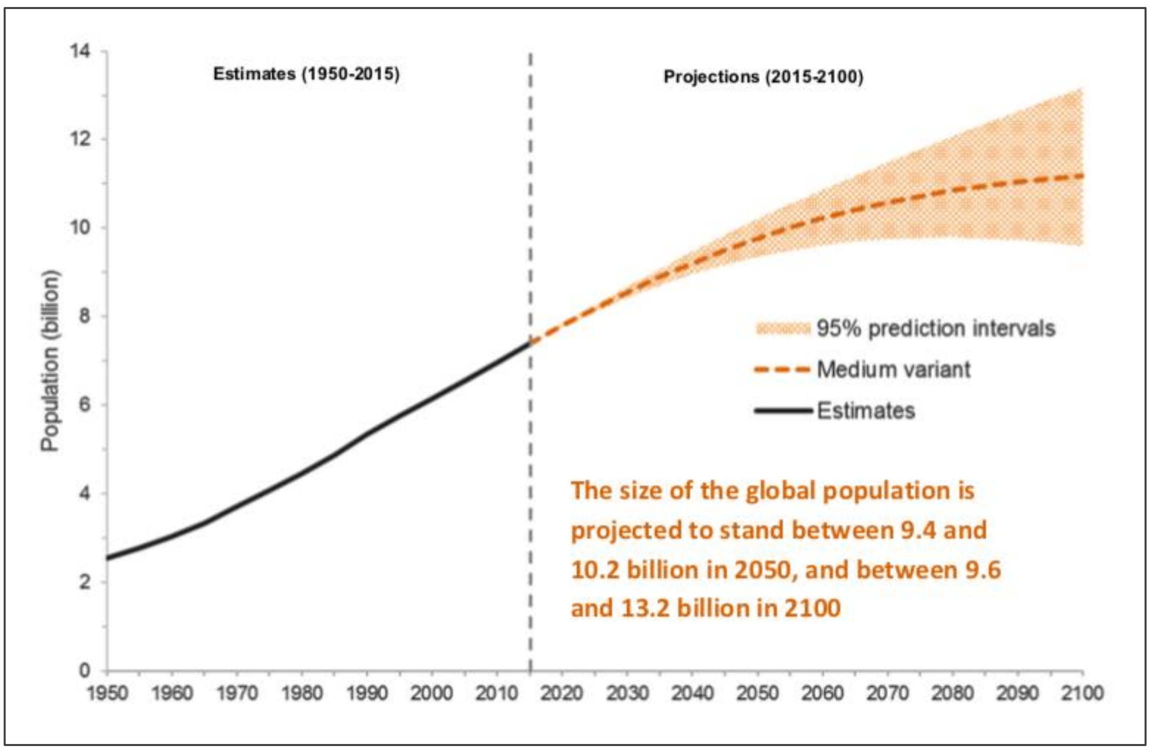

Figure 1 Projection of World population. Source: UN, 2017.

Considering this tremendous increase and the fact mentioned previously that water resources are finite, water stress is quite inevitable. In this regard, based on the estimation provided by Postel (2000), it can be seen that water supply per capita is projected to decrease by 11,000 m^3/capita within the period of 80 years.

As the water usage is characterized with three sectors which are agricultural, industrial and domestic, due to the population growth and urbanization, the water usage in all these three are also technically prone to increase which further creates an additional challenge. Among these three sectors, agriculture is the most water intensive sector by owning 70 percent of abstracted water globally followed with industry (20 percent) and domestic usage (10 percent) on a global scale according to the Food and Agriculture Organization of the United Nations (FAO) (Boberg, 2005). Climate change is another serious cause contributing to the water shortage problem globally. As the climate change intensifies, the changes in precipitation spatially and temporally is hard to avoid which further contributes to the increase in susceptibility for droughts and water shortages (Hall et al, 2008). The authors state that climate change leading to surface, ocean and atmosphere temperature rise, snow melt and sea level rise has a certain impact on water resources. Thus, they claim reduction in water supplies, intrusion of salt water into freshwater and aquifers, reduction in aquifers' storage and recharge due to the decrease in evapotranspiration, as well as increasing water demand due to the temperature rise are among many consequences as a result of climate change.

1.1. Problem statement

Water resources in the Kura River Basin carry special importance for the basin countries not only to meet their freshwater requirements, but also contribute to the economy in many ways. In this regard, water from rivers in the basin area is utilized for irrigation (68 percent), power generation (11 percent), industry (6.9 percent), domestic purposes (6.3 percent), agriculture (5.2 percent) and forestry (2.6 percent) based on the information provided by Rzayev (2017). In this regard, in terms of agricultural sector which is the most water consuming sector, irrigation is quite vital for the agricultural activities in three of the basin countries, since irrigated agriculture makes up 80 percent, 60 percent and 75 percent in Azerbaijan, Armenia and Georgia, respectively. Therefore, water resources of the Kura River Basin might be considered as a backbone of agricultural activities of the basin countries.

Regarding the freshwater demand, the basin countries demonstrate an increasing trend for the population growth which hints the further water demand increase (World Bank Database). In this regard, the increase in terms of water consumption can be captured in most basin countries such as 7 percent in Azerbaijan, 7 percent in Eastern Georgia, 8.5 percent in Armenia and 4.1 percent in Iran (Rzayev, 2017).

According to the information provided by the World Bank, it can be deduced that in all basin countries share of the water demanding sectors in Gross Domestic Production (GDP) is still quite high which further highlights the significance of the water resources in the study area one more time (Table 1).

Table 1 GDP - Composition by Sector (%). Data source: Central Intelligence Agency

Countries	Agriculture	Industry	Service
Armenia (2017 est.)	16.7	28.2	54.8
Azerbaijan (2017 est.)	6.1	53.5	40.4
Georgia (2017 est.)	8.2	23.7	67.9
Iran (2016 est.)	9.6	35.3	55
Turkey (2017 est.)	6.8	32.3	60.7

The Kura River is important, especially in the case of Georgia and Azerbaijan as its contribution to both domestic and economic sectors is hard to deny. In the case of Azerbaijan, along with being the main freshwater source for more than 70 percent of the population including most urbanized cities, the Kura River also plays a role in electricity generation, agricultural and industrial activities. Agriculture needs to be highlighted further since considering the fact that Azerbaijan's agricultural sector is highly dependent on irrigation by having approximately 85 percent of the total cultivated area with installed irrigation, water abstracted from the rivers constitutes 60 percent of irrigation water (Hansen, 2003; Rzayev, 2017).

Along with the increasing water consumption and demand, climate change in the region also adds up the problem of water shortage in the region for the future. According to the Environment and Security Initiative (ENVSEC) (2011), changes in the climatic indices have already been captured in three of South Caucasus regions. In this regard, report by ENVSEC (2011) shows that in Armenia, Georgia and Azerbaijan, increasing trend in terms of air temperature, desertification (in the case of Georgia for some areas), melting ice (information for Armenia is not available) and extreme events, decreasing trend for precipitation (except for Georgia as some areas have an increasing trend) and water shortages for the future are identified. Furthermore, according to the list of the world's most water-stressed countries in 2040 prepared by the World Resource Institute (Gassert et al. 2013), all countries of the basin are indicated to experience certain level of water shortage by 2040 with Iran (24th) being ranked among top 25 countries followed by Azerbaijan (50th), Armenia (63rd), Turkey (66th) and Georgia (95th).

The quick analysis prior to conducting this research study by using the Global Surface Water data (Pekel et al, 2016) provided by European Joint Research Center through Google Earth Engine also captured certain changes in terms of the surface water of the Kura River Basin which are depicted in Figure 2 and Figure 3. The codes utilized for getting the results are illustrated in Appendix A.

In this regard, according to Figure 5, between two period of 1984-1999 and 2000-2015 in terms of the frequency, total frequency of the loss of occurrence in surface water of the basin area is more than the increase in occurrence, meanwhile zero change is still dominant.

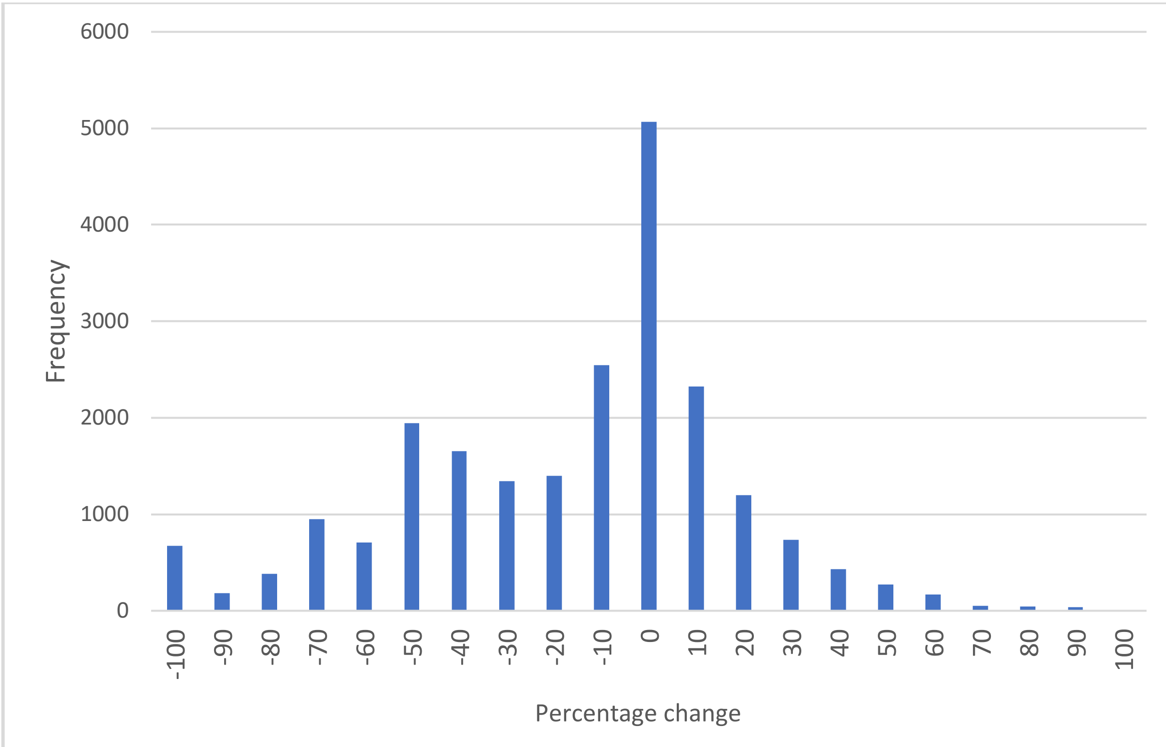

Figure 2 Surface water change intensity in the Kura River Basin between two periods: 1984-1999 and 2000-2015. Source: Generated by analysis of the Global Surface Water data (Pekel et al, 2016) on Google Earth Engine computational platform.

Meanwhile, Figure 3 illustrates the transition in the surface water body areas comparing the first (1984) and last years (2015). According to the chart, while 45 percent of permanent water body area remained unchanged, for the seasonal water bodies, the percentage is 5 percent. The chart also illustrates the losses in terms of both permanent and seasonal water bodies so while the loss permanent bodies experienced was 1 percent, lost area for seasonal water body is quite high, 11 percent. However, along with the loss, new seasonal and permanent water bodies also appeared accounting for 13 and 5 percent of surface water body area, respectively. Furthermore, shifts are also obvious especially in the case of permanent to seasonal, so 2 percent of area of permanent water turned into seasonal. Finally, area of short-term seasonal water body that disappeared is also noteworthy since it equaled to 17 percent of the total area.

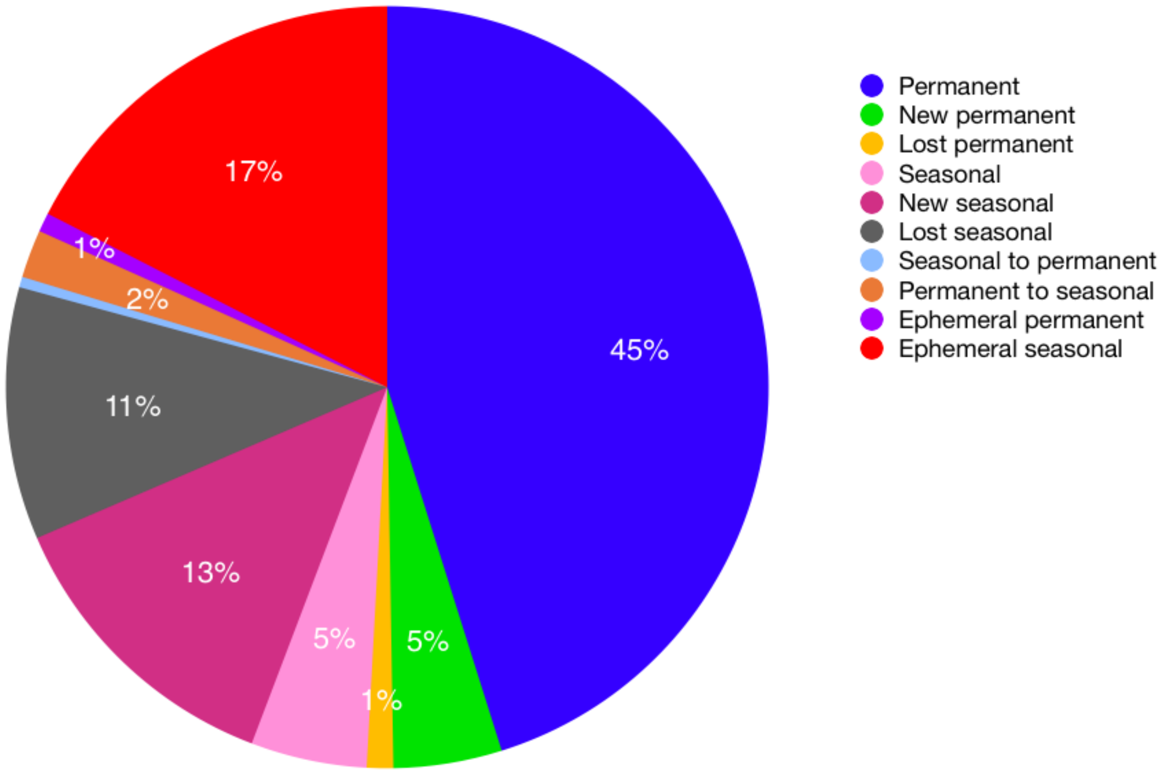

Figure 3 Summary of transition class areas for the Kura River Basin according to 1984 and 2015. Source: Generated by analysis of the Global Surface Water data (Pekel et al, 2016) on Google Earth Engine computational platform.

All in all, certain changes are observed in this analysis, however since the outcomes concern the overall surface water in the study area as well as change intensity compares only two years of 1984 and 2015, further detailed study is required to see the trends in the streamflow and climatic indices as well as to find out whether these changes are due to the climate change.

1.2. Research gap and study contributions

Despite of above-mentioned significance of the issue and the essence of the Kura River for the basin countries, unfortunately this particular topic captured less attention in academia. In this regard, number of research studies dedicated to this study area on the topic concerned is non-existent and the studies which somehow touch the issue are not either comprehensive or up-to-date or grounded scientifically. Taking into account this research gap, this study is expected to play a basis role for further studies dedicated to the climate change and hydrology in the basin area by assessing impact of climate change on hydrology of the Kura River Basin. Furthermore, the results of the research study will be delivered to the project coordinators and policy-makers dealing with the issue at stake in the region which also adds up to the contribution of the research study.

1.3. Research aim and objectives

The research aims at studying the impact of climate change on the hydrology of the Kura River Basin. To reflect on this specific aim, further research questions and respective objectives are defined:

1. RQ1: What are the hydrological trends in the Kura River Basin?
   a) Identify the patterns of the monthly, annual and seasonal streamflow series in the Kura River Basin.
2. RQ2: What are the trends in temperature and precipitation in the Kura River Basin?
   a) Identify the patterns for monthly, annual and seasonal climatic indices (i.e. precipitation and temperature) over the Kura River Basin.
   b) Draw connections between these patterns and the climate change.
3. RQ3: Is there any impact of the climate change on hydrology of the Kura River?
   a) Diagnose whether there is a linkage between hydrology and climate change.
   b) Analyze how the trends in climatic indices might affect the hydrology of the Kura River.

1.4. Thesis outline

Started with a brief **Introduction (Chapter 1)**, the following chapters of this thesis will adequately serve to reach the research aim and objectives presented.

In this regard, **Literature Review (Chapter 2)** presents the major theoretical background and principles regarding the issue concerned. The main theoretical concepts covered within this particular chapter are climate change science, river hydrology and flow variations, and the impact of climate change on the river hydrology. Furthermore, the role of statistical methods in hydrological studies is also discussed based on the literature review and R software as a tool to conduct statistical computations is introduced.

Following the literature review, in **Methodology** section **(Chapter 3)**, the issues such as research design, data collection, data preparation steps as well as methods utilized for conducting analysis are presented.

Afterwards, **Chapter 4** on the **Kura River Basin** gives a general overview regarding the study area including physical characteristics, hydrology as well as reservoirs operating.

Later on, **Chapter 5** provides the information regarding availability of and access to hydroclimatic data for the Kura River Basin based on the experience throughout this research study.

In the following **Chapter 6**, results of the streamflow series trend for Kura River as well as related limitations and discussion are presented.

Afterwards, **Chapter 7** provides the results and limitations for the trend analysis of both meteorological stations as well as spatial variations based on remotely sensed data. The chapter also introduces the previous studies on the similar topic in the study area. Finally, the chapter concludes with the discussion covering both trend analysis as well as comparing them with the previous research studies concerning climatic indices for the Kura River Basin.

Based on the results in previous chapters as well as correlation test, **Chapter 8** presents the results for the assessment of impact of climate change on the streamflow along with the limitations encountered as well as comprehensive discussion.

In the following **Chapter 9**, the possible effects of the changes detected in this research study on basin countries are discussed within the concept of Water-Energy-Food nexus.

Finally, in **Chapter 10**, a concise summary of the research work and the key findings as well as prospect for future studies are presented.

2. Literature Review

The main rationale of this particular part of the thesis is to introduce the main concepts as well as theoretical framework which are concerned throughout the study by providing better understanding regarding the scope of the study. In this regard, literature review on climate change science will be followed by the concepts of river hydrology and flow variations which will help to identify the key concepts and terms. Later on, conceptual link between these two variables including possible impacts, responses will be presented based on the works of scholars. Finally, outcomes of the previous studies on climate change concerning the Kura River Basin will be discussed and the gaps within the existing literature will be identified.

2.1. Climate change

Climate change is one of the essential problems of our time and unfortunately it is in such a phase that its consequences are felt all over the globe while posing serious threats for future. Before proceeding to its implications, it is quite essential to understand the science and mechanism behind this concept.

Despite the words are used interchangeable most of the time, climate contrary to the weather is a long-term variation which can be perceived as an average weather over the particular time-span for a specific region (Armstrong et al., 2018). In this regard, to study the climate change, it is quite important to look at the long record of climatic variables rather than short. Another important distinction should be made between climate variation and climate change since they refer to completely different phenomena even though they might be mistaken. Hereinafter, while climate variability is the state of a fluctuations in climatic parameters differing from long-term averages, climate change refers to the change in climatic mean or variations which is statistically significant and lasting for longer period of time (Hegerl et al., 2007).

Among all the concepts discussed, climate variability and weather, climate change is more important and riskier as its effects are for longer period of time and changing its state is quite difficult once the threshold has been passed. Therefore, it is a necessity to understand the causes before building up any prevention or adaptation mechanism against it. In this regard, human-induced greenhouse gas emission is indicated as the main contributor to the climate change by the Intergovernmental Panel on Climate Change (IPCC) (2014) which will be discussed further.

The greenhouse gases are important for the life on Earth as thanks to them Earth temperature is kept in a level that is suitable for the habitation (King, 2005). However, when the greenhouse gases exceed its normal level, energy reaching to the Earth is trapped which further causes warming of atmosphere, the oceans as well as land surfaces (Armstrong et al., 2018). This is what occurs today and the main reason behind is human-induced activities causing accumulation of greenhouse gases, particularly carbon dioxide, methane and nitrous oxide according to many scientists (e.g. King, 2004; Armstrong et al., 2018). In this regard, King (2004) states that due to the human activities, greenhouse gasses increased by 50 percent in the atmosphere comparing to its pre-industrial level. Furthermore, Armstrong et al (2018) adds that within 30 years' time period between 1970 and 2000, emission of greenhouse gases from human-induced activities such as burning fossil fuel increased by 1.3 percent each year, while between 2000-2010 this increase reached 2.2 percent each year accounting for 49 billion tons per year.

As a result of the above-mentioned increase in greenhouse gases, temperature is also increasing. IPCC (2013) states that almost all globe experienced surface warming based on the results of calculations from 1901 to 2012 and since 1850 each of the last three decades was warmer than the previous one. Meanwhile the latest report by the IPCC (2018) informs regarding 1.0 ^{o}C global warming above the pre-industrial levels and warns that this number is estimated to reach 1.5 ^{o}C between 2030-2050 if it proceeds with the same level of increase. Meanwhile, according to Armstrong et al (2018), the current warming rate is approximately ten times faster than the average of the one after ice age.

Climate change is not only limited to the warming in atmospheric level so paves the way to many other phenomena. Armstrong et al. (2018) mention increasing temperature and acidity level in oceans, sea level rise, melting ice as well as changing local and regional weather among other impacts. Whereas, King (2005) adds increasing water vapor which plays a role in greenhouse effect due to the clouds, loss of forests as a result of rainfall and forest fires, as well as extreme events such as heatwaves, floods and droughts to this list. In this regard, according to IPCC (2013), ice sheet in the Greenland and Antarctic experienced loss whereas the Arctic sea and Northern Hemisphere's spring snow cover decreased for the last two decades. In terms of the sea level, the report states that from 1901 to 2010 average global sea level increased by 0.9 m (IPCC, 2013).

Precipitation is another factor to be affected. Thus, while the intensity and frequency of heavy precipitation increased for some part of the globe, the other ones experienced a significant drop according to IPCC reports (2007). Regarding variations in precipitation, IPCC (2007) mentions that due to the changes in precipitation and evaporation, ocean salinity also changed since 1950.

All in all, all these changes have a direct impact on the life on Earth causing threat to only humans, but also biodiversity which has already experienced a certain decline. For instance, King (2005) notes the impact of increasing ocean acidity on the plankton and coral reefs which experiences a decrease further changing the balance in the food chain.

2.2. River hydrology and flow variations

Basic understanding on river hydrology as well as its variations is quite essential before proceeding to any analysis dealing with the river. As defined by Hendricks (1962), hydrology is a study dealing with storage and movement of water, its chemical and physical interactions with the environment as well as its relation to the living organisms. Whereas, more concise definition is provided by Fryirs and Brierley (2012) which defines hydrology as the study on movement of the water through hydrological cycle which further is defined as the movement and storage of water through atmosphere, lithosphere, biosphere and hydrosphere. The authors also add four main components of hydrological cycle which are atmosphere water, precipitation, evaporation and transpiration and surface water. Further, hydrological cycle combining with climatic conditions forms the hydrological regimes which are the specific seasonal as well as daily flow patterns (Zeiringer at al., 2018).

Hydrological regimes are quite essential to understand the characteristics of any river as well as to identify changes within the river system which is the case in this research study. The main four hydrological regimes were explained further by Zeiringer et al., 2018. According to the authors, glacier regimes are attributed to river which are flowing from high altitudes and mainly receive water from glacier melting with seasonal peaks during summer. This is quite different for the river flowing in lower altitudes in which seasonal peaks may vary with snow melting during spring or heavy rainfall at any time of the year which is further called nival and pluvial regimes, respectively () (Zeiringer et al., 2018).

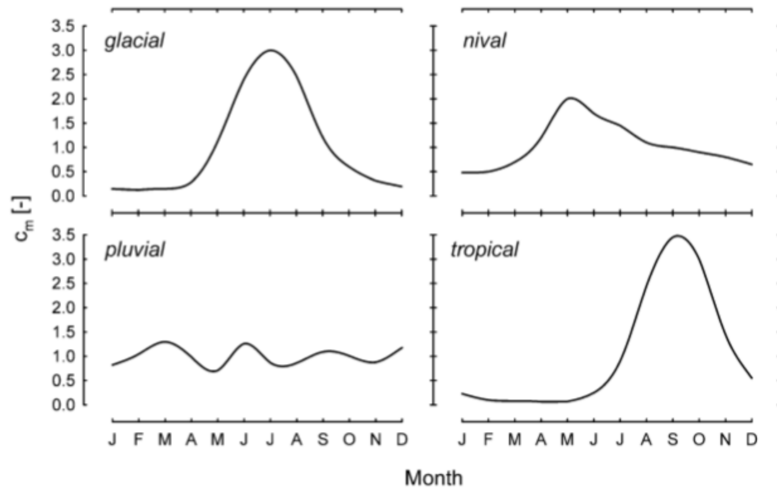

Figure 4 Illustration of hydrological regimes for glacial (Ötztaler Ache River), nival (Mur River), pluvial (Stiefing River), and tropical (Niger River) rivers. Source: Zeiringer et al., 2018.

Catchment is another important component of the river. It is an area that collects water within a drainage basin further form a river basin that is a combination of catchments for all the river tributaries (Zeiringer et al., 2018).

To assess the river, hydrology as well as watershed, one of the essential components to be analyzed is streamflow which is also widely used as an identifier to determine the impact of climate change. It also should be highlighted that in most literatures, streamflow, discharge and channel run-off are used interchangeable which will be the case in this study as well. According to Kuusito (1996), discharge is described as volume of the water passing through a cross-section in a unit of time which is measured in m^3s^{-1}.

Discharge can be measured with the following equation:

$$Q=wdv$$

in which Q (m^3s^{-1}) is the discharge, w(m) is the channel's width, d(m) is the channel's depth and v(ms^{-1}) is the flow's velocity (Fryirs and Brierley, 2012).

Variability in streamflow is attributed to the flow regime which is explained with the following components which are magnitude, frequency, duration, timing (or predictability) and rate of change (Poff et al., 1997). Certain definitions can be provided based on the explanations by Poff et al. (1997). While, magnitude is an amount of water passing certain point per unit time, frequency is an occurrence of a flow above the magnitude such as how often large-scale flood occurs. Duration and timing can be confused so while duration refers to length of the period when specific flow pattern occurs, timing is regularity with which it occurs. Finally, rate of a change in flow is defined by the authors as with which rate flows alter from one magnitude to another.

Variations in the flow regime can be due to natural and human induced causes. Within the natural cause, seasonal variation of the streamflow in rivers differs from river to river and mainly is affected by several factors such as local seasonal cycle of precipitation, evaporation, timing of snowmelt, as well as travel period of the water from runoff sources (Dettinger and Diaz, 2000).

Regarding the human-induced activities leading to alterations in flow regime, Zeirenger et al. (2018) mention dams, water diversion, urbanization along with drainage, channelization and groundwater pumping as prior activities contributing to the variations. Among all of the activities, dams need to be highlighted more as it changes that magnitude and frequency of the river's flow, especially peak seasons which also will be observed in this study area. All the above-mentioned factors have a direct impact on the river flow and the changes are observed in relatively short period of time.

There is also another human-induced activity such as climate change which affects the flow regime in an indirect way and the impact is observed in a long-run. As the research study closely concerns with this phenomenon, existing literature will be discussed further in detail in the following section.

2.3. Effects of climate change on river hydrology

Impact of the climate change on water resources is also inevitable since the river hydrology is closely linked to the climatic variables. In this regard, changes in climatic indices including precipitation and temperature have a direct impact on streamflow and they further indirectly contribute to the modifications in flow regime (Li et al., 2013). Therefore, flow peaks in the rivers are prone to change which further leads to severe draughts and floods. There are also numerous other studies discussing the possible causes of climate change. For instance, Bouwer et al. (2008) indicates that changes in climatic indices affects the water availability as well as frequency and intensity of extreme events. Meanwhile, Wigley and Jones (1985) states that increasing carbon dioxide level in the atmosphere leads to the decrease in evapotranspiration leading to more runoff and eventually change in hydrological cycle.

The topic of water resources within the discourse of climate change is also reflected itself in IPCC reports. According to Shiklomanov and Lins (1990), studies reveal the great sensitivity of river watersheds towards changes in climatic indices, even to the ones that are small. Thus, while the watersheds in arid and semi-arid zones are especially vulnerable to variability in precipitation and evapotranspiration, watersheds supplying water from snowmelt show sensitivity to not only warming air temperature, but also changing precipitation.

Regarding the snowmelt, Shiklomanov and Lins (1990) also note that as the temperature rise has an impact on winter snow zones, climate change result in precipitation more in a form of rain rather than snow leads to increasing winter run-off and decreasing spring and summer snowmelt flows. This is especially true for the nival rivers dependent on snowmelt since impact of climate change reflects itself on variations in the streamflow distribution over the year rather than annual values (Shiklomanov, 2009).

Along with the issues concerning water quantity, climate change also affects water quality as the decrease in water level also lags the process of pollutant dissolving as well as increase in pH level in water due to the increase in CO_2 concentration of water leads to the increase in salinity level

(Shiklomanov, 2009). According to the author, this is specially a risk for developing countries where the policy on water quality is less stringent.

2.4. The role of statistical methods in hydrological studies

Statistical methods in hydrological studies are widely used especially within the study of assessing the impact of climate change on river hydrology (e.g. McBean and Motiee 2008; Masih, 2011; Rientjes et al., 2011). Considering the fact that hydroclimatic variables are mostly associated with randomness, these particular methods are very handy to tackle this challenge and to devise management strategies (Maity, 2018). There are also numerous other benefits of application of statistical methods in hydrological and hydroclimatic studies such as understanding interrelated processes, selection of suitable variables for devising predictions, as well as detection of patterns for constructing mitigating actions (Maity 2018).

2.4.1. Review of R software

Taking into account the essence of statistical computation especially in this research study, R software was chosen as the main computational platform. R statistical computing system is widely used environment for statistical analysis. As the open-source software, R based on the S programming language is developed by Chambers et al. at Bell Labratories in 1960 and enables running of wide-variety of computations with the help of numerous packages (Cisty and Celar, 2015).

As the hydrology is also quite data-intensive area, usage of R is preferred among all the other computation platforms such as Phyton and Matlab due to its effective data handling capacity, simple programming language, as well as graphic capabilities for data analysis and visualization which is especially important while dealing with the raster dataset. In this regard, several research studies dedicated to hydrology and climate change used R programming language and embedded packages for the analysis and visualization purposes. For instance, Salvacion et al. (2018) used R and its packages for analysis and visualization of the spatial distribution of climatic trends in Philippines. Meanwhile, Kahya and Kalayci (2003) performed streamflow trend analysis for studying the hydrological changes in Turkey.

Considering the user-friendly characteristic, easy and free accessibility as well as wide-variety of capabilities coupled with the fact of its wide utilization in similar studies making its academically reliable, R will be the main environment in this study to conduct all statistical analysis.

3. Methodology

This chapter is dedicated to the discussion of the main techniques undertaken for both data preparation and analysis. In this regard, while the research is mainly based on the quantitative method that was the statistical analysis, certain qualitative methods such as literature review and consultation with an expert were also carried out.

3.1. Research design

To address the research, aim regarding studying the impacts of climate change on the hydrology of the Kura River Basin which was mentioned in previous chapter, the research is designed in a following way:

Research Questions	Objectives	Main Steps
RQ1: What are the hydrological trends in the Kura River Basin?	**Ob1:** Identify the trends of the monthly, annual and seasonal streamflow series in the Kura River Basin.	1. Consult regional/local expert on characteristics of the river 2. Collect streamflow data for gauging stations 3. Conduct literature review to determine methodology 4. Conduct statistical analysis to identify the trends and their extents as well as to detect the change points/transition years for streamflow series.
RQ2: What are the trends in temperature and precipitation in the Kura River Basin?	**Ob1:** Identify the patterns for monthly, annual and seasonal climatic indices (i.e. precipitation and temperature) over the Kura River Basin. **Ob2:** Draw connections between these patterns and the climate change.	1. Collect streamflow data for gauging stations. 2. Collect remotely sensed data. 3. Conduct literature review to determine methodology. 4. Conduct statistical analysis to identify the trends and their extents as well as to detect the change points/transition years for climatic series.
RQ3: Is there any impact of the climate change on	**Ob1:** Diagnose whether there is a linkage between	1. Conduct literature review to determine methodology.

hydrology of the Kura River?	hydrology and climate change based on the station data. **Ob2:** Analyze how the trends in climatic indices might affect the hydrology of the Kura River.	2. Conduct literature review on climate change effects of hydrology. 3. Run statistical analysis (Bravais-Pearson's correlation). 4. Compare trend results with the correlation outcomes. 5. Interpret trend results of streamflow and climate change regarding possible future implications.

3.2. Data collection

For conducting this research study, several data sources were utilized to acquire the necessary information which were government agencies, regional/local experts on hydrology, and online databases for obtaining both remotely sensed data and accessing academic studies.

Among all collected data, two main groups which are data from stations and remotely sensed data need to be discussed further to have a better understanding since the current methodology section is closely concerned about them.

3.2.1. Data from stations

Collection of hydroclimatic data from stations was achieved through the request to governmental agencies concerned. This will be discussed in more detail in Chapter 5 since it is quite essential to highlight the data acquisition process and certain procedures as it might be helpful to the future research studies dealing with the same region.

In general, data from stations were regarding streamflow and climatic series (i.e. temperature and precipitation) for particular gauging (i.e. 5 gauging stations) and meteorological stations (i.e. 3 meteorological stations) for the certain period of time.

The key factors played roles for the gauging stations' selection were the consistent and quality data availability and geographical location. Meanwhile for the meteorological station data, along with the previous criteria considered as record length and data quality, the proximity to the previously selected hydrological stations was also taken into account for the assessment of climate change impacts.

3.2.2. Remotely sensed data

Along with the climate data from meteorological stations, remotely sensed data is also utilized both for temperature and precipitation. In this regard, two different data sources were used for temperature and precipitation following the previous research studies. Regarding the temperature data, GLDAS Noah Surface Model L4 V2.0 monthly data with 0.25x0.25 grid size was downloaded from Global Land Data Assimilation Systems (GLDAS) provided by the National Aeronautics and Space Administration (NASA) (Rodell et al. 2004) for the period of 1948-2010. Gridded precipitation data (0.5x0.5) from the Climate Research Unit Time Series (CRU TS) (Harris et al., 2014) for 1901-2019 was utilized to detect the spatial climatological trends. This particular dataset has been widely used in numerous previous research studies (e.g. Salvacion et al., 2018; Asfaw et al., 2018; Hadi and Tombul, 2018).

3.3. Data preparation

3.3.1. Data from the stations

Obtained gauging station data was daily, therefore before proceeding to the trend analysis, daily data was converted into mean monthly data and sorted according to the months of the year. There were gaps in some months of some years in the streamflow data, however they were not filled for the Mann-Kendall trend analysis considering the fact that that particular trend analysis allows gaps in the data record without any effect on the result. However, for the test to analyze the abrupt changes in mean value in the time series, the gaps were filled with the mean value of the particular series which allowed to check the change without having any impact on the result. Finally, the test for the autocorrelation was undertaken in R and the data with autocorrelation was tested with modified Mann-Kendall trend test with pre-whitening procedure. Checking serial correlation in time series data is quite essential as it can affect the outcome of the nonparametric trend test by giving a wrong result for the null hypothesis (Masih, 2011; Croitoru and Minea, 2014). In this research study, serial correlation in time series data was checked by using autocorrelation function (acf) in R.

To tackle with the challenge of serial correlation in trend analysis, the procedure called pre-whitening is utilized which is proved to decrease the probability of attaining a wrong result for the null hypothesis according to von Storch (1995) and Yue et al. (2002) (Bayazit and Önöz, 2007). Therefore, in this study modified Mann-Kendall test was utilized with the pre-whitening procedure proposed by Yue and Wang (2004) by utilizing modifiedmk package (Patakamuri and O'Brien, 2019) in R.

3.3.2. Remotely sensed data

Remotely sensed data to be utilized for the spatial trend analysis were cropped according to the extent of the study area with R and files containing monthly time series were extracted by using Phyton. The corresponding codes used in Phyton can be found in Appendix B and Appendix C.

3.4. Analysis

3.4.1. Detection of Streamflow and climatic trends

By taking into account numerous studies dedicated to the trend analysis of the hydrological and climatic time series (e.g. Kahya and Kalayci, 2003; Masih, 2011; Rientjes et al., 2011; Croitoru and Minea, 2014; Salvacion et al., 2018), Mann-Kendall trend test was chosen for the trend analysis for this study. Mann-Kendall test named after Mann (1945) for trends and Kendall (1975) for statistic distribution is a non-parametric rank-based test mainly utilized for testing randomness in time series (Kahya, 2004; Rientjes et al., 2011). There are many advantages of Mann-Kendall test such as no particular distribution is required for the data which allows data gaps and there is no effect of the extreme data points on the result due to the rank-based characteristic (Rientjes et al., 2011).

Mann-Kendall trend test statistics (S) is defined with the following equation (McLeod and Hipel, 1994; Kahya, 2004):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)$$

where

$$sgn(x) = \begin{cases} +1, & (x_j - x_k) > 0 \\ 0, & (x_j - x_k) = 0 \\ -1, & (x_j - x_k) < 0 \end{cases}$$

thus, in the case of zero mean variance of S (Var(S)) is computed as (McLeod and Hipel, 1994; Kahya, 2004):

$$Var\,(S) = \frac{\{n(n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j - 1)(2t_j + 5)\}}{18}$$

To elaborate on the equations, n is the number of data values, x_j and x_k are the values in two consecutive data period, t is the extent of the any given tie, i is the extent of the tie (Kahya, 2004; Rientjes et al., 2011).

While the value of data is greater than 10 (n>10), standard normal variate (p) can be calculated as (Kahya, 2004; Rientjes et al., 2011)

$$p = \begin{cases} \dfrac{S-1}{\sqrt{Var\,(S)}} & S > 0 \\ 0 & S = 0 \\ \dfrac{S+1}{\sqrt{Var\,(S)}} & S < 0 \end{cases}$$

In this regard, the null hypothesis of having independent and identically distributed random variable is accepted in the case of $|p| \leq z_{\alpha/2}$ (Rientjes et al., 2011). In this study, test was performed at 0.05 significance level. Furthermore, it is also noteworthy to mention that positive value of S denotes to the upward trend while the negative sign indicates the downward trend (Kahya, 2004). The test statistic tau (τ) is also utilized as an indicator for the direction of the trend and range between -1 and 1 (Meals et al., 2011).

τ is defined by Meals et al. (2011):

$$\tau = \frac{S}{n(n-1)/2}$$

Thus, similar to S, positive sign of τ indicates an increasing trend while the negative value signals the negative trend. In this research, the sign of the τ value was considered for identifying the direction of the trend.

The magnitude of the change can also be estimated with the Sen Slope according to (Helsel and Hirsch, 1992).

Sen slope is estimated:

$$\beta_1 = median\left(\frac{t_j - t_k}{y_j - y_k}\right)$$

where k>j, and the median of the slope of the all pairs gives the value for the Sen slope (Meals et al., 2011).

For the trend analysis both station data for the whole basin, kendall package (McLeod, 2011) and modifiedmk package (Patakamuri and O'Brien, 2019) of R were utilized for serially non-correlated and correlated series, respectively. Meanwhile, to identify the spatial distribution of climatic trends in the basin area, kendall and trend (Pohlert, 2017) packages, to convert the results into raster format and to clip to the study area, raster (Hijman et al.,2014) package, and to visualize the result, ggplot2 (Wickham, 2009) and rasterVis (Lamigueiro and Hijmans, 2019) packages of R were used. Since the trend analysis for the station data was in excel file format, basic commands by utilizing packages were run and results were obtained without constructing complicated codes. Therefore, only the R codes for the spatial climatic trend distribution and visualization will be shared as the codes were constructed from the scratch and can be useful in other studies (Appendix D).

3.4.2. Pettit's test for changing point

Pettit's test developed by Pettit (1979) is a non-parametric method commonly utilized for detecting single abrupt change point in mean value of time series and test the hypothesis whether the change point exists (Oyerinde, 2017). According to Pettit's test, change point exists in the case that common distribution function, $F_1(x)$ of random variables, x_1, x_2, $x_3 \ldots x_y$ with a change point at f is different from common distribution function, $F_2(x)$ of random variables, x_{f+1}, x_{f+2}, $x_{f+3} \ldots x_{f+y}$ (Pettit, 1979). In this regard, the test statistic which is labeled as U_f is defined (Pettit, 1979; Jaiswal et al., 2015):

$$U_f = \sum_{i=1}^{f} \sum_{j=f+1}^{y} sgn(x_f + x_j)$$

where

$$sign(x_f - x_j) = \begin{cases} +1, & (x_i - x_j) > 0 \\ 0, & (x_i - x_j) = 0 \\ -1, & (x_i - x_j) < 0 \end{cases}$$

The test statistic (K) and approximated significance probability (p) corresponding to K is defined (Pettit, 1979; Jaiswal et al., 2015):

$$K = Max\left|U_f\right|$$

$$p \cong 2exp\left(\frac{-6K^2}{n^2 + n^3}\right)$$

Thus, Pettit (1979) states that approximation holds in the case of p≤0.05.

Trend (Pohlert, 2017) package in R was utilized to detect the change points in both hydrological and climatic data.

3.4.3. Identifying linkages between streamflow and climate data

3.4.3.1. Bravais-Pearson test

To analyze the correlation between streamflow and precipitation data as well as temperature data, Bravais-Pearson linear correlation and coefficient was undertaken by following the studies of Masih (2011) and Croitoru and Minea (2014). The method allowing the identification of the linear relations between variables is calculated as:

$$r(P,Q) = \frac{\frac{1}{N}\sum_{i=1}^{n}(P_i - \bar{P})(S_i - \bar{S})}{\sigma(P)\cdot\sigma(S)}$$

In this equation, r is the Bravais-Pearson value, P and S denote to the variables to be checked, P_i and S_i are the corresponding values, $\bar{Q}$ and $\bar{S}$ are the average values, and N and n are the number of observations (Croitoru and Minea, 2014).

The interpretation of the test result is done through r since if r>0.5, there is a correlation between variables (Croitoru and Minea, 2014).

Bravais-Pearson correlation test was also run in R and correlation between streamflow data and precipitation data as well as temperature records from meteorological stations were tested. It is quite essential to highlight that the streamflow data regarding one of the stations in Azerbaijan, Surra was treated carefully since the Surra gauging station is on such a part of the Kura River where it has already joined its biggest tributary, Aras as well as due to the canals for water withdrawal purposes and reservoirs upstream (i.e. Varvara, Shamkir and Mingechevir), it has lost its natural flow. Therefore, it was not utilized for the correlation test analysis of the impact of precipitation and temperature on streamflow

4. The Kura River Basin

4.1. Physical characteristics

4.1.1. Geographical location

The Kura River Basin (sometimes called as the Kura-Aras River Basin*)* as a transboundary river basin locates in the area of four countries which are Georgia, Armenia, Azerbaijan, Turkey and Islamic Republic of Iran. The area of the basin is indicated as 190, 110 km^2 (188, 072 km^2 indicated by UN (2011)) of which 65 percent belongs to the South Caucasus countries, Azerbaijan (31.5 percent), Georgia (18.2 percent) and Armenia (15. percent while remaining parts of the basin are in Iran Islamic Republic (19.5 percent) and Turkey (15.1 percent) (FAO/AQUASTAT, 2008). The basin is bordered with northeastern Turkey, central and eastern Georgia and the northwestern Iran while the whole territory of Armenia and more than half of the area of Azerbaijan lays within the basin area (FAO/AQUASTAT, 2008) (Figure 5).

Figure 5 The Kura River Basin. Source: ENVSEC, 2011.

4.1.2. Climate

The climate in the basin is ranging from permanent snow cover and glaciers to humid subtropical forests and humid semi-desert steppes. The main reason for this diversity in climate across the basin area is due to its location as the basin lays in the area where conjunction of humid Mediterranean and dry continental air occurs coupled with the mountainous relief (FAO/AQUASTAT, 2008). Annual average temperature of the basin is approximately 9 ^{o}C, while the annual average precipitation is around 565 mm. January which is the coldest month in the basin has the average temperature of -4 ^{o}C which can decrease to -13 ^{o}C. Meanwhile, July in the basin area has the average temperature of 22 ^{o}C which can reach to 28 ^{o}C in some places.

Countries in the basin area have the specific climatic conditions which can be discussed based on the information from FAO/AQUASTAT, (2008). Climate of Armenia, territory of which entirely lays within the Kura River Basin is highland continental characterized by warm summer and cold winters with an annual average temperature of 5.5 ^{o}C. Average temperature throughout the year ranges from 26-24 ^{o}C to -6.7 ^{o}C. Despite of spatial variations in precipitation, annual average precipitation in the country is 592 mm. While the most humid areas are high mountains with 1000 mm annual precipitation, the driest areas can be found in Ararat Valley and Meghri region with a precipitation of 200-250 mm (FAO/AQUASTAT, 2008).

Being located in subtropics and moderate climates coupled with the proximity to Caspian Sea and the effect of solar radiation, in Azerbaijan climatic diversity is captured. While the climate in Azerbaijan is continental, humid tropical weather can be found in areas near the Caspian Sea. Lowland areas with arid weather experiences average summer temperature of 22 ^{O}C, whilst this number can be lower than 0 ^{o}C for the mountainous areas for the winter season. Finally, annual average precipitation is around 447 mm/year in the country.

Georgia, which also has significant portion of the territory laying within the border area is characterized by subtropical dry climate followed with relatively cold winters and arid, warm summer periods. While the average temperature differs within the range of 1 ^{o}C. and 22 ^{o}C. in January and July, respectively, the average precipitation annually varies between 500-1100mm. The authors also state that the period with the main precipitation is March-October within the significant portion of the area in Georgia and precipitation less than 800 mm/year of precipitation requires irrigation for the cultivation purposes.

4.2. Hydrology in the Kura River Basin

Kura (Mtkvari) river starting from Allahuekber Mountains Range at the height of 3,068 m with the length of 1,515 km discharges into Caspian Sea passing through the areas of Turkey, Georgia and Azerbaijan. Mammadov (2012) states that the main portion of the Kura River in terms of length belongs to Azerbaijan with 819 km followed with Georgia and Turkey with 522 km and 174 km, respectively. According to (UN, 2011), the main tributaries of Kura are Aras (Araks), Iori (Gabirri), Alazani (Ganykh), Debed (Debeda), Agstay (Aghstafachai), Potskhovi (Posof) and Ktsia-Khrami. Regarding the inflow of the tributaries of the Kura River, FAO/AQUASTAT (2008) provides the following estimated flow data:

Table 2 Main tributaries of the Kura River and their annual flow. Data source: UN (2011)

River	**Annual flow**
Kura from Turkey to Georgia	0.91 km^3
Potskhovi from Georgia	0.25 km^3
Debet from Armenia to Georgia	0.89 km^3
Aghstay from Armenia to Azerbaijan	0.35 km^3
Aras (and its tributaries which are Arpa, Voratan and Vokhchi) from Armenia to Azerbaijan	5.62 km^3
Aras from Islamic Republic of Iran to Azerbaijan	7.5 km^3

The largest tributary of the Kura River, Aras with 1072 km also starts from Turkey, Bingol Mountain Range and joins the Kura River in the area of Azerbaijan, 150 km before discharging into Caspian Sea (FAO/AQUASTAT). According to Mammadov (2012), Aras's main portion belongs to Turkey with 357 km while the remaining 628 km and 87 km passes from Armenia and Azerbaijan, respectively.

The main source of the water in the Kura river is mainly snow and glacier, precipitation and groundwater (Mammadov, 2012). Author also mentions that during the period of April-May, river experiences increase in terms of water quantity while it decreases through the summer period. However, quantity of the water in river in summer is relatively higher than the one in winter period (Mammadov, 2012).

4.3. Reservoirs on Kura River

There are several reservoirs and HES operating on the Kura River in all three countries serving various purposes. While in the case of Azerbaijan, they have multifunctional purposes such as irrigation, energy generation and drinking water, in the case of Georgia, it is mainly utilized for the purposes of irrigation and energy generation (Official Website of Ministry of Ecology and Natural Resources of Azerbaijan Republic (MENR); Tvalchrelidze et al., 2011) In Turkey, according to the information provided by Ardahan Provincial Directorate of Environment and Urbanism (2018), the reservoirs on Kura River are specifically utilized for energy generation thanks to the operation of two HES, however the source also indicates the usage of the river for irrigation purposes (Table 3). Furthermore, the source also indicates that four more reservoirs/HES are planned to be constructed which are Said, Chayirli, Gurturk, Beshikkaya.

Table 3 Reservoirs on the Kura River. Source: Official website of MENR; Tvalchrelidze et al., 2011; Ardahan Provincial Directorate of Environment and Urbanism, 2018.

Azerbaijan	**Reservoir**	**Utilization Purpose**	**Construction Year**	**Area (km^2)**	**Volume (km^3)**
	Mingachevir	Multifunctional	1953	605	15.73
	Shamkir	Multifunctional	1983	116	2.68
	Yenikend	Multifunctional	2000	23.2	1.58
	Varvara	Multifunctional	1952	22.5	0.06
Georgia	**Reservoir**	**Utilization Purpose**	**Area (km^2)**	**Volume (1000 m^3)**	
				Total	**Industrial**
	Zahesi	Power	2	12	3
	Jandari	Melioration	12.5	52	23
	Kumisi	Melioration	5.4	11	4
Turkey	**Reservoir**	**Utilization Purpose**	**Area (km^2)**	**Volume (1000 m^3)**	
	Kayabeyi/Akinji	Power	N/A	N/A	
	Koroghlu/Kotanli	Power	N/A	N/A	

5. Availability of hydroclimatic data for the Kura River Basin

Data availability plays a crucial role in all possible fields and allows variety of measures including assessment of the status of the phenomena and generation of predictions. This especially rings true in the case of hydrology and water resource management as thanks to the consistent data on hydrological observations, assessment of the impacts of anthropogenic and natural changes on water quantity and quality can be carried out and prevention and management of disasters as well as mitigation measures can be designed (Terakawa, 2003).

The current research study was also heavily depended on the hydroclimatic data availability and certain steps were undertaken to acquire the required data which will be discussed throughout this chapter. This section will also include the discussion regarding certain barriers encountered and measures that had been taken to tackle them. To clarify, remotely sensed data utilized in the research study was excluded from this chapter as the main goal of this particular section is informing regarding the data acquisition from government agencies in the region concerned and Global Runoff Data Center.

5.1. Hydrological data

Monthly mean streamflow data of the Kura River were obtained from five gauging stations that are situated in Georgia and Azerbaijan. Three of gauging stations belonging to Georgia are Khertvisi, Borjomi and Tbilisi and data were acquired from Hydrometeorological Department of National Environmental Agency (NEA) of Georgia. Meanwhile, remaining data from two gauging stations which are Girag-Kesemenli and Surra situated in Azerbaijan were obtained from Ministry of Ecology and Natural Resources of Azerbaijan Republic (MENR) and Global Runoff Data Center (GRDC). More information regarding streamflow data records can be found in the Table 4 while the locations of the gauging stations are indicated in Figure 6.

Table 4 Characteristics of selected hydrological stations and corresponding data records.

	Gauging stations	Country	Longitude	Latitude	Time period	Number of missing years
1	Khertvisi	Georgia	41. 28 N	43.17 E	1945-2016	8 (1995-1997, 2000-2001, 2003-2005)
2	Borjomi	Georgia	41.50 N	43.22 E	1936-2016	11 (1995-2005)
3	Tbilisi	Georgia	41.42 N	44.47 E	1935-2011	-
4	Girag-Kesemenli	Azerbaijan	41.14 N	45.26 E	1993-2017	-
5	Surra	Azerbaijan	40.06 N	48.33 E	1930-2017	-

Data acquisition from both NEA of Georgia and MENR were done through official data request sent to the bodies concerned. While for NEA, the official response came in less than a week, for the request to MENR, the additional follow-up with the ministry in person was the case since the bureaucratic procedures for data dissemination took time and data fee had to be paid in person to the bank.

Regarding the access to the data, while data for gauging stations in Georgia were provided free of charge considering the applicant's status of being student under certain conditions accepted, for MENR, data was provided by paying certain amount of data fee set by the national legislation.

Furthermore, considering that the Kura River also passes from the territory of Turkey, search for data regarding gauging stations on the Kura River in Turkey was also undertaken. However, after searching online database of the General Directorate of State Hydraulic Works of Turkey and contacting them, it was discovered that since only small part of Kura flows within Turkey and it is transboundary in nature, streamflow data for the Kura River is not collected on a regular basis and if they had, dissemination of data for foreigners living outside of Turkey is not free of charge and requires official letter to be sent for the data request.

Considering the record length of the data provided for the gauging stations in Azerbaijan, additional data request was also sent to Global Runoff Database Center (GRDC). GRDC as an international archive of data operates under the auspices of World Meteorological Organization possessing runoff data for more than 9500 stations from 161 countries (GRDC Website). Data access is quite easy since prior to sending necessary documents such as short research summary, order form and signed user declaration, requested data is delivered through an email. The main data source for GRDC is national hydrometeorological agencies, thus the database contains the runoff data that is provided by them. Therefore, since GRDC contained the data for only Surra station on the Kura River and record length of the data obtained from MENR regarding Surra was quite short, additional request for streamflow data for Surra is made from GRDC.

5.2. Climate Data

In order to run the climatic trend analysis for the region, along with the remotely sensed data, data from meteorological stations was also accessed. In this regard, data of temperature and precipitation for three meteorological stations were obtained from NEA Georgia which were Akhaltsikhe, Borjomi and Gardabani (Table 5). Locations of the meteorological stations can be found in Figure 6.

Table 5 Characteristics of selected meteorological stations and corresponding data records.

	Meteorological stations	Country	Longitude	Latitude	Time period	Number of missing years	
						Temperature	**Precipitation**
1	Gardabani	Georgia	41.45	45.10	1960-2006	4 (1995-1996, 2000, 2005, and some months)	4 (1995-1996, 2000, 2005, and some months)
2	Akhaltsikhe	Georgia	41.63	42.98	1960-2012	-	
3	Borjomi	Georgia	41.83	43.38	1960-2012	3 (1995-1997, and some months)	4 (1995-1997, 2006, and some months)

Unfortunately, for other countries, only the analysis based on the remotely sensed data was relied on considering the long procedure of accessing data and data fee required. This fact is quite essential to highlight since sometimes accessing certain meteorological data is costly, time-consuming or impossible at all due to the station availability so in these cases remotely sensed data can be very handy to observe the status of the climatic indices especially in the light of climate change. Therefore, considering the difficulties in data acquisition, it is always recommended to look for the several data sources rather than sticking to one to conduct the research study.

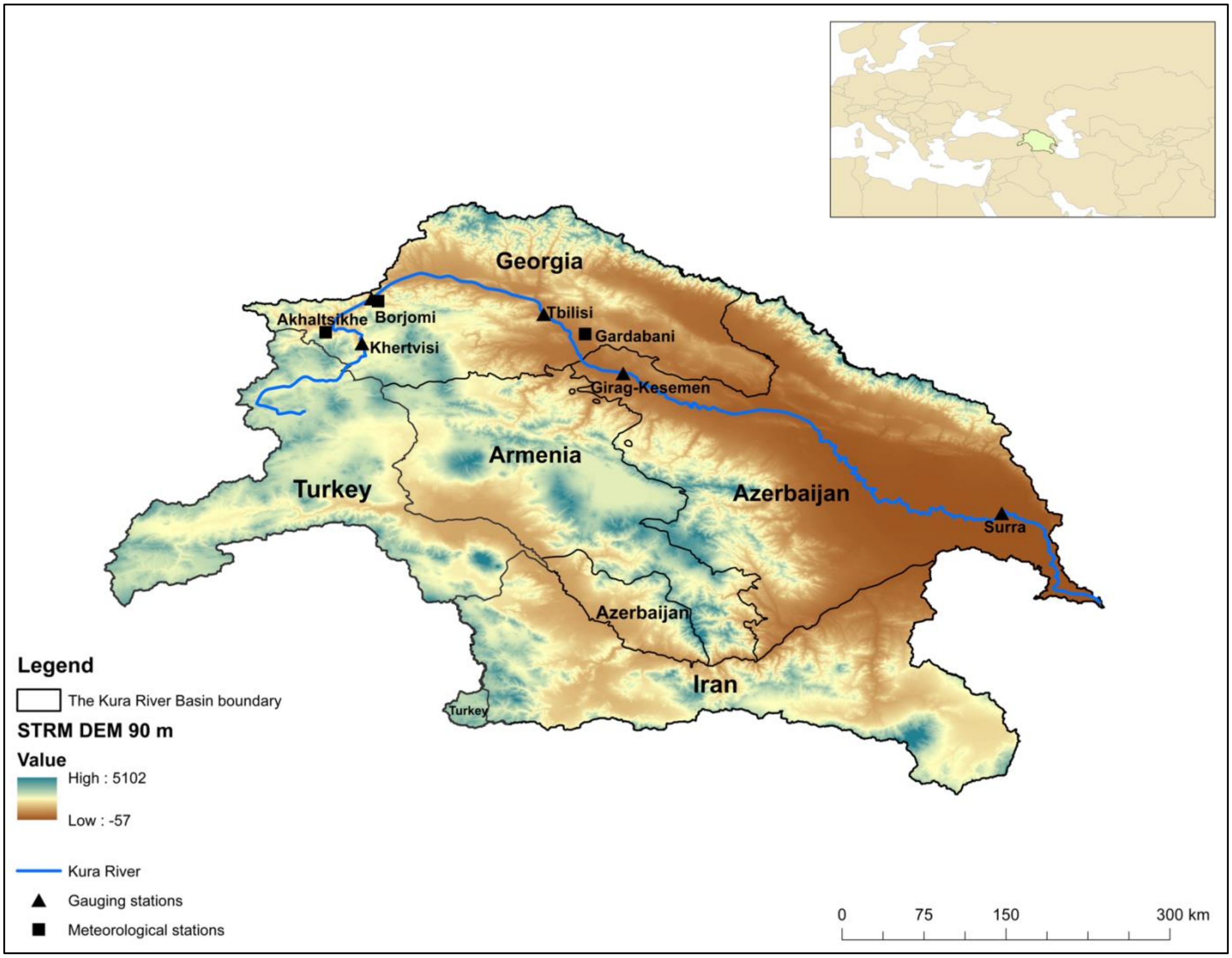

Figure 6 Location of the gauging and meteorological stations in the study area

6. Streamflow trends of the Kura River

6.1. Trend Analysis

This chapter will provide the answers for the first objective regarding the identification of trends in streamflow of the Kura River by analyzing the data from five gauging stations that have already been presented in previous section. Results of the trend analysis are presented in Table 6 and Table 7 for monthly as well as annual and seasonal streamflow series, respectively.

Regarding the trend analysis of monthly streamflow series across all stations (Table 6), comparatively small share of all analyzed data shows significant trend (30 percent), whereas the remaining trends captured are statistically insignificant at 5 percent significance level. More than half of the identified trends (60 percent) demonstrate a decreasing trend of which 10 percent is statistically significant. Meanwhile, positive trends consist of 40 percent of the overall trends of which approximately 33 percent is statistically significant.

Trend analysis of the mean monthly streamflow series across five stations also demonstrates that in all four stations except Khertvisi, decreasing trend overweighs the increasing trend, however in the case of significant results only, it is obvious that there is a clear divide between the stations in Georgia and Azerbaijan. In this regard, while in gauging stations of Georgia (Khertvisi, Borjomi and Tbilisi), statistically significant increasing trend overweighs decreasing trend, in gauging stations of Azerbaijan (Girag-Kesemen and Surra) mainly decreasing trends are observed across the months.

In terms of the extent of the significant trend, value of Sen's slope indicates that among all stations Surra and Girag-Kesemen experienced comparatively higher magnitude of trend than other stations. In this regard, the highest values of Sen's slope are captured in Surra and Girag-Kesemen, -13.636 m^3/san (May) and -11.757 m^3/san (April), respectively, the lowest value is in the case of

Borjomi, 0.170 m^3/san (September). Generally, relatively higher trend slopes are captured in Surra and Girag-Kesemen, followed by the remaining three gauging stations.

Trend analysis across months shows variability in terms of trend of streamflow in five gauging stations, thus no month was captured with a consistent trend direction. In all months except, January, February, March and December, number of decreasing trends (regardless of significance) exceeded number of increasing trends. Among these months, large number of decreasing trends were captured especially in the months of May, August, September, October and November (4 out of 5 stations).

Regarding significant monthly trends, in all months except November, significant trend was captured. While, in January, February, March, September and December only increasing significant trends were detected, the remaining months had decreasing significant trend only with the exception of April in which number of times with decreasing trend was higher than the increasing trend.

Very similar to the monthly streamflow series trend results, Table 7 demonstrates that annual and seasonal mean streamflow series trend results follow similar pattern by having more decreasing trends comparing to increasing trends. In this regard, while more than half of all trend outcomes (60 percent) indicated decreasing trend of which 40 percent is statistically significant, the remaining share demonstrated increasing trend with two percent of it being statistically significant. Overall, 8 out of 25 trend analysis results of annual and seasonal streamflow series trend of five gauging stations are statistically significant.

Regarding stations, in all five stations significant trend in annual and seasonal streamflow series are captured. In terms of the direction of the all captured trends in gauging stations regardless of their statistically significance, in the case of Girag-Kesemen only decreasing trends were detected for both annual and seasonal series. The remaining stations had variability in terms of trends so while in Khertvisi and Borjomi number of increasing trends overweigh, in the case of Tbilisi and Surra, this is contrary. However, when only the significant trends are considered, only two stations which are Borjomi and Tbilisi experienced decreasing trend.

As indicated in monthly trend analysis previously, similar results regarding the slope of the significant trend can be observed in the case of annual and seasonal streamflow series as well. Among all five stations, Surra and Girag-Kesemen have the highest Sen's slope values, -8.264 m^3/san and -5.902 m^3/san, respectively, while the lowest slope value belongs to Khertvisi with -0.005 m^3/san.

Regarding annual mean streamflow series trend analysis result, in three out of five stations, decreasing trend was observed two of which are statistically significant (i.e. Surra and Girag-Kesemen stations).

Within the seasonal streamflow series trend, all seasons except autumn had significant trend. While looking at all significant and insignificant trend results, only in winter season, number of increasing trends overweighs. In the remaining seasons, relatively more decreasing trends were captured and in autumn, number of decreasing trends identified is higher than the other two seasons (4 out of 5 stations). Meanwhile, significant trend results across the seasons demonstrate only decreasing trends for two seasons which are summer and spring, whereas in winter there is a balance between the number of increasing and decreasing trends.

Table 6 The results of Mann-Kendall test for trend analysis of mean monthly streamflow series from Khertvisi, Borjomi, Tbilisi, Girag-Kesemen and Surra stations.

Station	Value	January	February	March	April	May	June	July	August	September	October	November	December
Khertvisi	tau	-0.155	-0.130	0.095	0.176	0.016	0.061	0.100	-0.022	-0.122	-0.033	-0.030	-0.079
	p-value	0.072	0.129	0.268	**0.041**	0.857	0.483	0.244	0.803	*0.116*	0.706	0.728	0.360
	Sen’s slope	-0.022	-0.017	0.043	0.545	0.051	0.120	0.059	-0.005	-0.019	-0.005	-0.005	-0.013
	significant trend	no	no	no	yes (+)	no	no	no	no	no	no	no	no
Borjomi	tau	0.286	0.312	0.275	0.076	-0.069	0.004	0.084	0.137	0.207	0.142	0.115	0.241
	p-value	***0.002***	***0.000***	**0.001**	0.356	0.410	0.963	0.312	0.097	**0.012**	*0.118*	0.164	***0.010***
	Sen’s slope	0.205	0.194	0.363	0.449	-0.389	0.011	0.129	0.118	0.170	0.137	0.119	0.189
	significant trend	yes (+)	yes (+)	yes (+)	no	no	no	no	no	yes (+)	no	no	yes (+)
Tbilisi	tau	0.253	0.135	0.135	-0.071	-0.161	-0.039	-0.066	-0.091	-0.099	-0.001	0.115	0.135
	p-value	**0.001**	0.086	0.085	0.365	**0.041**	0.621	0.405	0.249	0.210	0.989	0.144	0.086
	Sen’s slope	0.374	0.223	0.505	-0.659	-1.759	-0.304	-0.251	-0.191	-0.198	-0.004	0.280	0.279
	significant trend	yes (+)	no	no	no	yes (-)	no	no	no	no	no	no	no
Girag-Kesemen	tau	-0.427	-0.218	-0.0835	-0.384	-0.213	-0.181	-0.314	-0.324	-0.174	-0.16	-0.244	-0.238
	p-value	**0.003**	0.135	0.575	**0.008**	0.141	0.216	**0.030**	**0.025**	0.233	0.272	0.093	0.102
	Sen’s slope	-3.122	-1.414	-1.236	-11.757	-7.621	-5.708	-3.938	-1.720	-1.360	-1.406	-2.307	-1.964
	significant trend	yes (-)	no	no	yes (-)	no	no	yes (-)	yes (-)	no	no	no	no
Surra	tau	0.174	0.108	-0.083	-0.478	-0.494	-0.492	-0.395	-0.028	-0.073	-0.211	-0.088	0.078
	p-value	***0.018***	0.142	0.256	***0.000***	***0.000***	***0.000***	**0.000**	0.703	0.317	**0.004**	0.232	*0.260*
	Sen’s slope	1.909	1.417	-1.076	-8.405	-13.636	-9.538	-3.043	-0.211	-0.487	-1.444	-0.667	0.710
	significant trend	yes (+)	no	no	yes (-)	yes (-)	yes (-)	yes (-)	no	no	yes (-)	no	no

Notes:
a Values in italics refer to the results of the pre-whitened data
b Values in bold refer to the significant results at 95 percent confidence level
c Value of Sen’s slope is in m3/san corresponding to measurement unit of streamflow

Table 7 The results of Mann-Kendall test for trend analysis of mean annual and seasonal streamflow series from Khertvisi, Borjomi, Tbilisi, Girag-Kesemen and Surra stations.

Station	Value	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Khertvisi	tau	0.144	-0.171	0.166	0.088	-0.055
	p-value	0.094	***0.047***	0.054	0.305	0.528
	Sen's slope	0.096	-0.023	0.332	0.088	-0.005
	significant trend	no	yes (-)	no	no	no
Borjomi	tau	0.089	0.294	0.082	0.033	0.149
	p-value	0.284	***0.004***	0.323	0.690	0.088
	Sen's slope	0.130	0.196	0.236	0.066	0.118
	significant trend	no	yes (+)	no	no	no
Tbilisi	tau	-0.062	0.184	-0.062	-0.069	-0.013
	p-value	0.437	***0.002***	0.431	0.385	0.876
	Sen's slope	-0.171	0.288	-0.486	-0.348	-0.019
	significant trend	no	yes (+)	no	no	no
Girag-Kesemen	tau	-0.301	-0.347	-0.058	-0.267	-0.230
	p-value	***0.038***	***0.016***	0.710	0.065	0.112
	Sen's slope	-3.225	-2.028	-5.902	-4.013	-1.575
	significant trend	yes (-)	yes (-)	no	no	no
Surra	tau	-0.391	0.161	-0.475	-0.458	-0.139
	p-value	***0.000***	*0.058*	***0.000***	**0.000**	0.057
	Sen's slope	-3.450	1.300	-8.264	-4.345	-0.911
	significant trend	yes (-)	no	yes (-)	yes (-)	no

Notes:
a Values in italics refer to the results of the pre-whitened data
b Values in bold refer to the significant results at 95 percent confidence level
c Value of Sen's slope is in m3/san corresponding to measurement unit of streamflow

6.2. Pettit's change point analysis

The results of the Pettit's test for both monthly as well as annual and seasonal streamflow series are presented in Table 8 and Table 9. In terms of mean monthly streamflow series data, in all stations except Khertvisi and Tbilisi, significant change was detected. Hereinafter, both in Borjomi station and Girag-Kesemen station, mainly two close years which are 1986 and 1987 (i.e. in the case of Borjomi) and 2007 and 2011 (i.e. in the case of Girag-Kesemen station) were captured as the transition years by the Pettit's test. While in Borjomi station, these change points were captured in all months except April, May, June, July which did not have any significant results, in Girag-Kesemen station, transition points are attributed to January and April. Meanwhile, in Surra station all months except March, August and September had significant change points mainly in the years of 1953, 1954, 1969, 1978.

Table 8 The results of applied Pettit's change point test to mean monthly stream-flow series.

Station	Value	January	February	March	April	May	June	July	August	September	October	November	December
Khertvisi	change point	1964	1960	1976	1967	1986	1985	1998	2008	1983	1951	1951	1959
	p-value	0.065	0.088	0.582	0.093	1.351	0.747	0.382	0.359	0.177	0.411	0.355	0.220
	sample size	64	64	64	64	64	64	64	64	64	64	64	64
Borjomi	change point	1986	1986	1987	1967	1954	1975	1986	1986	1986	1986	1986	1986
	p-value	**0.000**	**0.000**	**0.006**	0.266	0.835	1.314	0.084	**0.001**	**0.000**	**0.000**	**0.001**	**0.000**
	sample size	70	70	70	70	70	70	70	70	70	70	70	70
Tbilisi	change point	1985	1985	1973	1942	1965	1959	1946	1946	1959	1951	1986	1986
	p-value	0.001	0.080	0.224	1.091	0.086	1.047	0.770	0.335	0.658	0.325	0.112	0.042
	sample size	76	76	76	76	76	76	76	76	76	76	76	76
Girag-Kesemen	change point	2007	2007	2011	2006	2007	2011	2011	2009	2006	2006	2007	2006
	p-value	**0.010**	0.101	0.441	**0.009**	0.088	0.200	0.101	0.188	0.462	0.148	0.101	0.088
	sample size	25	25	25	25	25	25	25	25	25	25	25	25
Surra	change point	1954	1954	1985	1969	1969	1969	1978	1998	1998	1969	1978	1953
	p-value	**0.001**	**0.011**	0.290	**0.000**	**0.000**	**0.000**	**0.000**	0.059	0.051	**0.002**	**0.000**	**0.020**
	sample size	87	87	87	87	87	87	87	87	87	87	87	87

Note: Values in bold refer to the significant results at 95 percent confidence level

Table 9 The results of applied Pettit's change point test to annual and seasonal stream-flow series.

Station	Value	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Khertvisi	change point (p-value)	1985 (0.141)	1960 (**0.027**)	1986 (0.162)	1985 (0.484)	1951 (0.392)
	sample size	64	64	64	64	64
Borjomi	change point (p-value)	1986 (**0.038**)	1986 (**0.000**)	1975 (0.335)	1986 (0.512)	1986 (**0.000**)
	sample size	70	70	70	70	70
Tbilisi	change point (p-value)	1944 (0.405)	1985 (**0.001**)	1965 (0.776)	1946 (0.674)	1951 (0.402)
	sample size	76	76	76	76	76
Girag-Kesemen	change point (p-value)	2011 (**0.023**)	2007 (**0.032**)	2007 (**0.023**)	2011 (0.077)	2006 (0.139)
	sample size	25	25	25	25	25
Surra	change point (p-value)	1969 (**0.000**)	1953 (**0.000**)	1969 (**0.000**)	1978 (**0.000**)	1978 (0.057)
	sample size	87	87	87	87	87

Note: Values in bold refer to the significant results at 95 percent confidence level

Contrarily, in the case of Pettit's test results for annual and seasonal streamflow series, all stations had significant change points in terms of seasonal series, whereas in terms of annual series only Khertvisi and Tbilisi did not have any significant change point. Looking at the overall results, stations like stations like Borjomi, Girag-kesemen and Surra had a similar transition year with the previously discussed monthly change point results. Furthermore, it is also important to note that in Borjomi and Tbilisi stations, the change points detected which are 1985 and 1985 are quite close, thus hinting to the change happened in upstream affecting the streamflow in downstream stations of Georgia.

Regarding the change points, unfortunately no information was obtained in terms of the specific anthropogenic factors which played a role. Only in the case of Surra station, the transition points of 1953 and 1954 detected by Pettit's test is most likely due to the construction of the biggest reservoir on Kura, Mingechevir which was completed in 1953.

6.3. Limitations

To capture more precise understanding of the hydrological trend in the basin area, it would be better if different tributaries were also analyzed rather than only having the main river. Unfortunately, this was not possible considering the constrains of time and quality data availability.

Another limitation in this part of the analysis was regarding not having any gauging station from the part of Turkey where the Kura River starts. Due to the reason stated in Chapter 5, the gauging stations in Turkey were eliminated from the research study. However, this limitation is not believed to affect the results of the analysis in a serious way since most of the gauging stations mentioned in this study locate on natural flowing Kura, more or less, and power plants constructed (except Surra) till the gauging station are run-of-the-river hydroelectricity plants which requires very small or no water storage to operate.

As the last limitation, data record obtained from MENR regarding Girag-Kesemen (25 years) and Surra (initially 25 years) stations were shorter comparing to the other three stations. While it was possible to complete data record of Surra station with the data from GRDC, for the case of Girag-Kesemen, it was not quite possible. While there is a debate over the minimum record length for the hydrological trend analysis as according to Kundzewicz and Radziejewski (2006), minimum 50 years of data record is preferable to study the streamflow trends in a response to climate change, there are several research studies utilized 25 years of the record length as the threshold (e.g. Burn and Hag Elnur, 2002; Dixon et al., 2006). According to Burn and Hag Elnur (2002), minimum record length of 25 years is acceptable for attaining statistical validity in results. Therefore, the length of Girag-Kesemen station did not pose any challenge during the study.

6.4. Discussion

RQ1: What are the hydrological trends in the Kura River Basin?

Looking at the overall picture of the trend analysis regarding hydrological series of the Kura River, there is a clear distinction regarding the dominant trends between Georgia and Azerbaijan. In this regard, while in the case of gauging stations from Georgia except Tbilisi (for May streamflow) and Khertvisi (for winter streamflow), the main significant trends were captured appeared to be increasing, looking at the results of the trend analysis in gauging stations of Azerbaijan, one can observe only the decreasing trends with few exceptions. This rings true especially in the context of the list prepared by World Resource Institute regarding the water stressed countries by 2040 (Gassert et al. 2013) that has been mentioned previously so in terms of the projected water stress level, Azerbaijan is the way ahead of Georgia in that list which resonates with the trends acquired.

While analyzing the change point results, it is observed that after Khertvisi gauging station till Tbilisi, certain modifications occurred that both Borjomi and Tbilisi stations had similar period for transition in mean streamflow which is 1985-1987. Unfortunately, no exact information was attained regarding these years. Another interesting result was in the case of Girag-Kesemen signaling the change in 2007-2011 which might be due to the several reasons such as hydrological constructions or water withdrawal on these years. Finally, in the case of Surra, all change points as already mentioned were closely linked to the reservoir construction which should be highlighted not to be confused with the natural reasons.

7. Trends in climatic indices in the Kura River Basin

7.1. Trends in precipitation and temperature (Based on the station data)

7.1.1. Precipitation

The results of the trend analysis for monthly as well as annual and seasonal mean precipitation and temperature series for three meteorological stations are presented in Table 10 and Table 11. Regarding monthly precipitation trend analysis outcomes, Table 10 demonstrates that very few significant trends were captured across the stations (3 out of 36 results) and one station which is Gardabani does not have any significant trend at all. Hereinafter, among the significant trends identified, all three of them are decreasing trends which were detected in June for the case of Borjomi station and in December for the cases of both Borjomi and Akhaltsikhe stations.

Taking into account both statistically significant and insignificant trends in monthly precipitation, frequency of decreasing trends across all months and stations is more than increasing trends since approximately 55 percent of all identified trends are negative. In this regard, while in two stations (i.e. Borjomi and Gardabani) number of decreasing trends overweighs of which 25 percent is statistically significant for Borjomi station, in the case of Akhaltsikhe more increasing trends were captured among which there was not any significant trend.

Looking at individual months' trend outcomes across stations, while April, June and December had only decreasing trends in all stations of which two of them are statistically significant, increasing trend was captured in all the stations in the case of March. Meanwhile, remaining months had no consistent outcomes for the stations. So, while in June, July and August, number of times decreasing trends detected is larger (2 out of 3 stations), in February, March, September, October and November, it is completely opposite.

Annual precipitation series different from monthly trend analysis do not have any significant result, however overall trend results regardless of statistical significance demonstrate that while in Akhaltsikhe and Gardabani stations, decreasing trends were observed, Borjomi station had an increasing trend. Meanwhile seasonal analysis captured only one statistically significant trend which is a decrease for summer season in Borjomi station. Overall, different from monthly precipitation series trend outcomes, seasonal trend analysis is resulted in more increasing trends than the decreasing trends by consisting of 58 percent of overall seasonal precipitation series trend outcomes without having any significant results among them.

Finally, looking at the significant trend slopes to detect the magnitude of the transition, in monthly precipitation analysis across all three stations, the highest slope value is in the case of Borjomi station identified in June which is -0.026 mm/year, whereas the lowest value, -0.011 mm/year belongs to Akhaltsikhe station for December. Meanwhile, in seasonal precipitation series only one value of Sen's slope is statistically significant which is -0.016 mm/year identified in Borjomi station for summer season.

Table 10 The results of Mann-Kendall test for trend analysis of mean monthly climatic indices (precipitation and temperature) series from Akhaltsikhe, Borjomi and Gardabani stations.

Station	Indices	Value	January	February	March	April	May	June	July	August	September	October	November	December
	Precipitation	tau	0.020	0.097	0.007	-0.012	-0.008	-0.018	0.049	0.011	0.053	0.077	-0.104	-0.237
		p-value	0.842	0.311	0.951	0.908	0.939	0.854	0.607	0.914	0.581	0.421	0.276	**0.013**
		Sen’s slope	0.001	0.005	0.000	-0.001	-0.000	-0.002	0.006	0.001	0.004	0.006	-0.006	-0.011
Akhaltsikhe		significant trend	no	no	no	no	no	no	no	no	no	no	no	yes (-)
	Temperature	tau	0.094	0.004	0.095	0.019	-0.047	0.198	0.196	0.321	0.233	0.279	-0.047	-0.001
		p-value	0.322	0.969	0.319	*0.560*	0.623	**0.037**	**0.039**	**0.001**	**0.014**	**0.003**	0.623	0.994
		Sen’s slope	0.026	0.002	0.017	0.004	-0.006	0.022	0.023	0.045	0.029	0.042	-0.005	-0.001
		significant trend	no	no	no	no	no	yes (+)	yes (+)	yes (+)	yes (+)	yes (+)	no	no
	Precipitation	tau	-0.015	0.052	0.047	-0.055	0.148	-0.278	-0.030	-0.156	-0.009	-0.061	0.119	-0.190
		p-value	*0.766*	*0.061*	0.644	0.587	0.136	**0.005**	0.769	0.126	0.936	0.546	0.237	***0.003***
		Sen’s slope	-0.002	0.004	0.003	-0.003	0.015	-0.026	-0.003	-0.014	-0.001	-0.006	0.020	-0.012
Borjomi		significant trend	no	no	no	no	no	yes (-)	no	no	no	no	no	yes (-)
	Temperature	tau	0.094	-0.020	0.091	0.165	-0.023	0.195	0.267	0.245	0.249	0.188	-0.066	-0.094
		p-value	0.379	0.862	0.404	0.121	0.834	0.070	**0.012**	**0.025**	**0.021**	0.081	0.544	0.386
		Sen’s slope	0.026	-0.005	0.017	0.033	-0.004	0.024	0.039	0.047	0.032	0.033	-0.011	-0.022
		significant trend	no	no	no	no	no	no	yes (+)	yes (+)	yes (+)	no	no	no
	Precipitation	tau	-0.068	-0.058	0.013	-0.056	0.187	-0.145	-0.050	-0.123	0.012	0.194	0.005	-0.037
		p-value	0.537	0.595	0.916	0.613	0.088	0.185	0.653	0.255	0.919	0.076	0.973	0.745
		Sen’s slope	-0.002	-0.004	0.001	-0.004	0.021	-0.021	-0.005	-0.009	0.000	0.014	0.000	-0.002
Gardabani		significant trend	no	no	no	no	no	no	no	no	no	no	no	no
	Temperature	tau	0.020	-0.048	0.136	0.073	-0.194	0.115	0.112	0.236	0.146	0.188	-0.088	-0.076
		p-value	0.866	0.665	0.221	0.508	0.076	0.296	0.307	**0.029**	0.181	0.086	0.425	0.493
		Sen’s slope	0.007	-0.016	0.030	0.018	-0.039	0.024	0.026	0.046	0.023	0.038	-0.014	-0.013
		significant trend	no	no	no	no	no	no	no	yes (+)	no	no	no	no

Notes:

a Values in italics refer to the results of the pre-whitened data

b Values in bold refer to the significant results at 95 percent confidence level

c Value of Sen’s slope is in mm and Co corresponding to measurement units of precipitation and temperature

Table 11 The results of Mann-Kendall test for trend analysis of mean annual and seasonal climatic indices (precipitation and temperature) series from Akhaltsikhe, Borjomi and Gardabani stations

Station	Indices	Value	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Akhaltsike	Precipitation	tau	-0.026	-0.044	-0.010	0.007	0.019
		p-value	0.788	0.651	0.921	0.945	0.848
		Sen's slope	-0.001	-0.001	0.000	0.000	0.001
		significant trend	no	no	no	no	no
	Temperature	tau	0.234	0.089	0.054	0.324	0.209
		p-value	**0.014**	0.353	0.576	***0.000***	**0.028**
		Sen's slope	0.018	0.016	0.004	0.031	0.023
		significant trend	yes (+)	no	no	yes (+)	yes (+)
Borjomi	Precipitation	tau	-0.055	-0.055	0.135	-0.222	0.057
		p-value	0.604	0.595	0.180	**0.032**	0.576
		Sen's slope	-0.002	-0.003	0.006	-0.016	0.003
		significant trend	no	no	no	yes (-)	no
	Temperature	tau	0.108	0.007	0.199	0.264	0.152
		p-value	0.334	0.955	0.065	**0.017**	0.159
		Sen's slope	0.019	0.001	0.023	0.030	0.016
		significant trend	no	no	no	yes (+)	no
Gardabani	Precipitation	tau	0.075	0.069	0.009	-0.154	0.173
		p-value	0.522	0.545	0.942	0.160	0.113
		Sen's slope	0.004	0.002	0.001	-0.014	0.008
		significant trend	no	no	no	no	no
	Temperature	tau	0.038	-0.105	-0.013	0.251	0.129
		p-value	0.744	0.345	0.916	**0.021**	0.238
		Sen's slope	0.006	-0.015	-0.003	0.035	0.016
		significant trend	no	no	no	yes (+)	no

Notes:
[a] Values in italics refer to the results of the pre-whitened data
[b] Values in bold refer to the significant results at 95 percent confidence level
[c] Value of Sen's slope is in mm and C° corresponding to measurement units of precipitation and temperature

7.1.2. Temperature

Trend analysis results for monthly temperature depicted in Table 10 indicate that comparing to precipitation trend, relatively more significant results were captured so the significant trends consist of 25 percent of the overall results and all of them are increasing. In this regard, increasing trends were detected for the months of June and October in Akhaltsikhe station, July and September in both Akhaltsikhe and Borjomi stations and for August in all stations. While, the highest slope for the increasing significant trend was detected in Borjomi for August with 0.047^{o} C, the lowest one belongs to Akhaltsikhe station for June with 0.022^{o} C.

Looking at the overall monthly temperature trend results, more than half of the all identified monthly trend results (approximately 69.4 percent) are increasing trends of which 36 percent is statistically significant. In this regard, in all stations frequency of increasing trends is dominant.

In terms of the individual months, some consistency across the stations was detected so while the months of January and June-October were characterized with the increasing trend only across all three stations, May, November and December results had only decreasing trends. Whereas, for February in two of out of three stations decreasing trend was detected.

Regarding annual and seasonal temperature series, similar pattern is captured where the increasing trends regardless of being statistically significant overweigh in all stations for both annual and seasonal trend analysis with the exception of Gardabani station where the frequency of increasing and decreasing trends are same for the seasonal series. In this regard, trend results of the annual series show that all stations have an increasing trend where in Borjomi, it is statistically significant. Meanwhile, in terms of seasonal temperature series trend results, summer and autumn seasons show an increasing trend for all stations, whereas regarding winter and spring results, insignificant increasing trend is captured in all stations except Gardabani. Furthermore, while the trend results attributed to summer temperature series are all statistically significant across the stations, for autumn season, only Akhaltsikhe had a significant trend.

Finally, analyzing the magnitude of the annual and seasonal trend by looking at the values of Sen's slope, while for the annual temperature series, the only significant slope value was 0.018 in the case of Akhaltsikhe station, regarding the seasonal series, the lowest and highest significant trend slopes were captured in Borjomi and Gardabani for summer season with the values of -0.016^{o} C and 0.035^{o} C, respectively.

7.1.3. Pettit's change point analysis

Results of the change point analysis test presented in Table 12 and Table 13 indicate very few change points across the stations for both precipitation and temperature series. Concerning precipitation series both seasonally and monthly, only in one station which was Borjomi, significant change points were identified while regarding the mean annual precipitation series, all series across all stations were observed to be homogeneous with no significant change. In terms of the seasonal series, only one significant change point (1994) was detected which was for the winter precipitation series in Borjomi station (Table 12). While, within the monthly precipitation series, in two months, June and December significant change points were detected which was 1991 and 1993, respectively (Table 13).

According to the results of the mean temperature Pettit's change point test, relatively more change points are detected in all series and in all stations, except Borjomi which held homogeneous series with no significant change point.

Table 12 The results of applied Pettit's change point test to mean annual and seasonal. Values in bold refer to the significant results at 95% confidence level.

Station	Indices	Value	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Akhaltsike	Precipitation	change point (p-value)	0.921 (2001)	0.881 (1997)	0.555 (1988)	1.304 (1972)	1.067 (2001)
		sample size	53	53	53	53	53
	Temperature	change point (p-value)	**0.004** (1993)	0.238 (1994)	0.587 (1993)	**0.001** (1994)	**0.039** (1993)
		sample size	53	53	53	53	53
Borjomi	Precipitation	change point (p-value)	1.165 (1983)	**0.028** (1994)	0.425 (1971)	0.186 (1988)	0.927 (1995)
		sample size	49	49	49	49	49
	Temperature	change point (p-value)	0.214 (1993)	0.667 (1963)	0.262 (1993)	0.093 (1985)	0.303 (1993)
		sample size	43	43	43	43	43
Gardabani	Precipitation	change point (p-value)	0.716 (1966)	0.692 (1968)	1.675 (1998)	0.332 (1985)	0.214 (1966)
		sample size	47	47	47	47	47
	Temperature	change point (p-value)	0.597 (1978)	0.381 (1968)	1.663 (1998)	0.064 (1985)	0.198 (1995)
		sample size	47	47	47	47	47

Table 13 The results of applied Pettit's change point test to mean monthly precipitation and temperature series.

Station	Indices	Value	January	February	March	April	May	June	July	August	September	October	November	December
Akhaltsike	Precipitation	change point	1986	1984	1993	1987	1986	1992	1978	1999	1994	2000	1993	1979
		p-value	1.239	0.547	0.931	0.764	0.621	1.410	0.708	1.046	0.655	0.587	0.275	0.107
		sample size	53	53	53	53	53	53	53	53	53	53	53	53
	Temperature	change point	1993	1995	2000	1969	1971	1996	1995	1994	1997	1990	1971	1969
		p-value	0.411	0.783	0.509	1.153	0.524	0.052	**0.039**	**0.001**	**0.040**	0.018	0.571	0.861
		sample size	53	53	53	53	53	53	53	53	53	53	53	53
Borjomi	Precipitation	change point	1994	1984	1993	1987	1973	1991	1992	1984	1983	1980	1971	1993
		p-value	0.260	1.068	0.584	0.640	0.282	**0.024**	1.045	0.464	1.189	1.033	0.630	**0.030**
		sample size	49	49	49	49	49	49	49	49	49	49	49	49
	Temperature	change point	1993	1995	1976	1981	2002	1994	1994	1984	1977	1987	1971	1969
		p-value	0.575	0.644	0.943	0.317	1.042	0.262	0.049	0.082	0.174	0.214	0.716	0.491
		sample size	43	43	43	43	43	43	43	43	43	43	43	43
Gardabani	Precipitation	change point	1.159	0.214	1.071	0.957	0.348	0.165	1.071	1.042	0.780	0.068	0.597	1.071
		p-value	1993	1994	1976	1968	1969	1989	1993	1990	1965	1974	1996	1998
		sample size	47	47	47	47	47	47	47	47	47	47	47	47
	Temperature	change point	1980	1966	1987	1969	1975	1984	1969	1987	1977	1989	1971	1969
		p-value	0.901	0.957	0.204	0.532	0.262	0.289	0.901	0.099	0.214	**0.043**	0.398	0.767
		sample size	47	47	47	47	47	47	47	47	47	47	47	47

Notes: Values in bold refer to the significant results at 95 percent confidence level

Based on the results (Table 12), while significant change point of 1993 was detected in the case of annual mean temperature in Akhaltsikhe station, within the seasonal series, summer and autumn seasons from the same station experienced an abrupt significant change in mean values in 1994 and 1993, respectively. Meanwhile, the results of the monthly mean temperature series point out four significant change points (Table 13) which were 1994,1995 and 1997 identified for the month of July-September in Akhaltsikhe station and 1989 in Gardabani station for October.

7.1.4. Limitations

The major limitation concerning this particular part was the absence of the variability of the meteorological stations since all the stations belong to Georgia and no data was acquired from the stations of other basin countries. This was mainly due to the time and financial constrains regarding data purchase for the cases of Turkey and Azerbaijan as well as absence of the online meteorological data records concerning basin countries. This limitation was tried to be overcome with the help of the remotely sensed climatic time series available online, which will be discussed in the upcoming part.

7.2. Trends in rainfall and temperature (Based on the remotely sensed data)

7.2.1. Rainfall

Results of the trend analysis for the rainfall time series based on CRU TS data are depicted in Table 14 and Figure 7 describing proportion of the change in accordance to the months and spatial distribution of precipitation trends over the Kura River Basin, respectively.

Based on the results, only the months of January, February, March, and September have a significant trend. Among all the trends identified, increasing trends are relatively dominant both temporally and spatially. In this regard, while in January, February, March only increasing trend was captured, the month of September experienced only decreasing trend. Generally, the highest increase (0.19 mm/year) belongs to the months of March identified in the north of the Kura River Basin (i.e. the territory of Georgia), and the highest decrease (-0.16 mm/year) was observed in September again in the northern portion of the basin (i.e. in the territory of Georgia).

Table 14 Percentage (%) of areas with a significant rainfall trend in the Kura River Basin over the period of 1901-2018 based on the CRU TS.

Months	Total change	Increase	Decrease	No change
January	12.1	12.1	0	87.9
February	25.8	25.8	0	74.2
March	58.97	58.97	0	41.03
April	0	0	0	100
May	0	0	0	100
June	0	0	0	100
July	0	0	0	100
August	0	0	0	100
September	12.6	0	12.6	87.4
October	0	0	0	100
November	0	0	0	100
December	0	0	0	100

In terms of the percentage of area with a significant trend change (Table 14) the highest proportion of increase was identified in March with the percentage of 58.97 mainly in the middle, northern and western parts of the basin. While the highest proportion of decrease (12.6 percent) was detected during September in the northern and southern portion of the Kura River Basin which are within the territories of Azerbaijan and Iran.

To make generalization based on the results, increase of the rainfall in the basin area mainly occurred during the winter and early spring while the decrease was in the case of autumn. According to Trenberth (2018), as a side effect of the global warming, the amount of precipitation in the form of rain increases which causes early snowmelts leading to the increase in runoff and possible flooding in early spring and drought events during the summer.

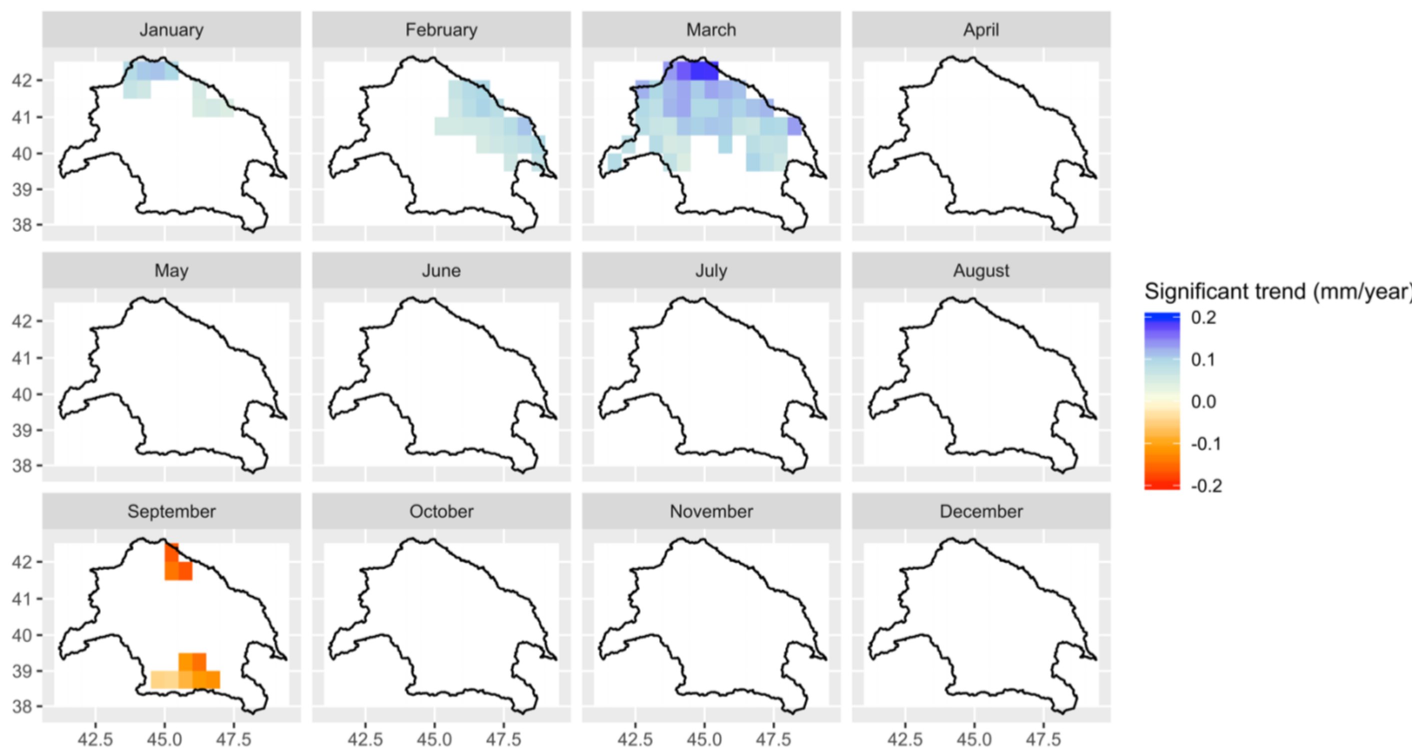

Figure 7 Spatial distribution of significant trends (at 5 percent significance level) for rainfall in the Kura River Basin (1901-2018). Generated through the computations in R.

7.2.2. Temperature

Certain patterns were captured regarding the temperature trend analysis in the Kura River Basin for the period of 1948-2010 based on GLDAS data. In this regard, while Table 15 illustrates the percentage of areas with certain change within the basin area, Figure 8 depicts the spatial distribution of significant trends.

Different from precipitation analysis previously discussed, more significant trends were captured in the case of temperature trend analysis. In this regard, significant temperature trends in the Kura River Basin are attributed to the month of March-June and August-October, and significant increases are dominant both spatially and temporally. Decreasing trend was only captured during May.

Table 15 Percentage (%) of areas with a significant temperature trend in the Kura River Basin over the period of 1998-2018 based on the GLDAS data.

Months	Total change	Increase	Decrease	No change
January	0	0	0	100
February	0	0	0	100
March	95.4	95.4	0	4.7
April	13.5	13.5	0	86.5
May	5.1	3.5	1.6	94.9
June	15.2	15.2	0	84.8
July	0	0.0	0	100.0
August	16.9	16.9	0	83.1
September	89.1	89.1	0	10.9
October	93.7	93.7	0	6.3
November	0	0	0	100
December	0	0	0	100

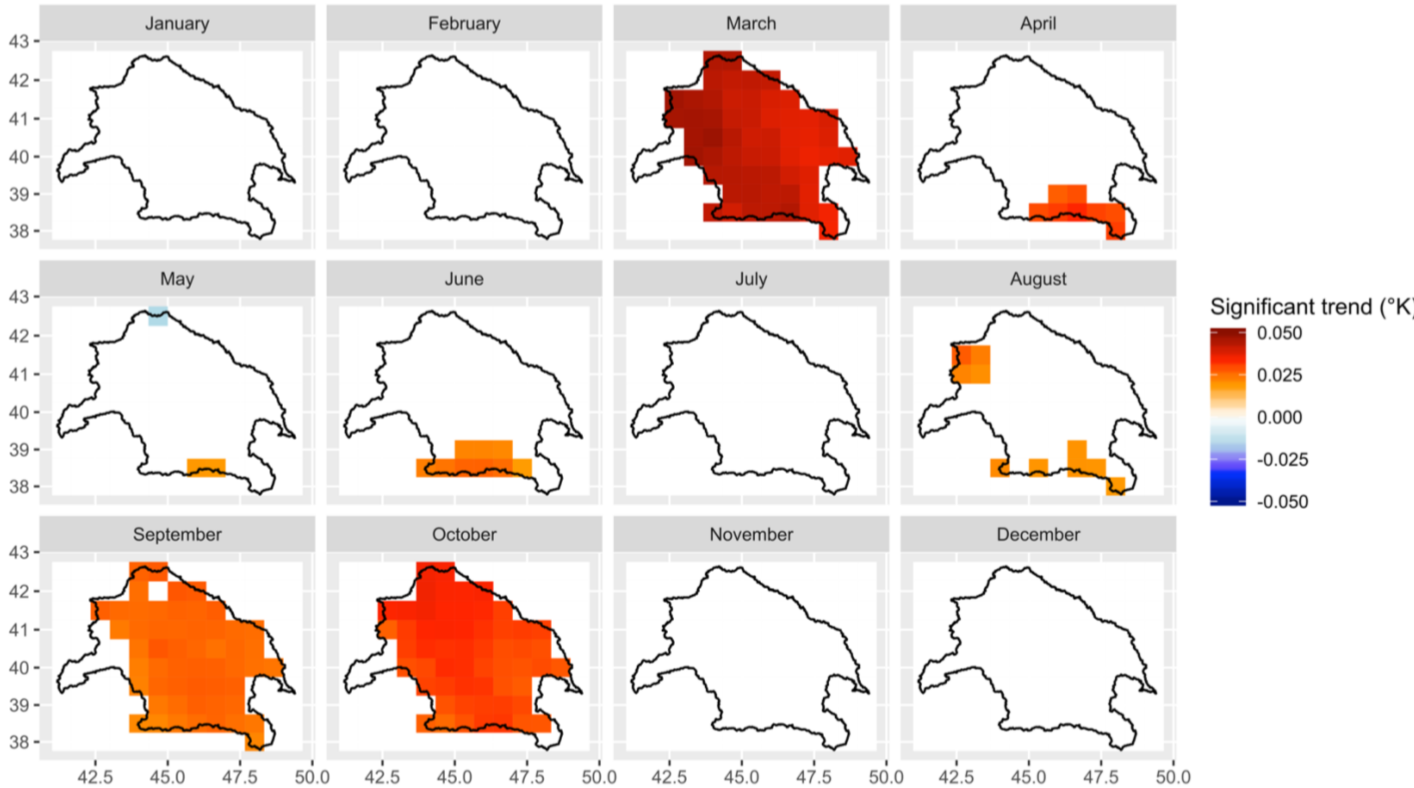

Figure 8 Spatial distribution of significant trends (at 5 percent significance level) for temperature in the Kura River Basin (1948-2010). Generated through the computations in R.

Based on the results, the highest increase which is 0.05 ^{o}K was detected during the period of March in mid-western portion of the Kura River Basin locating in the territory of Armenia. Meanwhile, the highest decreasing trend was -0.02 ^{o}K during May in the northern part of the basin which is in the territory of Georgia.

Regarding the proportion of the significant change in the Kura River Basin, the highest proportion of increase was detected in March with 95.4 percent covering almost all the territory of the basin except western portion. Meanwhile, the highest percentage of areas with significant decreasing trend was identified for May in the northern Kura River Basin.

7.2.3. Limitations

Fortunately, no significant limitation was encountered in this particular analysis since the data was easy to access and similar studies have been conducted previously by utilizing the same datasets.

7.3. Previous research studies on climate change in the Kura River Basin

Searching for existing literature on the climate change in the Kura River Basin, one can observe that there are not many studies undertaken and the ones which are completed are not extensive, not recent or are dedicated to the South Caucasus rather than this specific river basin. Therefore, the current thesis project is believed to play an essential role in this particular field.

One of the studies related to the Kura River Basin is within the project dedicated to the analysis of the impacts of climate change for the South Caucasus initiated by the Environment and Security (ENVSEC) and UNDP. Climatic analysis within that research project was mainly based on the meteorological station data from three countries in the region and was in the following time-span: data of 32 stations were analyzed for Armenia for the period of 1935-2008; regarding Georgia, 21 stations for 1936-2005; for Azerbaijan, 14 stations for 1960-2005 (ENVSEC, 2011). As an outcome of the study, it is stated that all three countries experienced an increase in temperature. While in Armenia average temperature reflected increase of 0.85C, in Azerbaijan, it increased by 0.5 to 0.6 since 1880s. For the Georgia, the regional variations are observed as while the eastern part of the country had an increase of 0.1C to 0.5C, the western part experienced a decrease by 0.1C to 0.3 C. However, the study also indicates that the different trend is captured taking into account the last 50 years data which demonstrates increase in both western and eastern Georgia by 0.2C and 0.3 C, respectively.

Furthermore, it should be highlighted that the study also detected the areas with highest temperature rise for both Azerbaijan and Armenia which is Greater Caucasus and Kura-Aras lowland for the case of Azerbaijan while Ararat lowland and area in-between Lake Sevan and border with Georgia for Armenia (Figure 9).

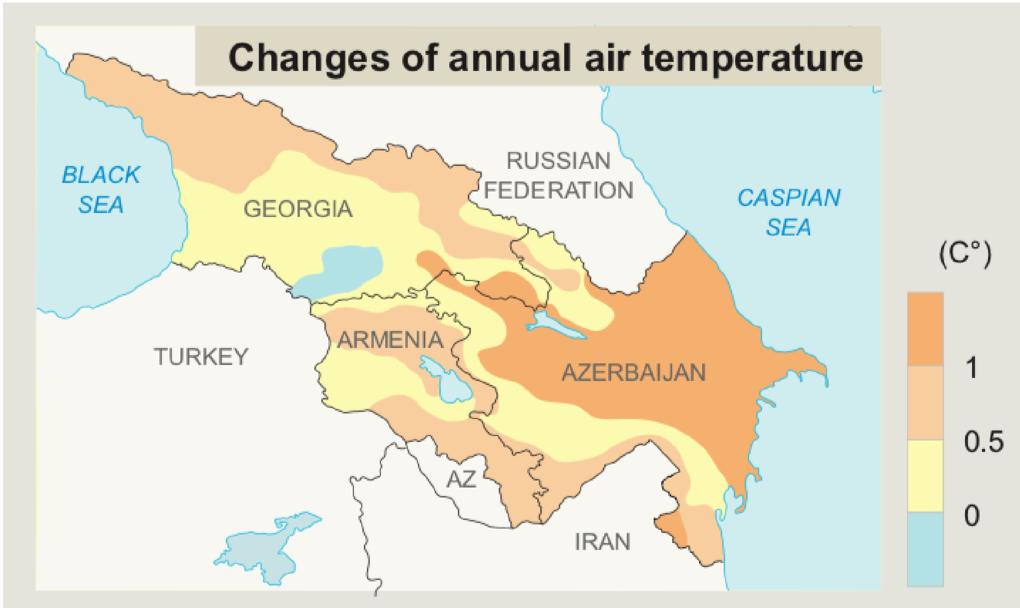

Figure 9 Trends in Annual Average Temperature in the Region of South Caucasus (Analysis period: 1935–2008 for Armenia, 1936–2005 for Georgia, 1960–2005 for Azerbaijan). Source: ENVSEC, 2011.

Precipitation as another indicator for the climate change is also analyzed in this project. Analysis of the data corresponding to the period of 70 years demonstrates an increase in precipitation for southern, north-western Armenia as well as Lake Sevan basin while central and north-eastern part of Armenia experienced a decreasing trend. Regarding the precipitation in Azerbaijan, study notes the decrease in rainfall level by 9.9 percent for 10 years period. The report does not show the exact change in precipitation for Georgia rather indicating climatic patterns in Georgia including average annual precipitation as signs for the changing climate in the region. According to the report by Sylvén et al. (2008), the change in precipitation for Georgia varies spatially which can be detected in Figure 10.

Finally, glaciers and snow cover also demonstrates certain pattern for the region. According to Sylvén et al. (2008), in the South Caucasus region, snow line rose from 1300-1500m to 1800-2000m, while the glaciers in Caucasus declined by 50 percent for the last decade based on the studies in Azerbaijan.

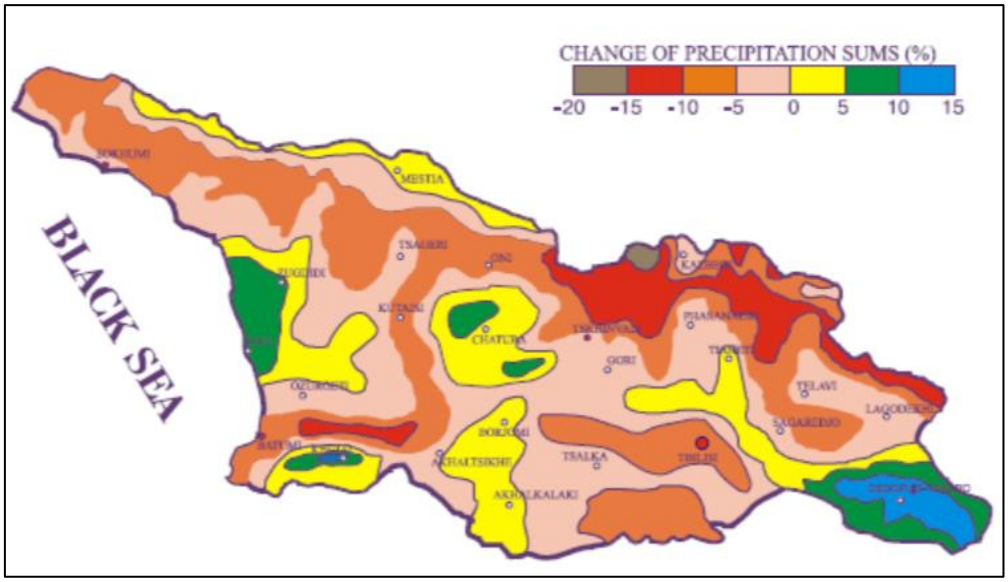

Figure 10 Change in precipitation over Georgia for the period of 1964-1990 relative to 1937-1964 (Taghiyeva, 2006). Source: Sylvén et al., 2008.

As the Kura River Basin is not limited to the above-mentioned countries but its relatively small parts also lay in the areas of Turkey and Iran, it would be important to delve into the literature dedicated to the climatic trends in these countries as well. One of the relevant trend analysis research for the climatic indices in Turkey was undertaken by Hadi and Tombul (2018) where the authors analyzed the data for 1901-2014 and found out certain trends. While the annual precipitation data over the years demonstrated decrease in southeastern Anatolia and Mediterranean regions, the increasing trends are detected for the regions of Marmara and Black Sea. The remaining regions have no particular pattern according to the outcome of the study considering the annual precipitation data. The seasonal precipitation data has a decreasing pattern in winter for all the regions except Marmara and Black Sea, while all the other seasons demonstrate an increasing trend except for the case of southeastern Anatolia. The authors also note an increasing trend for the temperature data for all regions for both annual and seasonal data with the highest trend in summer season. Thus, if we note that the part of the Kura River Basin in Turkey locates in Eastern Anatolia, according to the outcome of the study by Hadi and Tombul (2018), it can be indicated that while the precipitation data for winter has a decreasing trend, all the other seasons demonstrate increasing trend. Meanwhile, annual precipitation has no special pattern while the annual and seasonal temperature data has an increasing trend.

For the case of Iran, the trends regarding climate indices are also quite easy to capture which reflected itself in numerous studies. One of the studies dedicated to this topic was carried out by Rahimi et al. (2014) who are looking at the trends in extreme temperature and precipitation in Iran during 1960-2014. The results of the study demonstrate trends in both temperature and precipitation. Regarding temperature data, the authors state that while the cold extremes experience decreasing trend in magnitude and frequency, warm extremes have increasing trend which overlaps with previous studies. Meanwhile, the analysis of precipitation data demonstrates less significant trends relative to the temperature data and among the significant trends, data of simple daily intensity index and maximum one-day precipitation have an increasing trend, while the data on number of days with heavy precipitation, very and wet days demonstrate a decreasing trend for majority of stations. The authors also claim that according to the results of the study main warming trends are attributed to the northern and north eastern part of the country which also lays within the study area of this research.

All the findings discussed in this section will be referred while discussing the findings on climatic trends of the Kura River Basin to check the consistency in research studies.

7.4. Discussion

RQ2: What are the trends in temperature and precipitation in the Kura River Basin?

Both data from stations and remotely sensed data signaled certain patterns of climate change in the region. Starting with the precipitation, while the results based on the station data illustrated more frequency of decreasing trend, the results of spatial distribution of precipitation had increasing trends January, February and March while September has a decreasing trend. However, looking at the months where the significant increases are captured in the case of remotely sensed data, results of the station data is either insignificant or identified significant trends in the case of stations are insignificant in general according to the trend analysis of remotely sensed data. This variation in the results can be explained with the period that has been studied since according to the study by Dixon et al. (2006), selected study period certainly has an influence over the trend direction and magnitude. As mentioned in the literature review, this was also the case in the trend analysis by ENVSEC (2011) since results of the trend analysis for temperature for the period of 69 years differed from the period of 50 years.

Comparing the precipitation results with the results of related studies mentioned in the literature review, while for Armenia for 70 years period, ENVSEC detected increase in southern, north-western parts and decreasing trend in central and northern parts for annual series, in the case of this study only for March a significant trend was identified for Armenia covering eastern part of the country, While in the case of Azerbaijan for 10 years period. decreasing trend was captured which is presumably in annual basis, the monthly analysis of precipitation for the months of February and March identified increasing trend in this study. Meanwhile, the results by Hadi and Tombul (2018) for Turkey and Rahimi et al. (2014) for Iran resonates with the findings of current study since while in the case of Turkey results of the precipitation trend laying within the boundaries of the study area had insignificant trends mainly, in the case of Iran, decreasing trend was the case that has been captured in the month of September while the other months were insignificant in this study.

Meanwhile, temperature trend analysis for both station data and remotely sensed data had a dominant increasing trend across months as well as annual and seasonal series in the case of station data analysis. This also resonates with the all the other results previously undertaken covering the certain parts of the river basin which are mentioned previously (i.e. ENVSEC (2011) for South Caucasus, Rahimi et al. (2014) for Iran, and Hadi and Tombul (2018) for Turkey).

All in all, all the trends can be linked to the climate change since the patterns overlap especially in the case of increasing temperature and precipitation variations across months over the region.

8. Impact of climate change on hydrology of the Kura River Basin

8.1. Correlation

According to the results of the correlation test between two hydrological stations, Khertvisi and Borjomi and climatic variables (i.e. precipitation and temperature) from proximate two meteorological stations, Akhaltsikhe and Borjomi, generally streamflow showed positive correlation with precipitation and negative correlation with the temperature with some exception which will be discussed further. In general, the correlation r values were weak (r=0.2-0.39) or moderate (r=0.4-0.59) and, in most cases, very weak (r<0.2).

Based on the results depicted in Table 16, for Khertvisi and Akhaltsikhe stations, moderate positive correlations were detected between streamflow and precipitation for July (r=0.44) and October (r=0.56) while moderate positive correlation for March (r=0.50) were detected between streamflow and temperature. In this regard, positive moderate correlation between streamflow and temperature for March is most likely due to the effect of the snowmelt. Based Table 6 and Table 10, none of the variables had any significant trends.

Regarding the results for the Borjomi hydrological and meteorological stations (Table 16), moderate positive correlations were identified for June (r=0.42) between streamflow and precipitation and for March (r=0.58) and April (r=0.42) between streamflow and temperature. Based on Table 6 and Table 10, none of the variables had any significant trend except precipitation for June which has a significant decreasing trend.

According to Masih (2018), due to the complexities of hydrological processes, it is very likely that streamflow in a particular month can be affected by the climatic variables in different months with certain lag time. In this regard, monthly streamflow data for both stations with significant trend was tested with all the other months to identify the correlation and the results are presented in Table 17 and Table 18.

Table 16 Pearson's r values corresponding to the correlation test between streamflow data from Khertvisi and Borjomi and climate data (i.e. temperature and precipitation) from two meteorological stations, Akhaltsikhe and Borjomi.

	Khertvisi-Akhaltsikhe		Borjomi-Borjomi	
	Precipitation	Temperature	Precipitation	Temperature
January	0.26	0.29	0.27	-0.13
February	0.08	0.36	0.09	-0.11
March	0.34	0.50	0.15	0.58
April	0.10	0.15	0.10	0.42
May	-0.16	-0.05	-0.07	-0.06
June	0.35	-0.21	0.42	-0.21
July	0.44	-0.17	0.31	-0.07
August	0.24	-0.17	-0.02	-0.10
September	0.25	-0.11	0.19	-0.17
October	0.56	-0.06	0.33	0.05
November	-0.04	-0.08	0.22	-0.06
December	0.05	0.07	-0.10	-0.07
Annual	0.26	-0.33	0.28	-0.32
Winter	0.12	0.28	0.12	-0.17
Spring	0.08	-0.29	0.29	-0.26
Summer	0.34	-0.28	0.25	-0.18
Autumn	-0.07	-0.17	0.29	-0.01

Table 17 Pearson's r values corresponding to the correlation test between streamflow data from Khertvisi in April and climate data (temperature and precipitation) from Akhaltsikhe for all the months.

	Khertvisi-Akhaltsikhe (April)	Khertvisi-Akhaltsikhe (April)
	Precipitation	Temperature
January	0.43	-0.18
February	0.15	-0.29
March	-0.15	-0.22
April	0.10	0.15
May	-0.10	0.03
June	0.03	-0.12
July	-0.10	-0.01
August	-0.17	-0.16
September	-0.21	0.15
October	0.21	0.00
November	-0.13	-0.08
December	-0.23	-0.06

Table 18 Pearson's r values corresponding to the correlation test between streamflow data from Borjomi in February, March, September and December and climate data (temperature and precipitation) from Borjomi station for all the months.

Borjomi-Borjomi (February)			Borjomi-Borjomi (March)		
	Precipitation	Temperature		Precipitation	Temperature
January	0.26	-0.02	January	0.00	-0.09
February	0.09	-0.11	February	-0.05	-0.13
March	0.12	-0.02	March	0.15	0.58
April	-0.14	0.00	April	-0.23	0.12
May	0.00	-0.19	May	0.13	-0.22
June	-0.27	0.06	June	-0.14	0.25
July	-0.12	0.07	July	-0.34	0.43
August	-0.37	0.12	August	-0.25	0.24
September	0.01	-0.02	September	-0.02	0.24
October	0.24	0.27	October	0.27	0.20
November	-0.14	-0.11	November	-0.24	0.18
December	-0.34	-0.04	December	-0.28	0.01
Borjomi-Borjomi (September)			Borjomi-Borjomi (December)		
	Precipitation	Temperature		Precipitation	Temperature
January	0.33	-0.11	January	0.39	-0.06
February	-0.06	-0.11	February	0.12	-0.20
March	0.11	-0.17	March	0.10	-0.09
April	-0.12	0.09	April	-0.17	0.17
May	0.14	-0.22	May	0.15	-0.16
June	-0.21	-0.07	June	-0.22	-0.08
July	0.27	0.09	July	0.25	0.05
August	-0.06	-0.03	August	-0.14	0.03
September	0.19	-0.17	September	0.02	-0.16
October	0.13	0.35	October	0.12	0.13
November	0.11	-0.04	November	0.12	-0.03
December	-0.12	-0.20	December	-0.10	-0.07

Based on Table 17, April streamflow in Khertvisi seemed to be influenced by the precipitation for the January in Akhaltsikhe with the moderate positive correlation (r=0.43) with the lag time of three months. This can be explained based on the previous explanation by Trenberth (2018) indicating that increasing precipitation during cold months as a side effect of climate change can lead to the early snowmelts resulting in the increase in the river streamflow. Thus, significant increase in Khertvisi station for April depicted in Table 6, can be closely linked to the snowmelt as a result of the rainfall during January. Certain weak and very weak correlations were also detected in several months both for precipitation and temperature.

Meanwhile, among the results for the monthly streamflow data with significant trends in Borjomi station presented in Table 18, moderate correlation were only detected in the case of March streamflow series for March and July temperature series (r ranging from 0.58 for March and 0.43 for July). The same explanation for March that has been discussed previously regarding snowmelt, can also be attributed to the month of July. This can explain the reason behind an increasing trend for the streamflow of Borjomi for March. Similarly, weak and very weak correlations can be detected which will not be discussed as no significant outcome were attained.

8.2. Limitations

The major limitation in this particular analysis was regarding number of stations that were correlated which prevents attaining more precise results.

8.3. Discussion

RQ3: *Is there any impact of the climate change on hydrology of the Kura River?*

As observed in the previous result section, streamflow series seemed to be affected by the climate change especially concerning early snowmelts due to the increasing temperature and rainfall during cold months. This is the case in the Kura River since the river is characterized as nival and pluvial in nature that its streamflow is closely linked to the changes in snow cover and precipitation.

Furthermore, the lag time correlations for significantly increasing streamflow months were also captured with the precipitation for the cold months. This once again demonstrates the extent of the melting snow during cold months causing increase in streamflow in a regular basis.

Additionally, as observed in most of the studies, streamflow in this research study is also affected by the temperature in a way of negative correlation since increase in temperature leads to the increase in evaporation resulting in less water coupled with another stressor, the increase in water withdrawal.

Meanwhile, considering all previous trend results concerning both streamflow and climatic indices, it is obvious that with an increasing trend of temperature and precipitation variability, the seasonal changes in the streamflow is going to be the possible case. In this regard, shifts in the streamflow peaks due to the early snowmelt as well as decrease during the dry seasons are the possible consequences.

However, it is also quite important to keep in mind that trends captured in the streamflow series are not always due to the natural causes only since the hydrological regime is affected by the human intervention in a greater deal. In this regard, as already noted that streamflow decrease in the case of Surra might seem as a consequence of climate change, but the case is due to the hydrological constructions upstream which make it harder to distinguish the extent of the climate change impact on that particular part. In this regard, it is quite essential to look at the all the aspects of the hydrology before starting to assess.

9. Possible implications for the Water-Food-Energy nexus of the basin countries

The changes in hydrology and climate that this study highlighted will certainly have an impact on the Water-Energy-Food (WEF)nexus of the basin countries which will be noted in this section. To give a brief overview regarding WEF nexus, this is a widely utilized concept dealing with the interactions, synergies and trade-offs among these three components. Furthermore, with the increasing intensity of climate change and considering their direct or indirect links to the climate change, this nexus is also quite vulnerable to climate change. In this regard, the clear visualization of the concept can be found in Figure 6 provided by Arent et al. (2014).

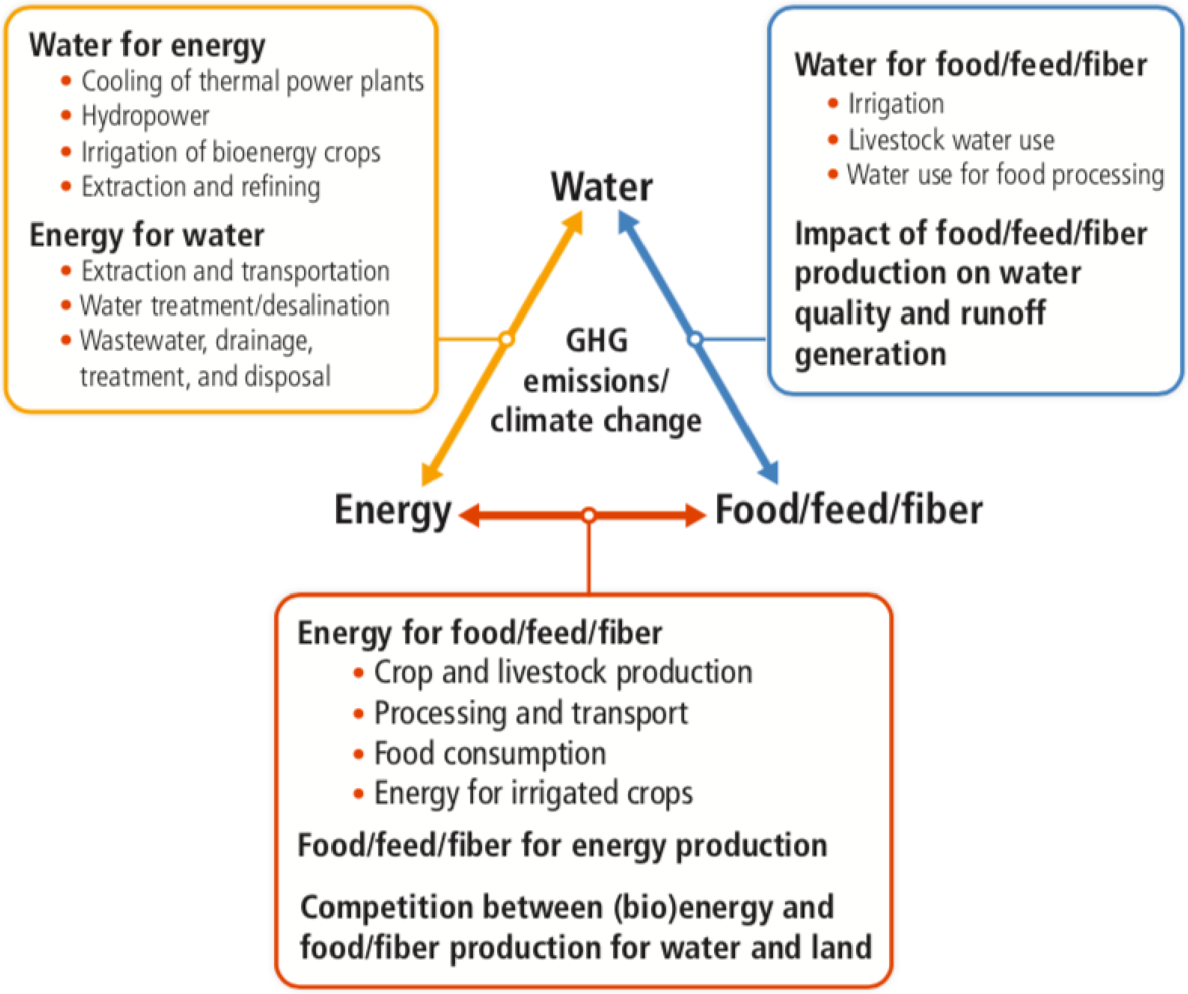

Figure 11 Water-Energy-Food nexus in the light of climate change. Source: Arent et al., 2014

Furthermore, it also should be stressed that components are not linked to each other in a same way everywhere, so the strength of linkages varies by countries depending on their water demand and economy (Arent et al., 2014). Therefore, intensity of the impact of the climate change on these components will also vary.

9.1. Role of the Kura River in WEF nexus

The Kura River plays a crucial role in the WEF nexus of the basin countries, especially the transboundary river countries (i.e. Turkey, Georgia, Azerbaijan) in direct and indirect ways. In this regard, the findings of this research study signal the possible stress on this nexus in all three countries with varying intensity.

Georgia

According to Campana et al (2008), the Kura River and its tributaries are mainly utilized for agricultural purposes for the case of Georgia. Meanwhile, (United Nations Economic Commission for Europe (UNECE), 2011) notes that along with agricultural sector, primary water consumers in the area of Kura River Basin of Georgia are industry, municipality and energy sector. However, the role of Kura River for the domestic usage is relatively weak.

Azerbaijan

In Azerbaijan, the Kura River is a primary freshwater source as it meets approximately 80 percent of population's water demand. However, the role of the Kura River for the irrigation in Azerbaijan is also very significant since according to Hansen (2003), approximately 85 percent of all cultivated areas have installed irrigation system which shows how agriculture depends on the water resources in the country. Additionally, approximately 71 percent of utilized abstracted water was used for irrigation purposes, according to the statistics of 2017 (The State Statistical Committee of the Republic of Azerbaijan). Finally, the Kura River also plays a role in energy generation due to the hydropower plant

Turkey

In the case of Turkey, the water from the Kura River mainly serves to the energy generation and irrigation purposes and with the realization of Turkey's Kura Master Plan, more than 38,000 ha is expected to be irrigated in near future (UNECE, 2011).

9.2. How the identified changes will affect WEF nexus of the basin countries

Increasing temperature during dry months and early snowmelts due to the increasing precipitation observed during cold months will certainly pose a huge threat in terms of the water and food security of all region. These changes will be followed by the increasing water demand for irrigation purposes by putting additional stress on water resources in the region. Furthermore, the streamflow trends captured demonstrates that in Georgia upstream part of the river experienced an increase in water while the in the downstream part (i.e. Tbilisi gauging station) as well as in Azerbaijan, decreasing trend is dominant in terms of streamflow. Taking into account all factors mentioned previously, Azerbaijan will most likely be the most vulnerable towards these changes due to being downstream country, poor in water resources as well as its high dependency on the Kura River. While in the case of Turkey and Georgia, the impact will be felt especially in agricultural and energy sectors but relatively small considering the role of the Kura River in the countries' water supply.

10. Conclusion

The research study aimed at assessing impact of climate change on the hydrology of the Kura River Basin, it was conducted in a way to provide answers to all three research questions raised to address the main aim. In this regard, starting with the first research question regarding the trends in streamflow of the Kura River, the overall results show quite opposite trends for upstream and downstream parts of the river. So, while in Georgia, streamflow series based on gauging station data mostly had an increasing trend, while for the case of Azerbaijan, the decreasing trend was dominant in both of the stations. However, an interesting finding was also identified since despite the fact that upstream stations had an increasing trend, they were observed mainly for the cold months such as January, February, December or the months of snow ablation period causing peak flow.

The second research question concerning trends in climatic indices also had certain patterns that should be highlighted. Since two kinds of data (i.e. station and remotely sensed) were utilized with different record periods, the results also slightly differed. In this regard, while the station data had mainly decreasing trend for precipitation, spatial variation based on remotely sensed data identified relatively more increasing trends. However, the patterns of climate change were also clear in the results since spatial variations of significant increasing rainfall trends mainly accumulated in cold months which is another climate change impact that further explains the reason of the increase in the streamflow that was mentioned.

Finally, the last and the main research question was addressed with correlation test as well as the results of the previous trend tests discussed. Outcomes of the correlation test also stressed the impact of climate change on hydrology due to the intensity of snowmelt, increasing rainfall during cold months, as well as increasing temperature. In this regard, all the results signal the possibility of water shortage in the streamflow during dry months and increase during cold and peak seasons posing threats of natural disasters.

Regarding the prospects for future studies, as mentioned in previous sections as well as considering the limitations, this study is a basis for the further studies dealing with the climate change and water security for the region. In this regard, more compressive study can be conducted by taking into account the other tributaries of the basin as well as by having more data from other basin countries.

Furthermore, since the current research was only intended to study the trends in hydroclimatic variables as well as to assess the impact of climate change on hydrology, future research on this topic also might include the modelling for the hydrology of the Kura River taking into account all the factors that play a role in hydrology of the region.

Bibliography

Ardahan Provincial Directorate of Environment and Urbanism.2018. *Ardahan Ili 2017 Yili Cevre Durum Raporu* [2017 Environmental Status Report for Ardahan Province].

Arent, D. J., Döll, P., Strzepek, K. M., Jiménez Cisneros, B. E., Reisinger, A., Tóth, F. L., & Oki, T. 2014. Cross-chapter box on the water–energy–food/feed/fiber nexus as linked to climate change. In *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea & L. L. White, 163-166. Cambridge and New York.

Armstrong, A., Krasny, M., & Schuldt, J. 2018. Climate Change Science: The Facts. In *Communicating Climate Change: A Guide for Educators*.7-20. London: Cornell University Press.

Asfaw, A., Simane, B., Hassen, A., Bantider, A. 2018. Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. Weather Climate Extremes 19: 29–41.

Bayazit, M., Önöz, B., 2007. To prewhiten or not to prewhiten in trend analysis? Hydrological Sciences Journal 52 (4): 611–624.

Boberg, J. 2005. Patterns of Demand for Fresh Water. In *Liquid Assets: How Demographic Changes and Water Management Policies Affect Freshwater Resources*, 29-36. California: RAND Corporation.

Bouwer, L. M., J. E. Vermaat, and J. C. J. H. Aerts. 2008. Regional sensitivities of mean and peak river discharge to climate variability in Europe. Journal of Geophysical. Research 113: D19103.

Burn, H. D., and Hag Elnur, A.M. Detection of hydrologic trends and variability. *Journal of Hydrology* 255 (1-4): 107-122.

Campana, E.M., Vener, B.B., Kekelidze, N.P., Suleymanov, B., Saghatelyan, A. Science for peace: monitoring water quality and quantity in the Kura–Araks basin of the South Caucasus. NATO Security through Science Series C: Environmental Security.

Cisty, M., & Celar, L. 2015. Using R in Water Resources Education. *International Journal of Innovation Education and Research* 3(10).

Croitoru, A.E. and I. Minea, 2015. The impact of climate changes on rivers discharge in Eastern Romania. *Theoretical and Applied Climatology* 120: 563–573.

Dettinger, Michael D., and Henry F. Diaz. 2000. Global Characteristics of Stream Flow Seasonality and Variability. *Journal of Hydrometeorology* 1 (4): 289–310.

Dixon, H., D. M. Lawler, A. Y. Shamseldin, and P. Webster. 2006. The effect of record length on the analysis of river flow trends in Wales and Central England. In *Climate Variability and Change-Hydrological Impacts (Proceedings of the Fifth FRIEND World Conference Held at Havana, Cuba, November 2006*). IAHS Publication 308: 490-495. Havana.

Fryirs, K. A. and Brierley, G. J. 2012. Catchment Hydrology. In *Geomorphic Analysis of River Systems*, eds. K. A. Fryirs and G. J. Brierley, 44-64. Blackwell Publishing Ltd.

Gassert, F., Reig, P., Luo, T., and Maddocks, A. 2013. A weighted aggregation of spatially distinct hydrological indicators. *World Resources Institute*.

GRDC (Global Runoff Data Centre), Dataset of 195 river discharge time series from the Global Runoff Data Centre. (Federal Institute of Hydrology, Koblenz, 2003).

Hadi, S.J., Tombul, M. 2018. Long-term spatiotemporal trend analysis of precipitation and temperature over Turkey. Meteorological Applications 25: 445–455

Hall, N., Stuntz, B., & Abrams, R. (2008). Climate Change and Freshwater Resources. *Natural Resources & Environment* 22(3), 30-35.

Hansen, B.J. (2003). Water management. In Environmental Performance Reviews of Azerbaijan, 91-104. United Nations Economic and Social Council.

Harris I, Jones P D, Osborn T J and Lister D H. 2014. Updated high-resolution grids of monthly climatic observation-the CRU TS3.10 dataset. *International Journal of Climatology* 34: 623-642.

Hegerl, G.C., F. W. Zwiers, P. Braconnot, N.P. Gillett, Y. Luo, J.A. Marengo Orsini, N. Nicholls, J.E. Penner and P.A. Stott. 2007. Under- standing and Attributing Climate Change. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* eds. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge: Cambridge University Press and New York.

Helsel, D. R. & Hirsch, R. M. 1992. Statistical Methods in Water Resources. *Studies in Environmental Science* 49. Amsterdam: Elsevier.

Hendricks, E. L. 1962. Hydrology. *Science* 135 (3505): 699–705.

Hijmans, R. J. 2014. Raster: Geographic data analysis and modeling. R package version 2.3-12. Retrieved from http:// CRAN.R-project.org/package=raster.

IPCC. 2007. Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* eds. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge: Cambridge University Press and New York.

IPCC.2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, eds. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley. Capridge: Cambridge University Press and United Kingdom and New York.

IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, eds. Writing Team, R.K. Pachauri and L.A. Meyer. Geneva: IPCC

IPCC. 2018. Summary for Policymakers. In *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the* *threat of climate change, sustainable development, and efforts to eradicate poverty*, eds. Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield. In Press.

Jaiswal, R.K., Lohani, A.K. & Tiwari, H.L. 2015. Statistical Analysis for Change Detection and Trend Assessment in Climatological Parameters. Environmental Processes 2 (4): 729–749.

Kahya, E. & Kalaycı, S. 2004. Trend analysis of streamflow in Turkey. *Journal of Hydrology* 289: 128-144.

Kendall, M. G. 1975. Rank Correlation Methods. London: Charles Griffin.

King, D. (2004). Climate Change Science: Adapt Mitigate, or Ignore? Science, 303(5655), 176-177.

King, D. 2005. Climate Change: The Science and the Policy: Climate Change: Science and Policy. Journal of Applied Ecology 42 (5): 779–83.

Kundzewicz, W.Z., and Radziejewski, M. 2006. Methodologies for trend detection. In *Climate Variability and Change-Hydrological Impacts (Proceedings of the Fifth FRIEND World Conference)*, IAHS Publication 308, 538–549. Havana.

Kuusito, E. 1996. Hydrological measurements. In Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes, eds. J, Batram and R. Balance, 303-314. London : E & FN Spon.

Lamigueiro, P.O and Hijmans, R. 2019. rasterVis. R package version 0.46.

Li, B., Su, H., Chen, F. et al. 2014. Separation of the impact of climate change and human activity on streamflow in the upper and middle reaches of the Taoer River, northeastern China. *Theoretical Applies Climatology* 118 (1-2): 271.

Maity, R. 2018. Introduction. In Statistical Methods in Hydrology and Hydroclimatology, 1-6. Springer Singapore.

Mammadov, M. 2012. *Azerbaycanin hidroqrafiyasi* [Hidrography of Azerbaijan]. Baku: Tehsil.

Mann, H. B. 1945. Nonparametric tests against trend. *Econometrica* 13: 245–259.

Masih, I. 2011. Understanding hydrological variability for improved water management in the semi-arid Karkheh Basin, Iran. Phd Thesis. Leiden, The Netherlands: CRC Press/Balkema.

McBean, E. and Motiee, H. 2008.Assessment of impact of climate change on water resources: a long term analysis of the Great Lakes of North America. *Hydrology and Earth System Sciences* 12: 239-255.

McLeod A.I. and Hipel K.W. 1994. Tests for Monotonic Trend. In Stochastic and Statistical Methods in Hydrology and Environmental Engineering, eds. Hipel K.W., McLeod A.I., Panu U.S., Singh V.P. Water Science and Technology Library 10/3. Dordrecht: Springer.

McLeod, A.I. 2011. Kendall: Kendall Rank Correlation and Mann-Kendall Trend Test. Available in http://CRAN. R-project.org/package=Kendall.

Meals, W.D., Spooner, J., Dressing, A.S., and Harcum, B.J. 2011. Statistical analysis for monotonic trends, Tech Notes 6. Developed for U.S. Environmental Protection Agency by Tetra Tech, Inc., Fairfax, VA.

Ministry of Ecology and Natural Resources of Azerbaijan Republic. Rivers, Lakes and Reservoirs. Official Website.

Oyerinde, G.T.; Lawin, E.A.; Odofin, A.J. 2017. Farmers' Responses to Changing Hydrological Trends in the Niger Basin Parts of Benin. *Hydrology* 4 (52).

Patakamuri and O'Brien, 2019. Modified Versions of Mann Kendall and Spearman's Rho Trend Tests. Available in https://rdrr.io/cran/modifiedmk/.

Pekel, J.F., Cottam, A., Gorelick, N., and Belward, A.S. 2016. High-Resolution Mapping of Global Surface Water and Its Long-Term Changes. Nature 540 (7633): 418–22.

Pettit, R. R. (1979), Discussion. *The Journal of Finance* 34: 470-472.

Poff, N. LeRoy, et al. 1997. The Natural Flow Regime. *BioScience* 47 (11): 769–784.

Pohlert, T. (2017). Trend: Non-parametric trend tests and change-point detection. Retrieved from https://CRAN.R-project.org/package=trend.

Postel, Sandra L. 2000. Water and World Population Growth. *Journal of American Water Works Association* 92 (4): 131–38.

Rahimi, M., Mohammadian, N., Rezei Vanashi, A. and Whan, K. 2018.Trends in Indices of Extreme Temperature and Precipitation in Iran over the Period 1960-2014. *Open Journal of Ecology* 8: 396-415.

Rientjes, T. H. M., Haile, A. T., Kebede, E., Mannaerts, C. M. M., Habib, E., and Steenhuis, T. S. 2011. Changes in land cover, rainfall and stream flow in Upper Gilgel Abbay catchment, Blue Nile basin – Ethiopia. Hydrology and Earth System Science 15: 1979-1989.

Rodell, M., P.R. Houser, U. Jambor, J. Gottschalck, K. Mitchell, C. Meng, K. Arsenault, B. Cosgrove, J. Radakovich, M. Bosilovich, J.K. Entin, J.P. Walker, D. Lohmann, and D. Toll. 2004. Rzayev, M. 2017. Some Remarks on the Current Efforts for Future Protection of the Kura Water Resources through Trans-Boundary Cooperation and Modernized National Policy Measures. *International Journal of Hydrology* 1 (4).

Salvacion, A.R., Magcale-Macandog, D.B., Sta. Cruz, P.C. et al. 2018. Exploring spatial patterns of trends in monthly rainfall and temperature in the Philippines based on Climate Research Unit grid. *Spatial Information Research* 26 (5): 471.

Shiklomanov, I. and Lins, H., 1990. Hydrology and water resources. In *IPCC (1990) Climate Change. The IPCC Impacts Assessment*, eds. W.J.McG. Tegart, G.W. Sheldon and D.C. GritIiths, 4-1-4-40. Canberra: Australian Government Publishing Service.

Shiklomanov, I.1999. Climate change, hydrology and water resources: The work of the IPCC, 1988–94. In *Impacts of Climate Change and Climate Variability on Hydrological Regimes* (International Hydrology Series), ed. Dam, J: 8-20. Cambridge: Cambridge University Press.

Sylvén, M., Reinvang, R., and Andersone-Lilley, Z. 2008. Climate Change in Southern Caucasus: Impacts on nature, people and society. WWF Norway.

Terakawa, A. 2003. Introduction. In *Hydrological data management: present state and trends*. Geneva: World Meteorological Organization.

The Environment and Security Initiative (ENVSEC). 2011. Climate Change in the South Caucasus: A visual synthesis. Zoï Environment Network.

The Global Land Data Assimilation System. *Bulletin of the American Meteorological Society* 85: 381-394.

The State Statistical Committee of the Republic of Azerbaijan. Environmental Protection: Water Resources. Official Website.

Tvalchrelidze, A., Silagadze, A., Keshelashvili, G., and Gegia, D. 2011. Natural Resources of Georgia. In *Georgia's Social & Economic Development Program.* Tbilisi: International Foundation for Sustainable Development – Georgia and Open Society – Georgia Foundation.

United Nations (UN) Food and Agriculture Organization (FAO)/AQUASTAT. 2008. Description of four transboundary river basins, 63-91. In Irrigation in the Middle East region in figures United Nations: AQUASTAT Survey 2008.

United Nations Economic Commission for Europe (UNECE). 2011. Drainage Basins of the Caspian Sea. In *Second assessment of transboundary rivers*, *lakes and groundwaters*, 132-164. United Nations Publications.

United Nations, Department of Economic and Social Affairs, Population Division. 2017. World Population Prospects 2017 – Data Booklet (ST/ESA/SER.A/401).

USA: Cambridge University Press.

von Storch, H., 1995. Misuses of statistical analysis in climate research. In: *Analysis of Climate Variability: Applications of Statistical Techniques*, eds. Storch, H. V., Navarra, A, 11-26. New York Springer-Verlag.

Wickham, H. (2009). ggplot2. New York: Springer. Retrieved from http://link.springer.com/10.1007/978-0-387- 98141-3.

Wigley, T. and Jones, P. 1985. Influence of precipitation changes and direct CO2 effects on streamflow. *Nature* 314:149-152.

Yue, S. & Wang, C. Y. 2004. The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. *Water Resources Managem*ent 18: 201–218.

Yue, S., Wang, C.Y. 2002. Applicability of prewhitening to eliminate the influence of serial correlation on the Mann-Kendall test. *Water Resources Research* 38 (6): 4-1-4-7.

Zeiringer B., Seliger C., Greimel F., Schmutz S. 2018. River Hydrology, Flow Alteration, and Environmental Flow. In *Riverine Ecosystem Management. Aquatic Ecology Series*, eds. Schmutz S., Sendzimir J. vol 8. Cham: Springer.

Appendices

Appendix A: Codes utilized for analysing the Global Surface Water data (Pekel et al, 2016) on Google Earth Engine and obtained maps showing change intensity and water occurrence

```
Imports (1 entry)
var basin: Table users/shahanabilalova/Modified_Kura

// Inputting data
var gsw = ee.Image('JRC/GSW1_0/GlobalSurfaceWater');
var occurrence = gsw.select('occurrence');
var change = gsw.select("change_abs");
var transition = gsw.select('transition');
var basin = ee.FeatureCollection('users/shahanabilalova/Modified_Kura');

//Mapping water occurance and change intensity
var VIS_OCCURRENCE = {
    min: 0,
    max: 100,
    palette: ['red', 'blue']
};

Map.addLayer({
  eeObject: occurrence.updateMask(occurrence.divide(100)),
  name: "Water Occurrence (1984-2015)",
  visParams: VIS_OCCURRENCE,
  shown: false
});
var VIS_CHANGE = {
    min: -50,
    max: 50,
    palette: ['red', 'black', 'limegreen']
};
Map.addLayer({
  eeObject: change,
  visParams: VIS_CHANGE,
  name: 'occurrence change intensity'
});

//Creating a mask for water and non-water areas (threshold is set to 90%)
var VIS_WATER_MASK = {
  palette: ['white', 'black']
};
var water_mask = occurrence.gt(90).mask(1);

Map.addLayer({
  eeObject: water_mask,
  visParams: VIS_WATER_MASK,
  name: '90% occurrence water mask',
  shown: false
});
// Generate a histogram object and print it to the console tab.
var histogram = ui.Chart.image.histogram({
  image: change,
  region: basin,
  scale: 1000,
  minBucketWidth: 10
});
histogram.setOptions({
  title: 'Histogram of surface water change intensity in the Kura River Basin for 1984-2015'
});
print(histogram);

//Preparing transition chart
   //First creating an image object containing area information and transition class infotmation
var area_image_with_transition_class = ee.Image.pixelArea().addBands(transition);

// Summarizing the class transitions within a region of interest
var reduction_results = area_image_with_transition_class.reduceRegion({
  reducer: ee.Reducer.sum().group({
    groupField: 1,
    groupName: 'transition_class_value',
  }),
  geometry: basin,
  scale: 30,
  bestEffort: true,
});
print('reduction_results', reduction_results);
```

```
//Preparing transition chart
  //First creating an image object containing area information and transition class infotmation
var area_image_with_transition_class = ee.Image.pixelArea().addBands(transition);

// Summarizing the class transitions within a region of interest
var reduction_results = area_image_with_transition_class.reduceRegion({
  reducer: ee.Reducer.sum().group({
    groupField: 1,
    groupName: 'transition_class_value',
  }),
  geometry: basin,
  scale: 30,
  bestEffort: true,
});
print('reduction_results', reduction_results);

//Extracting the transition classes
var basin_stats = ee.List(reduction_results.get('groups'));

// Creating a dictionary for looking up names of transition classes.
var lookup_names = ee.Dictionary.fromLists(
    ee.List(gsw.get('transition_class_values')).map(ee.String),
    gsw.get('transition_class_names')
);
// Creating a dictionary for looking up colors of transition classes.
var lookup_palette = ee.Dictionary.fromLists(
    ee.List(gsw.get('transition_class_values')).map(ee.String),
    gsw.get('transition_class_palette')
);
// Creating a feature for a transition class that includes the area covered
//Returning feature suitable for chart
function createFeature(transition_class_stats) {
  transition_class_stats = ee.Dictionary(transition_class_stats);
  var class_number = transition_class_stats.get('transition_class_value');
  var result = {
      transition_class_number: class_number,
      transition_class_name: lookup_names.get(class_number),
      transition_class_palette: lookup_palette.get(class_number),
      area_m2: transition_class_stats.get('sum')
  };
  return ee.Feature(null, result);   // Creates a feature without a geometry.
}

// Creating a JSON dictionary that defines piechart colors based on the transition class palette.
function createPieChartSliceDictionary(fc) {
  return ee.List(fc.aggregate_array("transition_class_palette"))
    .map(function(p) { return {'color': p}; }).getInfo();
}

//FeatureCollection having attributes to be illustrated
var transition_fc = ee.FeatureCollection(basin_stats.map(createFeature));
print('transition_fc', transition_fc);

// Add a summary chart.
var transition_summary_chart = ui.Chart.feature.byFeature({
    features: transition_fc,
    xProperty: 'transition_class_name',
    yProperties: ['area_m2', 'transition_class_number']
  })
  .setChartType('PieChart')
  .setOptions({
    title: 'Summary of transition class areas for the Kura River Basin for 1984-2015',
    slices: createPieChartSliceDictionary(transition_fc),
    sliceVisibilityThreshold: 0  // Don't group small slices.
  });
print(transition_summary_chart);
```

Appendix B: Codes for extracting monthly temperature series from GLDAS data by using Phyton

```
# -*- coding: utf-8 -*-
"""
Created on Mon Jun 24 10:47:28 2019

@author: shahanabilalova
"""

import os
from netCDF4 import Dataset
import pandas as pd
import numpy as np
import numpy.ma as ma

a = [name for name in os.listdir('.') if name.endswith('.nc4')]
variable = Dataset(a[0])
## To get the information related to variables and other attributes
related to dataset
#
#dims=variable.dimensions
#ndims=len(dims)
#print(dims)
#
#gattrs=variable.ncattrs()
#ngattrs=len(gattrs)
#for key in gattrs:
#    print(key + str(getattr(variable,key)))
#
#
#varia=variable.variables
#nvars=len(varia)
#for var in varia:
#    print(var,str(varia[var].shape))
#    vattrs=varia[var].ncattrs()
#    for vat in vattrs:
#        print(var+vat+str(getattr(varia[var],vat)))

##

latitude=variable.variables['lat'][:]
longitude=variable.variables['lon'][:]

def find_latindex(lat):
    for latindex in range(len(latitude)):
        if latitude[latindex]==lat:
            return latindex

def find_lonindex(lon):
    for lonindex in range(len(longitude)):
        if longitude[lonindex]==lon:
            return lonindex

latlonlist=[]
```

```
for i in range(len(latitude)):
        for j in range(len(longitude)):
            latlonlist.append((latitude[i],longitude[j]))
#latlonlist = list(zip(*latlon))
index = pd.MultiIndex.from_tuples(latlonlist, names=['Lat', 'Lon'])

dates = pd.date_range(start='1/1/1948', end='12/31/2010', freq="M")

dataarray=np.zeros((len(latlonlist),len(dates)))
for i in range(len(a)):
    variable1=Dataset(a[i])
    plotlist=np.array([])
    for j in range(len(latlonlist)):

value=variable1.variables['Tair_f_inst'][:,find_latindex(latlonlist[j][0])
,find_lonindex(latlonlist[j][1])]
        plotlist=np.append(plotlist,value)

    #mean[:,i]=plotlist
    #print i

    ma.resize(plotlist,(len(a),1))
    dataarray[:,i]=plotlist

df = pd.DataFrame(data=dataarray,index=index,columns=dates)
df.replace(-9999,np.nan,inplace=True)
df.to_csv('master_dataset.csv')

jan = df.iloc[:,df.columns.map(lambda x: x.month) == 1]
feb = df.iloc[:,df.columns.map(lambda x: x.month) == 2]
mar = df.iloc[:,df.columns.map(lambda x: x.month) == 3]
apr = df.iloc[:,df.columns.map(lambda x: x.month) == 4]
may = df.iloc[:,df.columns.map(lambda x: x.month) == 5]
jun = df.iloc[:,df.columns.map(lambda x: x.month) == 6]
jul = df.iloc[:,df.columns.map(lambda x: x.month) == 7]
aug = df.iloc[:,df.columns.map(lambda x: x.month) == 8]
sep = df.iloc[:,df.columns.map(lambda x: x.month) == 9]
octo = df.iloc[:,df.columns.map(lambda x: x.month) == 10]
nov = df.iloc[:,df.columns.map(lambda x: x.month) == 11]
dec = df.iloc[:,df.columns.map(lambda x: x.month) == 12]

jan.to_csv('jan_temp.csv')
feb.to_csv('feb_temp.csv')
mar.to_csv('mar_temp.csv')
apr.to_csv('apr_temp.csv')
may.to_csv('may_temp.csv')
jun.to_csv('jun_temp.csv')
jul.to_csv('jul_temp.csv')
aug.to_csv('aug_temp.csv')
sep.to_csv('sep_temp.csv')
octo.to_csv('oct_temp.csv')
nov.to_csv('nov_temp.csv')
dec.to_csv('dec_temp.csv')
```

Appendix C: Codes for extracting monthly temperature series from CRU TS data by using Phyton

```
#!/usr/bin/env python2
# -*- coding: utf-8 -*-
"""
Created on Wed Jul 10 18:08:16 2019

@author: shahanabilalova
"""

import os
from netCDF4 import Dataset
import pandas as pd
import numpy as np
import numpy.ma as ma

a = [name for name in os.listdir('.') if name.endswith('.nc')]
variable = Dataset(a[0])
## To get the information related to variables and other attributes
related to dataset
#
#dims=variable.dimensions
#ndims=len(dims)
#print(dims)
#
#gattrs=variable.ncattrs()
#ngattrs=len(gattrs)
#for key in gattrs:
#    print(key + str(getattr(variable,key)))
#
#
#varia=variable.variables
#nvars=len(varia)
#for var in varia:
#    print(var,str(varia[var].shape))
#    vattrs=varia[var].ncattrs()
#    for vat in vattrs:
#        print(var+vat+str(getattr(varia[var],vat)))
#
##

latitude=variable.variables['Latitude'][:]
longitude=variable.variables['Longitude'][:]

def find_latindex(lat):
    for latindex in range(len(latitude)):
        if latitude[latindex]==lat:
            return latindex

def find_lonindex(lon):
    for lonindex in range(len(longitude)):
        if longitude[lonindex]==lon:
            return lonindex
```

```
latlonlist=[]
for i in range(len(latitude)):
        for j in range(len(longitude)):
            latlonlist.append((latitude[i],longitude[j]))
#latlonlist = list(zip(*latlon))
index = pd.MultiIndex.from_tuples(latlonlist, names=['Latitude',
'Longitude'])

dates = pd.date_range(start='1/1/1901', end='01/01/2019', freq="M")

dataarray=np.zeros((len(latlonlist),len(dates)))
for i in range(len(a)):
    variable1=Dataset(a[i])

    for j in range(len(latlonlist)):

dataarray[j,:]=variable1.variables['pre'][:,find_latindex(latlonlist[j][0]
),find_lonindex(latlonlist[j][1])]


    #mean[:,i]=plotlist
    #print i

df = pd.DataFrame(data=dataarray,index=index,columns=dates)
df.replace(dataarray[0,0],np.nan,inplace=True)

df.to_csv('master_dataset.csv')

jan = df.iloc[:,df.columns.map(lambda x: x.month) == 1]
feb = df.iloc[:,df.columns.map(lambda x: x.month) == 2]
mar = df.iloc[:,df.columns.map(lambda x: x.month) == 3]
apr = df.iloc[:,df.columns.map(lambda x: x.month) == 4]
may = df.iloc[:,df.columns.map(lambda x: x.month) == 5]
jun = df.iloc[:,df.columns.map(lambda x: x.month) == 6]
jul = df.iloc[:,df.columns.map(lambda x: x.month) == 7]
aug = df.iloc[:,df.columns.map(lambda x: x.month) == 8]
sep = df.iloc[:,df.columns.map(lambda x: x.month) == 9]
octo = df.iloc[:,df.columns.map(lambda x: x.month) == 10]
nov = df.iloc[:,df.columns.map(lambda x: x.month) == 11]
dec = df.iloc[:,df.columns.map(lambda x: x.month) == 12]

jan.to_csv('jan_pre.csv')
feb.to_csv('feb_pre.csv')
mar.to_csv('mar_pre.csv')
apr.to_csv('apr_pre.csv')
may.to_csv('may_pre.csv')
jun.to_csv('jun_pre.csv')
jul.to_csv('jul_pre.csv')
aug.to_csv('aug_pre.csv')
sep.to_csv('sep_pre.csv')
octo.to_csv('oct_pre.csv')
nov.to_csv('nov_pre.csv')
dec.to_csv('dec_pre.csv')
```

Appendix D: Codes for detecting significant trends for spatial distribution of significant trends of temperature and precipitation for the Kura River Basin

```
require (raster)
require (rgdal)
require (netcdf4)
#Adding csv files into R extracted with the help of Phyton
jan <- read.csv(file="jan_temp.csv", header=TRUE, sep=",")
feb <- read.csv(file="feb_temp.csv", header=TRUE, sep=",")
mar <- read.csv(file="mar_temp.csv", header=TRUE, sep=",")
apr <- read.csv(file="apr_temp.csv", header=TRUE, sep=",")
may <- read.csv(file="may_temp.csv", header=TRUE, sep=",")
jun <- read.csv(file="jun_temp.csv", header=TRUE, sep=",")
jul <- read.csv(file="jul_temp.csv", header=TRUE, sep=",")
aug <- read.csv(file="aug_temp.csv", header=TRUE, sep=",")
sep <- read.csv(file="sep_temp.csv", header=TRUE, sep=",")
oct <- read.csv(file="oct_temp.csv", header=TRUE, sep=",")
nov <- read.csv(file="nov_temp.csv", header=TRUE, sep=",")
dec <- read.csv(file="dec_temp.csv", header=TRUE, sep=",")

#Performing Mann-Kendall trend test and extracting significant Sen's slope values
require (Kendall)
require (trend)

jan$Slope <- NA #January
for (row in 1:nrow(jan)) {
 if (MannKendall(jan[row,4:length(jan)-1])$sl<0.05) {
  jan[row,length(jan)] <- sens.slope(unlist(jan[row,3:length(jan)-1]),conf.level=0.95)$estimates
  print(row)
 }
}

feb$Slope <- NA #February
for (row in 1:nrow(feb)) {
 res1 <-
  if (MannKendall(feb[row,4:length(feb)-1])$sl<0.05) {
   feb[row,length(feb)] <- sens.slope(unlist(feb[row,3:length(feb)-1]),conf.level=0.95)$estimates
   print(row)
  }
}

mar$Slope <- NA #March
for (row in 1:nrow(mar)) {
 res1 <-
  if (MannKendall(mar[row,4:length(mar)-1])$sl<0.05) {
   mar[row,length(mar)] <- sens.slope(unlist(mar[row,3:length(mar)-1]),conf.level=0.95)$estimates
   print(row)
  }
}

apr$Slope <- NA #April
for (row in 1:nrow(apr)) {
 res1 <-
  if (MannKendall(apr[row,4:length(apr)-1])$sl<0.05) {
   apr[row,length(apr)] <- sens.slope(unlist(apr[row,3:length(apr)-1]),conf.level=0.95)$estimates
   print(row)
  }
}

may$Slope <- NA #May
for (row in 1:nrow(may)) {
 res1 <-
  if (MannKendall(may[row,4:length(may)-1])$sl<0.05) {
   may[row,length(may)] <- sens.slope(unlist(may[row,3:length(may)-1]),conf.level=0.95)$estimates
   print(row)
  }
}

jun$Slope <- NA #June
```

```
for (row in 1:nrow(jun)) {
 res1 <-
  if (MannKendall(jun[row,4:length(jun)-1])$sl<0.05) {
   jun[row,length(jun)] <- sens.slope(unlist(jun[row,3:length(jun)-1]),conf.level=0.95)$estimates
   print(row)
  }
}

jul$Slope <- NA #July
for (row in 1:nrow(jul)) {
 res1 <-
  if (MannKendall(jul[row,4:length(jul)-1])$sl<0.05) {
   jul[row,length(jul)] <- sens.slope(unlist(jul[row,3:length(jul)-1]),conf.level=0.95)$estimates
   print(row)
  }
}

aug$Slope <- NA #August
for (row in 1:nrow(aug)) {
 res1 <-
  if (MannKendall(aug[row,4:length(aug)-1])$sl<0.05) {
   aug[row,length(aug)] <- sens.slope(unlist(aug[row,3:length(aug)-1]),conf.level=0.95)$estimates
   print(row)
  }
}

sep$Slope <- NA #September
for (row in 1:nrow(sep)) {
 res1 <-
  if (MannKendall(sep[row,4:length(sep)-1])$sl<0.05) {
   sep[row,length(sep)] <- sens.slope(unlist(sep[row,3:length(sep)-1]),conf.level=0.95)$estimates
   print(row)
  }
}

oct$Slope <- NA #October
for (row in 1:nrow(oct)) {
 res1 <-
  if (MannKendall(oct[row,4:length(oct)-1])$sl<0.05) {
   oct[row,length(oct)] <- sens.slope(unlist(oct[row,3:length(oct)-1]),conf.level=0.95)$estimates
   print(row)
  }
}

nov$Slope <- NA #November
for (row in 1:nrow(nov)) {
 res1 <-
  if (MannKendall(nov[row,4:length(nov)-1])$sl<0.05) {
   nov[row,length(nov)] <- sens.slope(unlist(nov[row,3:length(nov)-1]),conf.level=0.95)$estimates
   print(row)
  }
}

dec$Slope <- NA #December
for (row in 1:nrow(dec)) {
 res1 <-
  if (MannKendall(dec[row,4:length(dec)-1])$sl<0.05) {
   dec[row,length(dec)] <- sens.slope(unlist(dec[row,3:length(dec)-1]),conf.level=0.95)$estimates
   print(row)
  }
}


#Writing data frame for months with the data of Latitude, Longitude and Slope values
janslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = jan[,66])
febslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = feb[,66])
marslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = mar[,66])
aprslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = apr[,66])
mayslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = may[,66])
junslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = jun[,66])
julslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = jul[,66])
```

```
augslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = aug[,66])
sepslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = sep[,66])
octslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = oct[,66])
novslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = nov[,66])
decslope <- data.frame("Lat"=jan[,1] , "Lon" = jan[,2], "Slope" = dec[,66])

#Writing csv files from data frames for each months
write.csv(janslope, "janmk.csv", na="", row.names=FALSE)
write.csv(febslope, "febmk.csv", na="", row.names=FALSE)
write.csv(marslope, "marmk.csv", na="", row.names=FALSE)
write.csv(aprslope, "aprmk.csv", na="", row.names=FALSE)
write.csv(mayslope, "maymk.csv", na="", row.names=FALSE)
write.csv(junslope, "junmk.csv", na="", row.names=FALSE)
write.csv(julslope, "julmk.csv", na="", row.names=FALSE)
write.csv(augslope, "augmk.csv", na="", row.names=FALSE)
write.csv(sepslope, "sepmk.csv", na="", row.names=FALSE)
write.csv(octslope, "octmk.csv", na="", row.names=FALSE)
write.csv(novslope, "novmk.csv", na="", row.names=FALSE)
write.csv(decslope, "decmk.csv", na="", row.names=FALSE)

#Importing previously created csv files containing significant slope values and coordinates accordingly
jan <- read.csv(file="janmk.csv", header=TRUE, sep=",")
feb <- read.csv(file="febmk.csv", header=TRUE, sep=",")
mar <- read.csv(file="marmk.csv", header=TRUE, sep=",")
apr <- read.csv(file="aprmk.csv", header=TRUE, sep=",")
may <- read.csv(file="maymk.csv", header=TRUE, sep=",")
jun <- read.csv(file="junmk.csv", header=TRUE, sep=",")
jul <- read.csv(file="julmk.csv", header=TRUE, sep=",")
aug <- read.csv(file="augmk.csv", header=TRUE, sep=",")
sep <- read.csv(file="sepmk.csv", header=TRUE, sep=",")
oct <- read.csv(file="octmk.csv", header=TRUE, sep=",")
nov <- read.csv(file="novmk.csv", header=TRUE, sep=",")
dec <- read.csv(file="decmk.csv", header=TRUE, sep=",")

#Converting csv files into raster format
January <- rasterFromXYZ(jan[, c('Lon', 'Lat', 'Slope')])
crs(January) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
February <- rasterFromXYZ(feb[, c('Lon', 'Lat', 'Slope')])
crs(February) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
March <- rasterFromXYZ(mar[, c('Lon', 'Lat', 'Slope')])
crs(March) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
April <- rasterFromXYZ(apr[, c('Lon', 'Lat', 'Slope')])
crs(April) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
May <- rasterFromXYZ(may[, c('Lon', 'Lat', 'Slope')])
crs(May) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
June <- rasterFromXYZ(jun[, c('Lon', 'Lat', 'Slope')])
crs(June) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
July <- rasterFromXYZ(jul[, c('Lon', 'Lat', 'Slope')])
crs(July) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
August <- rasterFromXYZ(aug[, c('Lon', 'Lat', 'Slope')])
crs(August) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
September <- rasterFromXYZ(sep[, c('Lon', 'Lat', 'Slope')])
crs(September) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
October <- rasterFromXYZ(oct[, c('Lon', 'Lat', 'Slope')])
crs(October) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
November <- rasterFromXYZ(nov[, c('Lon', 'Lat', 'Slope')])
crs(November) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
December <- rasterFromXYZ(dec[, c('Lon', 'Lat', 'Slope')])
crs(October) <- "+proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"

#Creating a stack containing all raster files
Temp_analysis<-stack(c(January, February, March, April, May, June, July, August, September, October, November, December))

#Renaming the files in stack with the names of the corresponding months
names(Temp_analysis)= c("January", "February", "March", "April", "May", "June", "July", "August", "September", "October", "November", "December")

#Importing the shapefile of the study area
studyarea.shape<-readOGR(dsn=path.expand('#Path to the file'), layer = "#Layer_Name")

temp_stuar <- crop(Temp_analysis, extent(studyarea.shape)) #Croping and masking to study area
temp_saa <- mask(temp_stuar, studyarea.shape)
```

```
#Increasing pixel sizes if required
temp_saa<-aggregate(temp_saa,2)

#Calculation of percentage of areas with significant trends

#Total area of study area
require (geosphere)
sqm<-areaPolygon(studyarea.shape) #calculate area of the polygon in m2
sqkm<-sqm/1000000 #converting to km2

#Calculation of percentage of areas with significant trends for each months
cell_size<-area(temp_saa$Jan, na.rm=TRUE, weights=FALSE) #January
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
January_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$Feb, na.rm=TRUE, weights=FALSE) #February
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
February_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$Mar, na.rm=TRUE, weights=FALSE) #March
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
March_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$Apr, na.rm=TRUE, weights=FALSE) #April
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
April_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$May, na.rm=TRUE, weights=FALSE) #May
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
May_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$Jun, na.rm=TRUE, weights=FALSE) #June
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
June_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$Jul, na.rm=TRUE, weights=FALSE) #July
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
July_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$Aug, na.rm=TRUE, weights=FALSE) #August
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
August_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$Sep, na.rm=TRUE, weights=FALSE) #September
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
September_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$Oct, na.rm=TRUE, weights=FALSE) #October
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
October_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$Nov, na.rm=TRUE, weights=FALSE) #November
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
November_percent<-raster_area/sqkm*100

cell_size<-area(temp_saa$Dec, na.rm=TRUE, weights=FALSE) #December
cell_size<-cell_size[!is.na(cell_size)]
raster_area<-length(cell_size)*median(cell_size)
December_percent<-raster_area/sqkm*100
```

```
#Plotting the results
require (ggplot2)
require (rasterVis)
gplot(temp_saa)+
 geom_tile(aes(fill=value))+
 scale_fill_gradientn(
  colours=c("darkblue","blue","lightblue","white", "orange","red","darkred"), #Color scale is chosen according to the theme
  name="Significant trend (°K)", na.value = "white", limits=c(-0.05,0.05), breaks=seq(-0.05, 0.05, 0.025))+
 theme(legend.position = "right")+
 facet_wrap(~variable)+
 geom_path(data=fortify(studyarea.shape),
      mapping=aes(x=long,y=lat,
           group=group))+
 theme(axis.title.x=element_blank())+
 theme(axis.title.y=element_blank())+
 coord_map()+
 ggsave("temperature.png", dpi = 1600) #Saving with a high quality
```